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Frithjof Stöppler, M.A., B.A.

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Gutachter:

Erstgutachter: Prof. Dr. Jörg Sydow

Zweitgutachter: Prof. Dr. Georg Schreyögg

Drittgutachter: Prof. Dr. Klaus G. Troitzsch

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Dedicated to Nanda and Leo,
my deepest personal ties.

Foreword

Over the time I was researching and writing this thesis, smartphones have become the main internet access device, and have clearly changed our lives, for better or worse. While important technological developments were required for making smartphones possible, it was the involved software ecosystems called 'platforms' and the ability to install 'apps' that made smartphones and later tablets commercially successful.

Smartphones are an illustrative example of emerging technologies more generally. Actors from different industries come together for making such new developments possible. While the technologies take the limelight, however, the workings of the social world behind the technologies typically remain in the dark.

This research is an exploration into the 'dark side' of a social structure called interorganisational networks, or 'alliances.' Networking is not only an essential part of business activity, but also a social process with risks and side-effects. The potential side-effect studied herein – firms' lock-in into a path dependent network of collaboration relationships – might sound harmless. When considering cases such as *VHS* vs. *Beta* or *Blu-Ray* vs. *HD-DVD*, however, we know there is severe damage and problems caused for firms that 'back the wrong horse.' Rarely are such decisions purely technological choices, but they involve collaborating – and thus potentially becoming trapped – within a network of firms. Thus, the importance of learning more about the social world behind the technologies becomes obvious and the topic of this thesis extremely relevant.

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'a network of alliances may gradually and inexorably link an individual company's destiny to that of the network'

\- Benjamin Gomes-Casseres, *Group vs. Group*, 1994

Zusammenfassung

Firmen nutzen Kooperationsbeziehungen mit anderen Firmen, um ihre wirtschaftlichen Aktivitäten und gemeinsame Projekte zu organisieren, aber solche interorganisationalen Netzwerke können eine ‚dunkle Seite' haben. Entgegen ihres Rufs als flexibel können solche Strukturen einschränkende Einflüsse mit negativen Konsequenzen für die strategische Flexibilität, Leistungsfähigkeit, und das Überleben der Firmen entwickeln. Diese Dissertation entwickelt ein Erklärungsmodell, um zu analysieren, wie solche Situationen entstehen. Sie integriert dazu den Netzwerkansatz der Organisations- und Managementforschung, die Theorien der Pfadabhängigkeit und des Sozialen Kapitals. Das Erklärungsmodell konzeptualisiert eine Entwicklungsdynamik ausgehend von anfangs nicht-deterministischen Beziehungen hin zu zunehmend stabilen, kohäsiven und dicht-verbundenen Gruppen von Organisationen, sog. Allianzen. Diese können durch die interagierenden kognitiven, relationalen und strukturellen Dimensionen des Sozialkapitalprozesses in einen Lock-in geraten – der Pfadabhängigkeitsmechanismus in interorganisationalen Netzwerken, der die Handlungsoptionen der Mitglieder in diesen Dimensionen einschränkt.

Empirische Belege einer Fallstudie zur Smartphone-Branche untermauern und verdeutlichen das Erklärungsmodell. Firmen dieser Branche haben um zentrale Akteure herum zwei konkurrierende Allianzen nebst Softwareplattformen entstehen lassen. Die Falldaten zeigen kohäsive, netzwerkinterne Dynamiken und erhebliches Lock-in-Potenzial mit resultierenden Schwierigkeiten. Um die konkreten Bedingungen der finalen Lock-in-Phase zu untersuchen, wurde ein agentenbasiertes Computersimulationsmodell zum Experimentieren mit kontrastierenden Netzwerkszenarien erstellt. Die Experimente zeigen die enorme Bedeutung der Verhaltensannahmen beim Entwurf von Agenten für die Lock-in-Bedingungen wie Häufigkeit, Zeit bis Lock-in, Netzwerkdichte und Gesamtnetzwerkstruktur. Szenarien mit Firmen, die Kooperationspartner auf Basis ihrer Netzwerkeigenschaften aussuchen, geraten öfter, schneller und in höherer Dichte in Lock-ins als Szenarios, in denen anhand individueller Eigenschaften, wie z.B. der Ressourcenausstattung gesucht wird. Die Dissertation trägt damit einen Mechanismus der Gesamtnetzwerkebene zur Pfadabhängigkeitsforschung bei und einen Mixed-Method Forschungsansatz mit Fallstudie und formalem Simulationsmodell. Firmen in vielen Branchen erschaffen konkurrierende Allianzen und diese Dissertation erklärt die Gründe für die potentiell nachteiligen Konsequenzen.

Abstract

Firms rely on productive relationships with other firms to organise their economic activities and joint projects, but interorganisational networks of this nature may exhibit a 'dark side'. Despite their reputation as flexible, these network structures can exert restrictive forces with negative consequences for firms' strategic flexibility, performance, and survival. To explain why and how such situations arise, this study develops an explanatory framework that integrates the network approach from organisation and management studies, path dependence theory, and social capital. The framework conceptualises a development dynamic from initial, non-deterministic relationships to increasingly stable, cohesive, and densely connected groups of organisations (alliances). These may lock-in through the interacting cognitive, relational, and structural dimensions of the social capital process – the mechanism driving such path dependence in interorganisational networks which reduces members' options in these dimensions.

Empirical evidence from a case study in the smartphone industry substantiates and illustrates the framework. Firms in this industry created two competing alliances around hub firms and respective software platforms. The case data revealed cohesive network dynamics and considerable lock-in potential with related difficulties. To study the specific conditions of the final, lock-in stage of the process, an agent-based social simulation model was used to experiment with contrasting network scenarios. The experiments revealed that the behavioural assumptions for conceptualising agents exert a strong influence on lock-in conditions regarding occurrence, time-to-lock-in, density, and the whole-network structure. Scenarios with firms seeking cooperation partners based on their network properties locked in alliances more often, faster and at higher densities than scenarios with firms seeking partners with attractive individual properties such as their resources. The study thus contributes a whole-network level mechanism to the path dependence literature and a mixed-method approach with a case study and a formal simulation model. Firms in many industries rely on creating competing alliances, and this study explains reasons leading to the potentially detrimental implications.

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Table of Abbreviations

Abbreviation	Meaning
3G	3rd Generation Mobile Technologies
4G	4th Generation Mobile Technologies
ABM	Agent-based modelling
API	Application Programming Interface
AR	Augmented Reality
ARM	originally: Advanced RISC Machine; RISC=reduced instruction set computing; company name
CA	Cellular Automaton/a
CAS	Complex Adaptive System
CEO	Chief Executive Officer
CES	Consumer Electronics Show, reg. Las Vegas technology event
EC	European Commission
EU	European Union
FTD	Financial Times Deutschland
GSM	Global System for Mobile Communications
HP	Hewlett-Packard
JV	Joint Venture
LTE	Long Term Evolution – see also: 4G
MWC	Mobile World Congress, reg. Barcelona technology event
NAO	Network Administrative Organisation
OEM	Original Equipment Manufacturer
OHA	Open Handset Alliance
OMS	Organisation & Management Studies
OS	Operating System
RBV	Resource-Based View
R & D	Research and Development
SD	System Dynamics
SDK	Software Development Toolkit
SF	Symbian Foundation
SIM	Subscriber Identity Module (card)
SNA	Social Network Analysis
TCE	Transaction Cost Economics
TIMES	Telecommunication, Information technology, Media, Entertainment and Security
UI	User Interface
UMTS	Universal Mobile Telecommunication System – 3G
VHS	Video Home System
VC	Venture Capital
VR	Virtual Reality
VRIN	Valuable, Rare, Inimitable, Non-imitable
WSJ	Wall Street Journal

1. Introduction

"A loss of autonomy is problematic for firms, since it binds them"
(Joe Lampel, 4 March 2011, Berlin).

It is important for firms to have productive relationships with partner organisations. These allow them to pursue their diverse goals and business activities and create mutually beneficial opportunities. The relationships formed range from loose supplier-customer supply chain relations to more cohesive, strategic partnerships and even consortia or alliances, where several firms cooperate closely to achieve a joint goal. Despite interorganisational networks' general image of being flexible forms of organising, such cooperative relations and network structures can become overly stable over time. Then they often reduce firms' strategic flexibility and adaptability and hinder their ability to link with new cooperation partners outside their existing network. This can be problematic for firms' performance and even survival, e.g. when changes in markets, technology or the unproductive nature of a relationship would require swift adjustment rather than continued cooperation.

Many questions are prompted by such a locked-in situation, e.g. When was the detrimental trend recognisable and potentially reversible? When did formerly productive relationships become liabilities? Is there a strategy to avoid such situations entirely? All these questions are relevant for organisations. However, in order to answer them, a sound understanding of the phenomenon itself is initially essential to be able to tackle overly stable network relations in the future. In this thesis, I thus ask "why, under which conditions, and by what processes can the interorganisational networks in which firms participate become path-dependent?"

This research question is important for organisation and management studies (OMS) since this academic field seeks to understand and reflect on the actions, situations, mechanism, and effects that organisations such as companies encounter while pursuing their diverse activities. Within OMS scholarship, network research is an important focus because it embraces the study of the social fabric in which organisations and their activities are embedded and organised (Granovetter 1985: 496-504). Interorganisational networks are the focus of the present study, because this network structure is the basis of all of firms' activities and developments, and for the emergence of potentially problematic mechanisms. Adapting a definition by Provan, Fish & Sydow (2007: 482), an interorganisational network exists when organisations enter into purposive, multilateral cooperation relations and when the resulting relations exceed the dyadic level and facilitate the formation of groups of three and more organisations, such as alliances, for instance. These networks may be dispersed across the world and are not limited to specific geographic locations.

Traditionally, OMS researchers have argued theoretically and substantiated empirically that such interorganisational networks are an inherently flexible and thus advantageous form of organising cooperative ventures (e.g. Powell 1990: 322-327). Benefits discussed range from resource access and (external) economies of scale and scope, to information advantages and learning – all supposedly producing economic gains superior to other organisational arrangements.

However, as indicated above, interorganisational networks can also have a flip side, in terms of the network-induced path dependence of the participant organisations which may arise from locked-in, overly rigid network structures, as several studies have identified (e.g. Walker, Kogut & Shan 1997; Kim, Oh & Swaminathan 2006; Maurer & Ebers 2006; Hagedoorn & Frankfort 2008; Burger & Sydow 2014; Schmidt & Braun 2015). Such research identified the phenomenon of networks' overstability (in relation to its environment) styling it in several different ways, e.g. historicity, imprinting, overembeddedness, inertia, lock-in, path dependence etc. Still, despite many years of scholars emphasising the need for increased investigation of this 'dark side' of networks, research-related neglect is responsible for a lack of systematic understanding of the processes and mechanisms leading to such network path dependence.

The complex phenomenon of a system lock-in (such as a network) to an unfavourable situation has been studied in OMS under the name 'path dependence' (Sydow, Schreyögg & Koch 2009: 694). Where network scholars often only refer loosely to path dependence – mostly metaphorically – path dependence scholarship has defined a clear conceptualisation of the mechanisms and the process leading to an unfavourable lock-in. Given that networks in general and their dynamics in particular are receiving ever-increasing attention in OMS research (Zaheer, Gözübüyük & Milanov 2010: 62, Majchrzak, Jarvenpaa & Bagherzadeh 2015: 1340) and the expressed need for the analysis of networks' 'dark side', it is surprising that networks and social structure arguments have rarely been an analytical or theoretical focus in path dependence research, with only few exceptions with specific applications (e.g. Sydow, Lerch & Staber 2010; Burger & Sydow 2014; Schmidt & Braun 2015). This lack of scholarly regard is particularly astonishing, because the high-tech industries that have been objects of much path dependence research for their strong standardisation tendencies tend to rely heavily on network structures when organising their activities. A network lens, however, has not been chosen for the study of the network structural side of vivid path dependence cases such as e.g. QWERTY or VHS.

The goal of this research is to gain an understanding, i.e. provide a theoretical[1] explanation of why, under which conditions and especially by what processes the interorganisational networks in which

[1] Here, 'theory' and 'theoretical' refer to the development of an abstract and (to some degree) generalisable causal explanation for a phenomenon under study. Such arguments can include already tested explanations and ones that allow for future testing.

firms participate can become path-dependent. In order to approach such an understanding, I see strong potential in linking the OMS subfield of interorganisational network research with that of path dependence. However, the present core path dependence explanations – the (social) mechanisms responsible for lock-ins – are not readily applicable to interorganisational networks. One study exists which connects interorganisational networks with path dependence via a concept called 'social capital' (Walker, Kogut & Shan 1997), but this has several weaknesses: It remains vague in its processual specification, peculiar in its conceptualisation of social capital as structural equivalence, static (comparative) in its operationalisation and thus superficial in its investigation of the network *dynamics* required for an application of path dependence theory. The present research surpasses such limitations and develops 'social capital' as a path dependence mechanism so that it fills the gap left by the two other research streams and connects them.

I thus develop an explanatory framework that integrates the three streams of literature: network research on interorganisational relationships (Gulati, Nohria & Zaheer 2000; Zaheer, Gözübüyük & Milanov 2010) and organisational path dependence theory (Sydow, Schreyögg & Koch 2009), with a newly developed path dependence mechanism devised as an integrated notion of the network concept of social capital which connects two formerly disconnected conceptualisations (Burt 2001; Burt 2005; Coleman 1990). This integration permits addressing gaps left in the literature: for network research, it answers the calls to studying the 'dark side' of networks and provides an understanding of why and how firms become trapped within the locked-in structure of the interorganisational networks in which they participate. For path dependence research, it permits an extension of and application to the study of interorganisational networks at the structural level.

Addressing the research question and thus developing the explanatory framework requires arguments at several different levels of description and analysis to meaningfully capture the constituent elements of the phenomenon, namely the *macro* level at which the consequences of path dependency emerge: over-stability of network structures and lock-in, potentially of a whole industry; the *meso* level, where groups of interconnected organisations (alliances) emerge through the cooperation (and thus connection) decisions at the *micro* level where individual firms interact, link and give rise to network structures and cross-level dynamics (see also Figure 13). This approach thus employs a complex adaptive systems (CAS) lens (Anderson 1998: 217; Page 2015: 23-37), further assuming that the phenomenon of an overly stable, locked-in interorganisational network composed of self-organising, learning agents (organisations) arises emergently as a non-linear process over time, like other path dependence phenomena (Sydow, Schreyögg & Koch 2009). The framework hence accounts for this non-linear emergent process and CAS nature of the network structures' development diverging from its initially unproblematic and flexible nature and becoming overly and problematically stable over time based on cross-level dynamics.

The structure of this research is outlined as follows: after providing clarity in definitions and discussing theory and extant research, I develop the novel explanatory framework. Subsequently, I substantiate this with empirical evidence from an exploratory case study on two interorganisational networks in the smartphone industry. Smartphones are a rapidly growing part of the TIMES[2] sector and prove helpful in theory-building and when refining, illustrating, and substantiating the developed framework, since the interorganisational networks emerging around the software ecosystems (or: platforms) give rise to new network structures with potentially binding forces.

To formalise and explore the processes detailed in that framework even further, and experiment with findings from the case study, I employ the method of agent-based computer simulation for abstractly modelling the development of interorganisational networks and studying path dependence processes unfolding within them in a formalised manner. This successfully reveals how far, how quickly and to what extent network structures and the social capital mechanism can entrap their members in form of a path-dependent network lock-in. Such a phenomenon has been studied for specific networks of individuals (e.g. Gargiulo, Ertug & Galunic 2009; Gargiulo & Benassi 2000) to some extent, but not for organisations such as firms, and without using the simulation method. The data collection restrictions on empirical networks, however, typically lead to a lack of analytical depth and process detail of empirical evidence, both of which can be effectively amended by employing agent-based computer simulation. Even though agent-based modelling (ABM) is still in its infancy in OMS (Harrison et al. 2007), it has already shown its value in studies of other path dependence phenomena, e.g. complementary institutions (Petermann 2010), two-sided markets (Meyer 2012), and organisational learning (Seidel 2013). One clear advantage of ABM lies in its ability to provide fine-grained data with continuous time points which, contrary to empirical network studies, allows for a dynamic representation of the phenomenon. It has virtually no data collection restrictions and together with its ability to (re)produce emergent phenomena through the complex interaction of the contained agents at several levels of analysis, this methodology serves the present purposes of studying a complex structural process unfolding its dynamics over time.

In summary, this research makes seven contributions: first, this study extends research on interorganisational networks by answering the call to shed more light on the 'dark sides' of networks (Zaheer, Gözübüyük & Milanov 2010: 71) and by providing an understanding of the path dependence of interorganisational networks. Second, it enriches path dependence theory, because it newly addresses the question of how path dependence may arise in interorganisational networks and affect both the development of cooperative relations and network member flexibility. Third, it reunites two conceptualisations of structural social capital (Burt 2001; Burt 2005; Coleman 1990), that were formerly deemed incompatible. This reconciled understanding reveals social capital as a driver (or mechanism) of network path dependence and introduces this processual conceptualisation of social capital

[2] TIMES = Telecommunication, Information technology, Media, Entertainment and Security.

into interorganisational and path dependence research. Fourth, a methodological contribution lies in the combination of a qualitative empirical case study to provide grounding for a theory-driven agent-based model as a mixed-method approach (Molina-Azorin 2012). Fifth, with the aid of this methodology combination, I expose the conditions under which network path dependence occurs, its causes and processes. Sixth, with the exploratory study of the smartphone industry, this research studies an emerging field that may create globally relevant standards and path dependence for several billion global users. Lastly, by employing computer simulation as a method to study path dependence, this research also answers calls to use this method by path dependence and network scholars alike (Vergne & Durand 2010: 750; Majchrzak, Jarvenpaa & Bagherzadeh 2015: 1358).

1. 1 Relevance of the research: interorganisational networks

The question of how far a (social) structure can influence firms has a long tradition in organisation and management studies (Galan & Sanchez-Bueno 2009: 1234). The still current 'structure vs. strategy' debate was initiated by Chandler (1962). In his book, he theorised that for a firm to be successful, its organisational structure should follow its strategy, embracing an almost deterministic perspective of planned firm development. Others later disputed this idea and posited that, in contrast, "strategy follows structure" (Hall & Saias 1980: 162), embracing an emergence-focused position. Some authors even point out a reciprocal interrelation between structure and strategy (Burgelman 1983: 67), indicating that the notion of unidirectional causality needs to be updated to that of bidirectional interaction. Yet conflicting evidence also exists, which indicates that the strategy-structure fit might play more of a role in certain industries: Habib & Victor (1991: 603) discovered how the strategy-structure fit had no influence on the performance of service firms but did influence that of manufacturing firms.

When Chandler initiated the 'structure vs. strategy' debate, the related research field of sociology was concerned with the issue of how to conceptualise society at large. Similarly, the parallel 'structure vs. agency' discussion focussed on the question of how strongly humans should be conceived of as 'social animals' or whether such a view was 'over-socialized' and agency was stronger than embeddedness. Just like the discussion in business research, some authors concluded that 'the truth lies in the middle' and that man is finally "social but not entirely socialized" (Wrong 1961: 191).

While the debate certainly has a long tradition, its focus on firms' internal developments may seem almost dated from a present-day perspective. The 'structure vs. strategy' debate is an outcome of the 1980s rise of multinational conglomerate firms. Today, the question of how much network structure can influence the performance and survival of a company (Gulati, Nohria & Zaheer 2000: 203) warrants significant attention, because firms, especially in technology industries, find themselves increasingly embedded in what has been called "strategic cooperative alliances" (Dyer & Singh 1998: 661), "strategic groups", "strategic blocks" (both Nohria & Garcia-Pont 1991: 105), or "alliance constellations" (Das & Teng 2002: 445). Focussing activities and strategies around certain core competences and capabilities[3] (Prahalad & Hamel 1990), international competition, a desire for flexibility, and technology convergence (Buckley & Casson 1998: 31-33) drives firms to rely on interorganisational networking as forms of organisation (Sydow & Windeler 1998: 266) rather than on more exclusive alternatives such as acquisitions and vertical (or horizontal) integration (Dyer, Kale & Singh 2004), as in the formerly popular conglomerates.

In essence, the structure of a network and its properties can exert a similarly important influence on firm performance and survival as does a firm's internal structure. It, too, may be planned in advance to some extent or develop emergently, and it too can have both positive and negative effects on performance, flexibility, and survival, simultaneously or differing over time (Sydow, Schüssler & Müller-Seitz 2016; Bakker et al. 2016). In our present volatile economic times, flexibility in a firm's activities is one important strategic goal for corporate actors. Swift reactions to market trends and sometimes over-night changes in technologies are the features of many high-tech industries, including the smartphone sector which is a focus of the present study. Impediments to that desired flexibility can have negative effects on firm performance and survival. Hence, when an unintentional network structure emerges and limits firms' strategic options through a loss of decision autonomy, such a development would be such a detrimental occurrence. Firm performance and survival and ultimately the performance and survival of a network or entire industry are thus at stake when network structures come to impede firm flexibility and thus their ability to autonomously implement their own strategies and decisions. Moreover, networks can be instrumental in the emergence of path dependence at a more macro level such as a market (Liebowitz & Margolis 1995b: 221). To address these issues, this research sets out to decipher the mechanisms behind this constraining capability of network structure, which can lead to firms' potential loss of flexibility, a phenomenon I will term 'network path dependence' for the purposes of this study.

The constraining property of structure was already at the heart of the debate on firms' *internal* structure (Hall & Saias 1980). This study's attention is directed at firms' *network* structure, because this puzzling enabling *and* constraining duality of (network) structure (Giddens 1984; Sydow & Windeler 1998: 267-270) needs to be studied more thoroughly at the interorganisational network level than the literature has achieved so far. Network relations and structures are described to enable certain activities, e.g. knowledge sharing, but they have also been described as possessing a constraining 'dark

[3] These are themselves not unproblematic with regard to path dependence, as masterly revealed by Leonard-Barton (1992).

side'. OMS network scholars discovered this phenomenon of constraining network relations and have given it many, sometimes confusing names: history/historicity (Gulati 1995; Gulati & Gargiulo 1999), network memory (Soda, Usai & Zaheer 2004), imprinting (Marquis 2003), rigidity (Nohria & Garcia-Pont 1991), over-stability (Vanhaverbeke & Noorderhaven 2001), overembeddedness (Uzzi 1997; Hagedoorn & Frankfort 2008), network inertia (Li & Rowley 2002; Kim, Oh & Swaminathan 2006), traps (Gargiulo & Benassi 2000), lock-in (Gulati, Nohria & Zaheer 2000), and finally path dependence (Walker, Kogut & Shan 1997; Sydow, Schreyögg & Koch 2009: 705).

When studying the path dependence in interorganisational networks, scholars used these terms metaphorically when referring to situations characterised by the problematic persistence of structures and relations. Only few of the above engaged in a systematic process analysis of the mechanisms and lock-ins that are an integral element of the phenomenon of path dependence. Path dependence research, in turn, has provided analytical tools, but hardly made use of them in a network context, as briefly outlined in the next section.

1.2 Relevance of the research: organisational path dependence

Path dependence research was originally concerned with the idea that markets do not always achieve an efficient outcome. David (1985: 336) and Arthur (1989: 117) introduced this idea through the historical analysis of the QWERTY computer keyboard layout case. While including strong criticism of conventional economics – which claims that the market as a transaction institution will always achieve the optimum, i.e. efficient, allocation of resources or solution to a (technical) problem – both authors additionally drew attention to the influence of the social sphere on these apparent 'market choices.'

Social actors, particularly from the supply side of the market, may have an interest in a favourable market outcome and thus an incentive to influence others concerning their choices to steer the direction in which an organisation, network, alliance, industry, or market develops. As a result, connecting influential actors and their activities may increase the likelihood that solutions favoured by the influencing actors will become adopted. The case for such connections can be stronger when actors seek to influence the development of technology products and services, especially those with platform character which have the tendency to develop into global standards. Particularly when future market choices are unclear due to technological uncertainty and when strategically important and extensive investments are required, partnering with other players appears to be an approach that actors employ to reduce risk, increase their influence and support, or even jointly create a favourable standard (Sydow, Lerch & Staber 2010). Such partnering creates interorganisational networks which may take various shapes of more or less formalised standardisation bodies or consortia, such as the well-known IEEE[4], W3C[5] or the GSMA[6] that tie together several companies to common technology standards or platforms. Through their cooperation and interaction, firms may become dependent on, or even locked-in to the (sub-)network of which they are members.

Generally, networking activities do not necessarily prevent markets from being able to choose the technologically or economically best solution. However, networking may also lead to problematic support for a (sometimes hypothetical) less favourable standard, as was shown in previous cases of technological path dependence (e.g. QWERTY, VHS etc.). In these cases, markets may choose a supported rather than efficient product or service solution, and path dependence at several (social) levels may be the result of such a process of influence through forms of networking. Furthermore, the option of such a sub-optimum market choice provides an incentive for firms to engage in networking, because it may lead to the market favouring the product or service that a firm supports through its network and investments, even if and especially if, the solution is technically or economically inferior, or if it is initially not yet clear which option will be superior.

However, such behaviour is risky, because the influencing endeavours can also fail. A failure easily drags previous investments and cooperation relations with these companies into irrelevancy. Thereafter, membership of networks proves strategically problematic for participant firms. At best, it may retrospectively render their activities useless and very expensive, or, at worst, prove detrimental to the survival of member firms. Conversely, for those firms locked-out of a standard-supporting network, the consequences may be equally dramatic: by gaining monopolistic positions, the networkers can gain monopoly rents and establish powerful "barriers to entry that restrict competitive forces" (Jacobson 1992: 782) – an important issue with serious welfare implications studied in the Industrial Organisations literature.

The relevance of interorganisational networks for path dependence research thus lies in a focus on standard-supporting, networking organisations in this research and to investigate the conditions and causes of situations in which network membership becomes problematic for the participant organisations. Apart from the QWERTY case, research on other historical path dependence cases such as JVC's VHS vs. Sony's beta video system (Liebowitz & Margolis 1995b: 218-222), has already revealed that networking among players is an important contributing factor in path-dependent developments. So far, however, little attention has been paid to the influence exerted by network structure and dynamics on processes of path dependence. This research seeks to close this gap and explain how

[4] The Institute of Electrical and Electronics Engineers – http://www.ieee.org/

[5] The World Wide Web Consortium - http://www.w3.org/

[6] The GSM Association - http://www.gsmworld.com/

the mechanism of social capital can lead such influence-seeking interorganisational networks to develop path dependence and become locked-in to their network structure.

1. 3 Structure of this study

In order to address this particular 'dark side' of interorganisational networks, the present study is structured as follows: first, I discuss extant research on interorganisational networks and their structure and stability which holds the basic ingredients for framing the phenomenon (Section 2.1-2.3). I then introduce organisational path dependence theory as a more consistent explanation of the phenomenon of stabilising social structures (Section 2. 4). With social capital (Section 2. 5), I subsequently develop a mechanism driving network structural path dependence. Afterwards, I condense the theoretical discussion into an integrated explanatory framework (Section 2. 6). In order to refine the theory, I then confront this framework with an empirical reality by means of an illustrative and substantiating case study involving two interorganisational networks working on technological platforms (Chapter 3). After discussing the findings of this case study, I use details derived from the case for a further systematic exploration of the explanatory framework dynamics by means of an agent-based model (Chapter 4) which provides a computer simulation implementation of the framework. I discuss the findings of the subsequent computer experiments with regard to their ability to inform the theoretical arguments regarding the path dependence of interorganisational networks and network structural lock-in. Finally, I discuss the overall findings, summarise the contributions of this study and discuss its limitations, implications for theory and practice and outline suggestions for future research (Chapter 5).

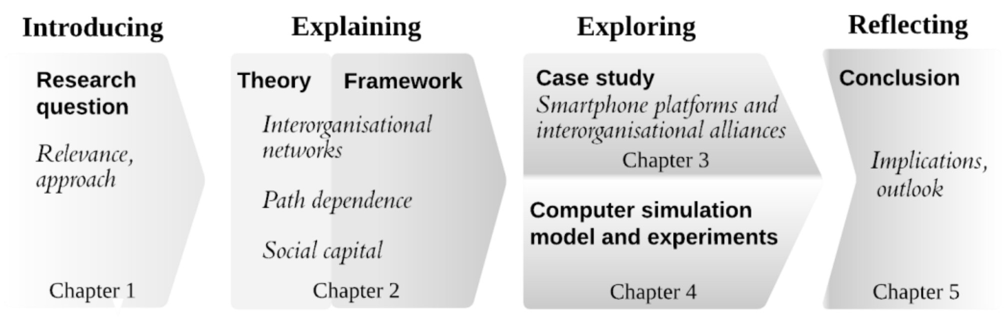

Figure 1: Study outline

2. Theory

"Theory is the answer to queries of why"
(Sutton & Staw 1995: 378).

This research seeks to provide an understanding of how the dynamics and mechanisms that actors may trigger in interorganisational networks may result in negative effects for network members – network path dependence and lock-in to overly rigid network structures. This theory chapter outlines and discusses the extant theory and research necessary for gaining such an understanding.

The first section (2. 1) introduces network research across disciplines, detailing broad developments and explaining the main terminology employed. Section 2. 2 distinguishes the present research from other network-oriented research in sociology, economics, and other OMS research on networks. Section 2. 3 reviews extant literature on interorganisational network research in OMS that are at the heart of this research. It covers several concepts of dynamics in interorganisational networks and details their relationships with the present research question. The section concludes by identifying and discussing the need for a more systematic and cohesive theoretical lens to capture and explain how interorganisational networks' structural dynamics can become so problematically rigid that they entrap their members in terms of becoming strategically restricted. Section 2. 4 introduces the theory of path dependence and its merits as far as answering the present research question is concerned by providing a more coherent process perspective than that currently offered by extant literature on networks. It outlines the elements of a path-dependent process and reveals the lack of a (social) mechanism in the interorganisational network realm. Section 2. 5 fills this gap by introducing the theoretical concept of social capital that can serve as an explanatory mechanism of path dependence in interorganisational networks. Thus far, the theory chapter sets the stage for the development of the new aggregated explanatory framework in Section 2. 6, which connects these three streams of literature into one coherent explanation of the phenomenon of path dependence in interorganisational networks and concludes the theory chapter.

2. 1 Network research

"Networks are present everywhere. All we need is an eye for them" (Barabási 2003: 7).

Network scholarship is not easily grasped or even categorised. Since its emergence in organisational sociology, it has developed into a broad field of interdisciplinary research with an assortment of methods, analytical constructs, and theories idiosyncratic to it alone. It is thus instructive to provide an overview of main network research fields and major ideas in order to distinguish the present research from other network research. In consequence, the following section (2. 1) gives a brief introduction to network research, including its main theme and history. Important terminology and analytical and theoretical constructs introduce the way in which the literature talks about network phenomena. Section 2. 2 differentiates this research from other major network research disciplines (Sociology, Economics) and from those in OMS that are not studying interorganisational, but other networks. Section 2. 3 subsequently focuses exclusively on interorganisational network research in OMS. Altogether, these sections provide the basis for understanding the phenomenon of path dependence in interorganisational networks that is ultimately of interest to the present study.

2. 1. 1 Network approach – the main concerns

Network research comprises all issues related to the fact that actors do not act and behave fully independently and autonomously as claimed (or implied) by e.g. the *homo oeconomicus* actors of neoclassical economic theory (Weise et al. 2002: 45-95). The term 'network' is intrinsically quite general and may cover any relations among social entities[7] ranging from individuals and their work or friendship relations to the interorganisational activities of interest here. This notion of networks and connectedness has been called an "approach" (Moliterno & Mahoney 2010: 22), the "network perspective" (Brass et al. 2004: 795), or even a "network paradigm" (Borgatti & Foster 2003: 991). The 'network approach' (the denomination I adopt for the purposes of this study) now constitutes a large area in OMS, and contributions are growing steadily as a result of its increasing popularity among scholars from many disciplines (Zaheer, Gözübüyük & Milanov 2010: 67). But where does this network approach come from, and how did it emerge as such an integral part of social science?

[7] It goes without saying that physical and technical networks such as the telephone communication system, the internet and the flight connections of airlines between airports can also be (and have been) considered networks. The focus here, however, lies exclusively on those networks in the social realm.

2. 1. 2 A concise history of the network approach

In recent decades, the use of the word 'network' has spread through many research fields. Interestingly, network research did (to some degree) originate from business-focused organisational sociology research, e.g. at Harvard University. It was there, in the 1920s, that anthropologically-oriented organisational scholars were the first to use sociograms in the famous Hawthorne studies (Kilduff & Tsai 2003: 13-14). Only in the 1970s, however, did social-psychological theorists building on theories by scholars including Lewin and Moreno (Schnegg 2010: 23-25) meet with the anthropological Manchester unit and the Harvard scholars (Jansen 2006: 38). Their work was then inspired by field theory in physics, matrix algebra, mathematical graph theory and block model analysis (Wasserman & Faust 1994: 394ff.) to form a separate research stream which went by the name of "Social Network Analysis" (Jansen 2006: 47).

Since the outset, "research on social environments of people, groups, or formal organizations as actors… is at the heart of network analysis" (Burt & Minor 1983: 9). Nowadays, though, not only do social scientists employ network arguments, but researchers from other sciences ranging from computer science to biology (Schnettler 2009: 167, Watts 2004: 243), and from literary studies to physics (Borgatti & Foster 2003: 991) have joined them. This new research later led to renowned literature on phenomena such as the "small world problem" and the connected theory of "six degrees of separation" (Borgatti et al. 2009: 892). Figure 2 broadly outlines the history of network research until the point where it forms the minimal canon of methods known as Social Network Analysis (SNA).

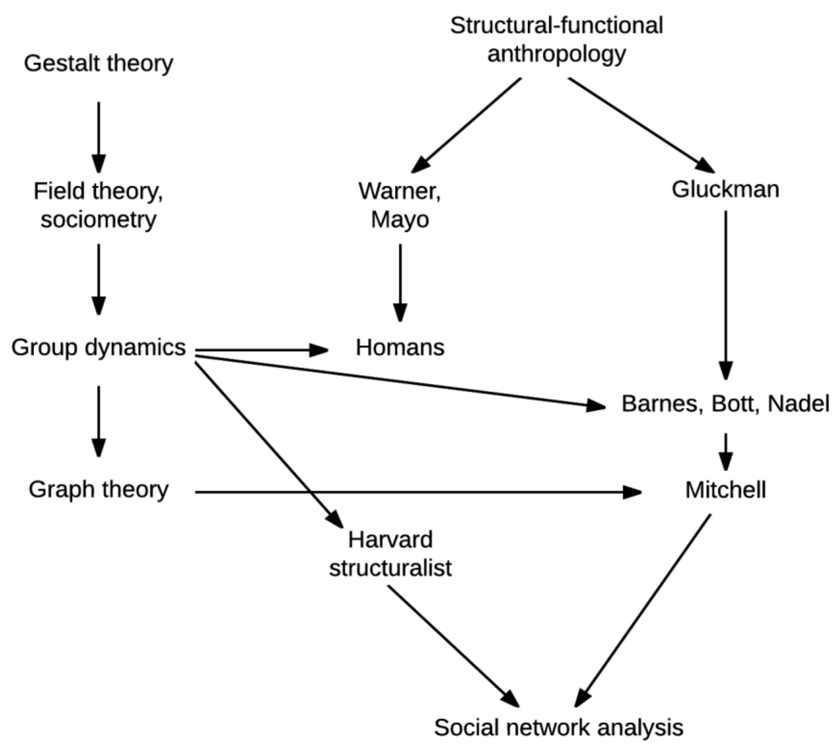

Figure 2: The linage of network research (adapted from Scott 2000: 8)

There is no universal agreement in the literature about whether (Social) Network Analysis constitutes a theory in its own right (Moliterno & Mahony 2010; Borgatti & Halgin 2011), whether it represents a perspective (Wasserman & Faust 1994: 4), or whether it is merely a canon of methods (Scott 2000: 37). While this question cannot be resolved in the present study, network approach research is unique in its ability to move "away from individualist, essentialist and atomistic explanations towards more relational, contextual and systemic understandings" (Borgatti & Foster 2003: 991). Furthermore, "(1) network research focuses on relations and the patterns of relations rather than attributes of actors; (2)... is amenable to multiple levels of analysis, and can thus provide micro-macro linkages; (3) network research can integrate quantitative, qualitative and graphical data, allowing more thorough, in-depth analysis" (Kilduff & Tsai 2003: 19). The approach allows the study of emergent social structures (Bommes & Tacke 2006: 39) and offers "the possibility of helping us understand how individual actors create, maintain, exploit, and are constrained by social structures at several levels of analysis [... such as] the interorganisational environment" (Kilduff & Tsai 2003: 66).

2. 1. 3 Network approach – terminology

Discussing the structure of (social) networks necessitated a new set of terminology to capture the new approach's concepts, and network approach researchers have been producing an ever-growing canon of methods and theoretical concepts for the study of network phenomena. While not all research invoking network arguments actually uses mathematical and statistical methods of social network analysis, the terminology of the social network methodology is applied across disciplines and research foci. A relevant selection of network approach terminology and concepts requires clarification here.

Network research is about (social) entities and their relations. Not surprisingly, the two central elements of network parlance are the terms 'actor', referring to networks' social entities, and 'tie' referring to their linkages (Wasserman & Faust 1994: 17-18). The term 'actor' pays tribute to the fact that individuals or other social entities indeed *act* within their social structures. Several other terms for these two main elements also exist. The formalised graph theory developed in the 1970s calls the actor a 'node' and tie an 'edge' (Borgatti & Foster 2003: 992), referring to their graphical representation. Other literature refers to the ties between actors as 'links', 'relations' or 'connections.'

Actors and their ties can vary in their analytical characteristics depending on the theories employed and the levels of analysis (Jansen 2006: 58-61). The term 'ego' is employed when talking about an individual actor from *their point of view*. When talking about that actor's network, the term 'ego-network' is used to signify this perspective (Borgatti et al. 2009: 894). The collection of ego-networks is a popular strategy when collecting empirical network data based on individuals' statements. Measuring the network of several egos and then merging these networks can be a useful approach to gain a comprehensive picture of a complete network (Borgatti & Foster 2003: 992). Actors other than the ego under scrutiny are then typically referred to as 'alter(s).'

A pair of connected actors is habitually termed a 'dyad', a triplet of nodes as a 'triad', and bigger groups as 'cliques' (Kilduff & Tsai 2003: 6). The subsequent larger analytical layers are 'sub-groups', 'groups', 'organisations' and the 'network' itself. Given these different levels of analysis, 'node' can denote the relevant social entities at that level, e.g. individuals, groups, sub-groups of organisations, their divisions, companies and other organisations, cities, regions, societies, nations, continents, planets, or more abstractly, networks of networks.

In accordance with the different types of nodes and the theoretical and analytical focus of the research, the ties' denominations also vary. Relationship content ranges from transactions, communication, and friendship to acquaintance (or non-acquaintance), power, feelings, and family relations, corporate ownership structures etc. Exchange ties of various types (goods, support, money, resources etc.) may be found between almost all types of nodes. The same is true for 'who-knows-who' ties and (non-) communication networks.

The present study focuses on the cooperation ties that exist between organisations. Interorganisational networks are, of course, based upon networks of real people: "inter-firm relations [are] embedded in [..] personal ties" (Grabher 2005: 64), even if they rely on contracts or equity exchange, since this still requires contacts by real people, if only in their capacity as representatives of legal persons. To this extent, then, the social networks of managers and other organisational staff are also relevant since they provide the basis for creating interorganisational networks. This distinction has been the subject of so-called board interlocks studies, for instance, where board members' participation on several boards forms the basis for connections among the companies.

In this context, it is important to note that several relationships may frequently coexist at the same time between the same social units, and that one tie may serve multiple interests. This situation is referred to as a "multiplexity of ties" (Kilduff & Tsai 2003: 33). Examples are friendships that form the basis for work relations but continue to be friendships, while firms may do business based on supply contracts that develop into shareholdings. This multiplexity of ties may coexist and relations can influence each other, e.g. when a supplier firm is bought by a shareholder that then integrates it into its corporate group structure, which may end the (legal) supply relation. The 'strength' or 'intensity' of a network tie is a concept used to weight the relations between social units and can be measured in terms of factors including the size of a transaction in monetary flows, communication or resource flows between actors, or the rate of repetition – frequency – of interaction (Janssen 2006: 59). A tie further exhibits 'reciprocity' when actors symmetrically (report to) participate in a relation, e.g. when resources flow in both directions in a dyad (Kilduff & Tsai 2003: 33). Reciprocity is often required and enforced through emerging social norms of reciprocal behaviour.

2. 1. 4 Network approach – major concepts

Not only has a specific terminology developed within network scholarship, but certain theoretical and analytical constructs have also been created, some of these imported from other fields such as mathematics, others genuinely created in network research (Kilduff & Tsai 2003: 37). Concepts in the network realm can be distinguished from each other in several ways. One way is to consider, on the one hand, actor properties that arise from their positions in the network or influence within it, and, on the other hand, properties of ties and of the network or parts of it, based upon the relations between actors.

Most notable among the first is the concept of 'centrality' which has been conceptualised in several different ways (Wasserman, Scott & Carrington 2005: 4). The construct is concerned with "the structural importance or prominence of a node in a network" (Borgatti et al. 2009: 894) and generally based on the assumption that central actors will be heavily involved in network relations (Knoke & Burt 1983: 198). Centrality can be measured as degree, Betweenness, or closeness. These constructs can be used to identify the "stars" or "isolates" of networks (Wasserman & Faust 1994: 169), among other things, or to draw conclusions with regard to their access to certain resources in the network (Jansen 2006: 127). It is worth noting that in the case of (social) prestige interpretations, directed ties (e.g. in-degrees in a friendship network) are a requirement, whereas undirected cooperation links suffice for the identification of hubs in interorganisational networks, e.g. via 'Betweenness centrality'.

An important, yet diversely-defined construct is 'social capital' (Adler & Kwon 2000: 90-93). The general idea of the concept is that actors can appropriate or access certain resources as a result of their position in a network (Adler & Kwon 2002: 18), e.g. information flow, control over others through obligations etc. It thus serves as the actual or potential resource for social actions (Nahapiet & Ghoshal 1998: 243). I will deal with social capital in Section 2. 5 in more depth, since it constitutes the proposed mechanism that drives the emergence of network path dependence.

Structural role theory (Kilduff & Tsai 2003: 58-59) stems from structural network analysis and is concerned with the idea that certain actors may hold similar positions (and roles) in the same network or in different networks. When compared, actors might be grouped according to their 'structural equivalence', i.e. their equivalent way of being embedded in a network (Wasserman & Faust 1994: 348). Often, actors from similar structural positions are more linked to one another than across positions/roles. Examples include roles such as group leaders, who might work more with leaders of other groups than with their subordinates who, in turn. may be better connected with subordinates in other groups within the same network.

'Homophily' is a concept borrowed from social psychology related not to actors' structural equivalence, but to the fact that they are similar in some of their network-independent characteristics. These may lead these actors to form ties more readily and intensely with similar actors than with dissimilar ones. However, empirical research also shows that actors might choose the exact opposite strategy: 'heterophily', i.e. choosing diversity, leads actors to select alters for networking which are most different from themselves (Kilduff & Tsai 2003: 52-54).

Membership of certain network (sub-)groups is used in research, and 'cliques' is another concept from social psychology and a certain way of defining groups within networks. They can be considered highly dense regions in a network (Jansen 2006: 193), where 'dense' denotes relations between many actors of a certain network area. Membership typically generates a degree of homogeneity and structural cohesion and is measured by the criterion of a short 'path distance' between actors. 'N-cliques' are defined as groups of actors (at least 3) that form a subgraph of dense connections within a network, where N denotes the path distance within that group (Trappmann, Hummell & Sodeur 2011: 76). To illustrate, a 1-clique means that all group members are directly connected. In a 2-clique, they would be connected through a maximum of one indirect tie. A similar construct is a 'k-plex' that defines a group not via the reachability of members but conversely through their non-reachability. Groups may also work as a mechanism of exclusion, e.g. when intentionally using exclusive contracts to lock other firms out of supply relations (Borgatti et al. 2009: 895).

Important concepts relating to properties of the ties of actors are 'reciprocity' and 'frequency' which I have already outlined above. 'Density' and 'structural holes' are two further concepts that are related to the structure of ties among actors. A network's or (sub-)group's density is defined as the number of links between actors divided by the number of all possible links between the actors considered (Trappmann, Hummell & Sodeur 2011: 52).

$$d = \frac{number\ of\ established\ ties\ among\ actors}{number\ of\ all\ possible\ links\ among\ actors}$$

Equation 1: density of a network

This measure is a property of a network or subgraph of a network and typically serves as a measure of the connectedness among network members in the considered area. It can also provide information about the intensity of an actor's embeddedness within the network. The more connected a network, the more it may be considered 'closed' (Burt 2005: 95-97).

A 'structural hole' is defined as a gap in the network structure – a missing link – between actors or groups (Burt 2005: 16). These holes do not necessarily exist for special reasons other than that certain actors are not connected, and this creates a missing tie. Typically, many structural holes in network structure exist, and certain actors that strategically, or by chance, fill these gaps can gain certain benefits from bridging gaps via 'brokerage' (Burt 2005: 17-21). I will revisit these arguments below in Section 2. 5, in which the concepts of social capital are discussed.

2. 1. 5 Reflections on 'network theory' and network thinking

As already indicated, scholars disagree on the question of whether network research is a theory (with its own axioms, for instance) or even a paradigm, a perspective, or merely a canon of methods and constructs. This does not prevent researchers from identifying common concepts and shared approaches in network research. As part of this effort, Schnettler's (2009) review on "50 years of small world research" (2009: 165) finds that network studies can be divided into three related but distinguishable dimensions: structural, process, psychological (or cognitive). The first deals with the influence of network properties on actors, e.g. the likelihood of shared acquaintances. The second dimension focuses on processes that build on such structures such as. the diffusion of innovations and information or contagion of ideas etc. This third dimension encompasses the ways in which people deal with their network and the knowledge and experiences from and about it (Schnettler 2009: 166). While Schnettler covers network research relating to many disciplines, the categorisation holds similarly for network research in OMS.

With a different focus, Borgatti and Halgin (2011) identify two types of network theorising: "Network theory refers to the mechanisms and processes that interact with network structures to yield certain outcomes for individuals and groups … [i.e.] the consequences of networks [while] theory of networks refers to the processes that determine why networks have the structures they do – the antecedents of network properties" (2011: 1168). They further identify three different major models in 'network theory' research: the flow model, concerned with the travelling of certain resources, e.g. information, based upon network structure (Borgatti & Halgin 2011: 1173); the coordination/amalgamation/bond model that deals with alignment of actions of nodes that enables certain capabilities that extend individuals' capabilities (Borgatti & Halgin 2011: 1174); and the fact that networks can further be understood as mathematical models of the social world (Borgatti & Halgin 2011: 1174). This mathematical description allows for a clear analytic registration of ties. As regards outcomes of network theory research, the authors identify "choice," i.e. behaviours, attitudes, and beliefs, and "success, which includes performance and rewards" (Borgatti & Halgin 2011: 1175).

Borgatti and Halgin's 'flow model' and 'coordination model' are similar to the 'process' and 'psychological' categorisations that Schnettler uses, while his 'structural' analytical dimension relates to the 'mathematical' objectification of networks that Borgatti and Halgin posit. It appears, then, that there is at least some agreement in the literature concerning the kinds of categories or dimensions engaged in by network research.

When reflecting on these categories, it becomes obvious that distinguishing 'network theory' from a 'theory of networks' is useful when categorising network research. Yet, despite a medley of arguments, much research transcends this distinction, e.g. in theory (such as Moliterno & Mahony 2010) or when following qualitative approaches (such as Sydow & Lerch 2007). As the authors therefore rightly concede, "it might be expected that, in reality, the two kinds of processes occur together" which leads to their conclusion that "network theory and theory of networks are not disjoint sets (Borgatti & Halgin 2011: 1177)," especially due to endogeneity, context and social agency.

The present study embraces this view. A dynamically developing network structure is both the basis on which other effects, e.g. group cognition and resource exchanges, occur and that very network structure is also the result of precisely these processes (Sydow & Windeler 1998: 266; Windeler & Sydow 2001: 1040-1043). I argue below that increasingly rigid network structures can emerge through cooperative ties, on the basis of which other processes, such as the flow of information or the development of commonly shared ideas ('contagion'), unfold. Further, these processes have a causational feedback loop to the network structure that can lead to increases in density, for example, that allow for ever easier internal diffusion etc. – an argument that clearly transcends the distinction made by both Borgatti & Halgin (2011) and Schnettler (2009).

In that sense, this study fits more into the Borgatti and Halgin (2011) category "network theory of networks" as depicted in their useful 2x2 matrix below (Table 1). The "network theory of networks" box and all three types of models are relevant for this research. It is concerned both with the development dynamics (antecedents) of network structure and with the models building on it (network outcomes). It thus has network variables as both *explanandum* and *explanans* to account for the dual nature of network structure as both a result of and basis for social action (Giddens 1984) – the fundamental issue of endogeneity which is the reason for why classifying network variables into independent and dependent categories is often difficult due to their dynamic interaction.

Independent variable	**Dependent variable**	
	Nonnetwork variable as outcome	*Network variable as outcome*
Nonnetwork variable[8] *as antecedent*	(Nonnetwork theory)	Theory of networks
Network variable as antecedent	Network theory	Network theory of networks

Table 1: Network theory of networks (Borgatti & Halgin 2011: 1177)

I revisit these arguments and the phenomenon of endogeneity in more detail when discussing the network approach in interorganisational research (2.3.4) and when developing the integrated explanatory framework in Section 2. 6, and will thus suspend debate on the nature of network research at this stage. It is not only possible to categorise network scholarship in terms of the different models used, but also in terms of the disciplines using it. As indicated above, many disciplines employ SNA or its arguments. Because it is important to distinguish the approach adopted here from other routes of investigation, Section 2. 2 outlines the three major disciplines in the social sciences that use SNA

[8] I.e. actor's individual characteristics such as age, profession, industry, organisational size, etc. that are not derived from network membership such as their network structural position.

and/or its arguments, before focusing on interorganisational network research as part of OMS. Disciplines such as biology and literature studies are not included here, because despite their usefulness in producing network measures and constructs, they do not contribute to network theorising in a manner which proves expedient when seeking an answer to the present research question.

2. 2 Social-science disciplines and network research

"Most scholars [..] agree that no single grand theory of networks" exists
(Provan, Fish & Sydow 2007:482).

Research on networks has continued to gain in importance ever since Granovetter published his seminal papers "The Strength of Weak Ties" (1973) and "Getting a Job" (1974). He built these studies on early analytical ideas from graph theory and socio-metrics and used tie strength as an explanatory argument. Granovetter's impact stems from revealing that, counterintuitively, job seeking can be facilitated much more effectively by relying on subjects' looser connections with other individuals rather than on connections with their closest friends, for instance (1974). Although it has its roots in sociology, his work has become a landmark contribution transcending this field.

Given that the present research is sited at the interface of three scientific disciplines, it is instructive to provide a brief outline of network research in sociology and economics and differentiate these areas from OMS which will be the subsequent focus of analysis (2.3). A word of warning appears apt when "dividing" up the social sciences: many, if not most, of the disciplinary borders are transcended by research, e.g. when sociologists engage in studies on firms or when analysing the sociology of markets. No clear-cut categories exist, but rather research traditions that are often contorted or combined to answer novel, interdisciplinary research questions, e.g. in economic sociology or organisational economics, including questions such as that addressed by this study.

2. 2. 1 Sociology research on networks

After Granovetter's studies (1973; 1974), sociological research has been considered the 'home' of network research approaches. Over time, it has grown to be the largest body of network research. This is probably because sociology is heavily concerned with identifying structures and patterns in society, and the network approach offers a unique and powerful analytical toolset for such tasks. Not surprisingly, *Social Networks* is the journal which has offered a platform on which many of the advances in formulistic methodology have been débuted (e.g. Krackhardt 1987: 109ff.). Much sociological network research focuses on school classes (e.g. Collani 1987: 2), friendship networks (e.g. Trappmann, Hummell & Sodeur 2011: 19), social circles such as elites (e.g. Pappi 1984: 83) and, more recently, online social networks such as Facebook.com (e.g. Lewis et al. 2008: 330). Since sociological research is concerned with the connections of people and social structures, this literature embraces organisations insofar as it studies the relations of organisations' members, but typically not the relations of organisations. However, the lines between sociological research and management research are blurred, permeable and shifting. Largely due to the commonly shared toolset of network analysis and common social theories, management issues have entered the domain of sociology (e.g. Iseke

2007) and, vice versa, sociological explanations, e.g. elite circles, have entered the management debate.

2. 2. 2 Economics research on networks

Economists studying networks initially characterised these as a hybrid form of governing transactions, a middle ground in the markets and hierarchies' dichotomy (Williamson 1991), following Eccles' seminal terming of the "quasifirm" (1981:335). The research on these "network form of organization" (Powell 1990) is often close to sociology since they share aspects of both markets and hierarchies. They are integrated like hierarchies since there may be some form of power and control that certain actors can exercise over others. However, there is no 'line of command', and market features like prices play a role in transactions. Following a transaction cost economics line of argumentation and a control-oriented perspective, Hennart's (1993) comparative institutional analysis shows that these hybrid arrangements appear to be used in most actual transactions (Hennart 1993: 529), because hybrids can be more efficient: due to trade-offs between the costs of managing vs. the cost of transacting it may become "prohibitively costly to use either pure hierarchical or price methods" (Hennart 1993: 540).

A further area in economics is the concept of 'network externalities' or 'network effects' (Liebowitz & Margolis 1994). Since it deals mainly with technical and standardisation issues at market level, the network effects literature differs distinctly from the study of hybrids. It has predominantly been applied to the discussion of how industry standards emerge, and generally entertains a 'user base matters!' argument, often conflating "direct" and "indirect" network effects (Clements 2004: 641; Katz & Shapiro 1985; Farrell & Saloner 1986; Liebowitz & Margolis 1995a). Network effects can be characterised as direct and indirect network effects (Clements 2004) and both deal with the utility of a product or service that exceeds its inherent utility.

The effects ascribed to such networks are mainly arguments referring to the existence and size of a user base for a particular product or service and the individual and general utilities derived therefrom. The primary example for *direct network effects* is the telephony system: the system's utility to an individual user is low if they are connected to a switchboard alone. The utility rises, however, with every new user of the service, since the number of people connected increases the number of people a user can contact. Thus, every new user directly increases the overall utility of the service (Rohlfs 1974). The same argument also holds for services such as the railway network, where any new station increases the networks utility, all online social networks, e.g. Facebook and, of course, Telefax and email systems (Funk 2009b).

Indirect network effects are slightly more complex to trace, because they can only exist in relationship to a product or service that complements a connected main product or service. Indirect network effects occur when complementary products are required for a product or service to achieve its full utility, and the existence of these complementary elements again co-depends on the size of the user base (Clements 2004). A common example is the case of DVD players. Here, it is not the user base itself that has a utility-increasing effect (except, perhaps, for a small utility from sharing media with other users), but, instead, the availability of a great diversity of complementary playable media. The latter, however, does depend on the size of the available user base, because producers who depend on economies of scale are only willing to invest in production of such media if they can supply their product to a large enough customer group which allows them to profit from these economies of scale. Other examples of indirect network effects include credit cards, computer operating systems (Katz & Shapiro 1994; Shapiro & Varian 1999; Dobusch 2008) and smartphone platforms (Meyer 2012).

While economic approaches increasingly acknowledge the existence of networks (e.g. Williamson 1991; Hennart 1993) and consider their effects a potential source of market failure (Liebowitz & Margolis 1994: 134), they do not attribute importance to their structure, consequences for individual actors or effects of networks as explanatory aspects. In particular, the latter focus only on network size – a fact that recently received fervent criticism (Afuah 2013). Economists also disregard characteristics of the connections between social entities such as structural aspects, tie properties etc. This comes as no surprise, because it is traditionally in the nature of economic reasoning to be concerned with abstract transactional institutions and their efficiency, rather than with concrete business cases or the real-life implications for firms. These are, of course, of special relevance not least to practitioners, but also particularly to the researchers dealing with the empirical analysis of cases, industries, firms, and markets where the effects of network structure are unfolding on a day-to-day basis.

2. 2. 3 OMS research on networks

Organisation and Management Studies research has embraced arguments of the '*social* embeddedness of action' (Granovetter 1985, emphasis added) more readily than economics. It is in its tradition to integrate reasoning from other sciences like sociology or (social) psychology rather than to build abstract equilibrium models. Hence both psycho-social components and structural arguments find broad application in the business literature that deals with networks. Studies often integrate theories at individual, group or organisational level to answer their respective research questions. Since a cohesive theory of networks is still in its infancy (if it will ever exist), these links with other theories and disciplines are necessary and part of the reason for the diversity of perspectives in network research. Networks have gained so much attention that some scholars consider it a research paradigm in its own right (Borgatti & Foster 2003), a new multilevel theory of organisation (Moliterno & Mahony 2010), or a new conception of firms as relational rather than transactional (Belussi & Arcangeli 1998).

OMS research elaborates on a wide range of analytical foci and levels. This is reflected in its network research which is concerned with antecedents, formation, development, phases, effects, and outcomes of networks. It ranges from individuals, such as managers and their work environment networks with others (Iseke 2007; Gargiulo & Benassi 2000), to firms (Jarillo 1988; Liebeskind et al. 1996), multi-level networks between individuals and firms (Sydow & Staber 2002), the study of (Asian) family empires (Carney & Gedajlovic 2002), and regional networks and clusters (Marquis 2003; Grabher 1993). This multitude of foci and levels of analysis is the result of the fact that the "fundamental concern of network analysis [is] to inquire into the nature of interactional and organizational links between social units" (Craven & Wellmann 1973: 58).

With regard to business practice, the importance of networks has been noted for several industries. Many of these studies analyse knowledge-intensive or science-based (Pisano 2010) and/or creative industries (Vang & Chaminade 2007) where networks seem prevalent. Examples can be found in communications (Corrocher & Zirulia 2009), semiconductors (Gomes-Casseres 1996), biotechnology (Maurer & Ebers 2006), photonics (Sydow et al. 2007; Lerch, Provan & Sydow 2008), aviation (Berends, van Burg & van Raaij 2011), airlines (Hirnle & Hess 2007: 125), and media (Manning & Sydow 2011). Furthermore, many success stories from Silicon Valley in California have been attributed to strong interorganisational and interpersonal networks of support, employee transfer and – very importantly – investment within that specific geographical area (Saxenian & Hsu 2001).

Many of these examples stem from modern industries, e.g. of the so-called New Economy or the "network economy" (Barabási 2003: 199) and many are by their very nature network(ing) industries (Sydow 2006: 390). Their daily business reality involves dealing with highly uncertain investments in creative ventures that, to some extent, have to rely on the support of others. Thus, strategic networking with other firms appears to make sense or is a requirement for many, if not most, firms in these industries, because cooperative relations can overcome uncertainty or investments risks (Hoffmann & Schlosser 2001: 359), provide resource access (Hoffmann 2007: 828) and may consequently lead to competitive advantage (Provan, Fish & Sydow 2007: 505). However, they also "frequently fail to reap the anticipated benefits" (Kale & Singh 2009: 59). These arguments will be further discussed in the review included in Section 2. 3 below. From the research foci and levels of analysis in OMS network research, the sub-group of studies on interorganisational networks – i.e. networks between organisations – is the focus of this study. In the next main section, after a further differentiation and specification, a solid literature overview of this large research field dealing with this type of network will detail what this study is dealing with, what arguments have been made in the literature, and what gaps remain in the extant research.

2. 3 Interorganisational networks in OMS

"the most fundamental axiom in social network research is that a node's position in a network determines in part the opportunities and constraints that it encounters, and in this way plays an important role in a node's outcome" (Borgatti et al. 2009: 894).

Interorganisational network studies differ from other OMS network research in that the networks under scrutiny are of a strategic or at least purposive nature (2. 3. 1). Moreover, the majority of OMS research on interorganisational relations focuses on dyads, and I provide a brief outline of major contributions in that subfield (2. 3. 2). After condensing a working definition of strategic (interorganisational) networks (2. 3. 3), I give a broad literature overview by reviewing 12 reviews and meta-analyses of OMS research on interorganisational networks. This overview systematically indicates the main theories, research foci, methodology, and constructs used in this research to show the current state of the extant literature. It further lays the foundation for the study of path dependence in interorganisational networks by concluding with a discussion of the ambivalent effects that networks may have on their member firms.

2. 3. 1 Strategy in interorganisational networks

Interorganisational networks differ from the *social* networks that are often studied in OMS network research in one fundamental way. The focal networks emerge not by chance, as is often assumed to be the case in social networks, where managers establish friendship networks with peers they meet in the corporate cafeteria, for example. In a sharp contrast to this, connections between firms are typically established intentionally and are often part of a joint, aligned, or at least compatible strategy. The practice of networking helps firms to pursue their goals, which are usually expressed by the relation type, since they "are aimed at achieving the strategic objectives of the partners (Das & Teng 1998a: 491). Hence, relations with partners can be characterised as looser or closer forms of cooperation depending on their purpose. They can appear as looser contractual alliances, consortia, or joint ventures (Hoffmann 2007: 827), or closer (minority) equity alliances, R&D contracts, joint R&D, marketing, production, distribution alliances (Das & Teng 2000: 43). Many firms are involved in more than one type of network relation, not least since from a certain theoretical lens, any sales contract between two businesses can represent a type of network relation, for instance.

However, the fact that companies that use network organising typically rely on more than one relation does not mean that interorganisational research always considers this. In fact, most research focuses on a specific type of relation, e.g. sales contracts, but not on others, such as firms' investment network etc. Such a research strategy means that many studies are not concerned with the multiple relations that firms and their partners have among each other, but focus instead on uniplex, dyadic relations.

These are often used in large-scale quantitative empirical studies in the field of strategic management where tie properties typically serve as explanatory variables. Further, empirical data on networks is already difficult enough to collect, but data on dyads is considerably easier to collect than data on larger network scales.

Even though this dyadic lens is not chosen in this study, it must be acknowledged since it is, probably the largest part of OMS interorganisational "network" research by far. Many arguments used in this field are useful and it is not easy to make a clear distinction between dyadic research and 'truly' interorganisational network research because dyads are, of course, the building blocks of the larger network which this study's research question addresses. Therefore, this large and semi-detached research field will only receive a brief consideration in the present study.

2. 3. 2 'Strategic alliances' – the dyad focus

OMS research on dyads often studies firms' network relations in terms of contractual agreements and especially in their form as joint ventures, both equity and non-equity. The varying types of cooperation are typically referred to as 'strategic alliances', and research questions revolve around performance issues of these strategic alliances where tie properties serve as explanatory variables in regression models.

This research is informed by several theories. Scholars following the resource-based view (e.g. Barney 1991; 2001) have theorised and shown empirically that firms use networking to gain access to financial, technological, physical, and managerial resources (Das & Teng 1998b: 28). The pooling of these between firms allows for value maximisation, particularly when they complement each partner and fulfil the VRIN criteria of being valuable, rare, inimitable, and non-substitutable (Das & Teng 2000: 36). This is typically the case in vertical relations, e.g. between a supplier and their customer or when outsourcing takes place (Gulati, Nohria & Zaheer 2000: 203). Firms may also choose to partner horizontally with competitors when expanding their product portfolio or when similar resources are needed, and output products are heterogeneous (Garrette, Castañer & Dussauge 2009: 886).

Relating to the resource of knowledge, "knowledge-based view" research (Mowery, Oxley & Silverman 1996: 77), is a substantial body of literature that focuses on learning between companies as a driver for networking (Oliver 2001: 468; Powell, Koput & Smith-Doerr 1996; Podolny & Page 1998: 62-63; Kale, Singh & Perlmutter 2000). Drawing mostly on the *exploration* aspect of the exploration-exploitation distinction (March 1991), the widely-used concept of 'absorptive capacity' (Cohen & Levinthal 1990; Lane & Lubatkin 1998) conceptualises the ability of a firm to internalise and use the knowledge gained from interacting with a partner firm. While this can essentially be considered a network construct that could in principle embrace explanatory variables from a broader view at all connections of firms, it remains dyadic in most of its empirical applications.

Not only is gaining knowledge from others a driver for networking, but also the joint creation of knowledge. Research and Development is often carried out in the context of inter-firm cooperation, mainly because of similar interests or due to environmental interdependence (Doz, Olk & Ring 2000: 242-243). These ventures may lead to the creation of new formal entities and pursue the creation of technological standards (Das & Teng 2002: 454). Both incumbents and new entrants may rely on such R&D consortia, particularly in industries characterised by oligopolistic structures (Sakakibara 2002: 1043-1044). For knowledge creation (and other inter-firm ventures), reciprocity is an important feature of the relations required for the success of the networking efforts, because it can successfully remedy the risks of game-theoretic opportunism (Lubatkin, Florin & Lane 2001: 1358).

Partnering can further be used to reduce strategic uncertainty (Hoffmann 2007: 827; Gulati & Gargiulo 1999: 1441). Similarly, it can alleviate market risks, particularly when firms are in a process of internationalising their activities and seeking foreign partners for multinational expansion (Osborn & Hagedoorn 1997: 263-264) and for entering foreign markets (Sydow et al. 2010). While this approach seems like an adequate strategy for smaller companies in particular, research found that these often lack the necessary ability to manage their alliances (Hoffmann & Schlosser 2001: 367). Moreover, partnering with other firms has been found to offer transaction cost savings (Podolny & Page 1998), to enable economies of scale and scope (Gulati, Nohria & Zaheer 2000: 203), to generate relational rents (Dyer & Singh 1998: 661; 2004: 351-352) and, more generally, to lead to competitive advantages when successfully managing the strategic alliances (Ireland, Hitt & Vaidyanath 2002: 439).

Because of the many such potential benefits from strategic alliances with other firms, some have begun to strategically manage and optimise their alliances with a portfolio approach (Kale & Singh 2009: 56-57). However, the creation, configuration and management of alliance portfolios appears not to be trivial (Wassmer 2009: 146) and requires firms to develop a generalised "alliance capability" (Kale & Singh 2009: 57) in order to balance the benefits arising from multi-firm cooperation with the related costs, to manage learning, administer alliance governance etc. This portfolio perspective on interorganisational networking emphasises firms' agency in creating their "alliance portfolios" and the dynamism in their development over time (Ozcan & Eisenhardt 2009: 271). The 'alliance portfolio' idea is an active-management perspective which essentially refers to the concept of a firm's ego network (Wassmer 2009: 142; 155). The portfolio concept could potentially include a wider network perspective, but portfolios are typically studied only as sets of dyadic relations, thereby neglecting the networking relations among a firm's portfolio partners and their potential influence on the portfolio.

With few exceptions, the above contributions on 'strategic alliances' do not study relationships from a 'proper' multi-firm cooperation perspective and do not exceed the dyad level analytically (Hoffmann 2007: 828). Partly as a result of this, the term 'strategic alliance' has developed, which chiefly denotes dyads such as joint ventures. Several other denominations have also been used, e.g. 'alliance portfolios' (Ozcan & Eisenhardt 2009), 'alliance blocks' (Vanhaverbeke & Noorderhaven 2001), 'alliance constellations' (Das & Teng 2002), and 'consortia' (Doz, Olk & Ring 2000). The latter three terms imply the involvement of more than two firms, though this does not necessarily mean that the research embraces a network analytic perspective beyond dyads. Examples of research that engages network arguments and measures can be found in the work on alliance constellations such as R&D consortia, for instance (e.g. Das & Teng 2002: 454), because these involve multiple organisations.

What several of these studies have in common with the present research is that – despite their overall dyadic reasoning – they examine high-tech and knowledge-based industries similar to the smartphone platform case study undertaken here. Industries include biotechnology (Oliver 2001; Powell, Koput & Smith-Doerr 1996; Zollo, Reuer & Singh 2002), accounting (Koza & Lewin 1999), wireless gaming (Ozcan & Eisenhardt 2009), microprocessor technology (Gomes-Casseres 1996; Vanhaverbeke & Noorderhaven 2001), industrial automation (Gulati 1995), the automobile industry (Dyer & Nobeoka 2000), aeroplanes (Garrette, Castañer & Dussauge 2009: 886) and technology in general (Mowery, Oxley & Silverman 1996). It is no coincidence that many studies draw on data from these fields, because their products, know-how and services rely heavily on joint knowledge creation and sharing, often require resource pooling and involve highly uncertain strategic investments. Since these are cooperation drivers, it is no surprise that these business sectors engage in networking activities and then provide meaningful empirical data for research.

Since network *structure* is at the heart of the present research question, the majority of the above studies do not prove of great relevance here. While they are useful as far as revealing reasons and motivations why dyads exist or fail, underlining the fact that their management is important, network structure is obviously not among the constructs typically considered. Of course, dyads are the building blocks of the interorganisational network considered here, but sole concentration on these is limiting to network scholarship, preventing it from studying the influence of the wider structure of interorganisational networks. Remaining at the dyadic level may explain a network partner dependence or a relational lock-in, but not a network structure lock-in based on a network structure-driven process. This requires a close examination of the relations of and around a firm – hence a genuine network perspective and not a dyadic view of interorganisational relations.

2. 3. 3 Defining interorganisational networks

Taking the elements of interorganisational network research as a basis, I derive a definition that serves the present purposes of understanding path dependence in interorganisational networks. As already alluded to in the introduction, and in line with the definition by Provan, Fish & Sydow (2007: 482), an interorganisational network exists when organisations (nodes) enter into purposive, multilateral cooperation relations and when the resulting relations (ties) grow beyond the dyadic level and allow for the formation of groups of three and more organisations, such as alliances. These networks can be dispersed across the world and are not bound to particular geographic locations.

Since the term 'network' can refer to the phenomenon, theories at network level and network analysis as a methodology (Sydow 1992: 119), it is important to point out that, in this study, 'network' primarily denotes the empirical phenomenon of interconnecting firms and theory about the same at network level. To some extent, networks are a 'construed' concept in the sense that while the ties factually exist, their embeddedness in networks require (scholarly) identification and (social network) analysis in order to be identified as networks and to permit meaningful discussion.

To employ the terminology of strategic alliances, this research deals with interorganisational alliances as 'alliance constellations' i.e. as "groups of firms [... that] compete against other such groups and against traditional single firms" (Gomes-Casseres 1996: 3). The literature uses the term 'alliance block' almost synonymously, drawing on Gomes-Casseres' (1996) definition (Vanhaverbeke & Noorderhaven 2001: 1-3), but the term stresses the competition aspect. Vanhaverbeke and Noorderhaven stress that these 'blocks' transcend traditional industry boundaries and include vertical, horizontal, and particularly those standard-creating inter-industry R&D consortia which are the focus of the explorative, empirical case study in Chapter 3 in which firms find themselves in a 'co-opetition' environment (Madhavan, Gnywali & He 2004), where individual firms both cooperate and compete.

2. 3. 4 Interorganisational networks research

As elaborated above, strategic interorganisational networks have become very important in practice as well as in organisations and management research in recent decades. This section reviews 12 literature overviews, reviews, and meta-studies on interorganisational networks. These were identified in the wake of a thorough but not exhaustive search in the EBSCOhost Business Source premier database and Google Scholar. The search included the terms *interorganizational/ interorganisational network(s), network(s), interorganizational/ interorganisational relations, and alliance(s)* always in combination with *review* and *meta* and covered a time-frame from 1990-2016. The search was not restricted to certain journals and, at this stage, did not differentiate studies at different network levels of analysis or theories.

Abstract and bibliography scanning were used to identify articles suitable to enable an informed discussion of the development and state of the art of OMS research on interorganisational networks. Therefore, I excluded papers concentrating on a single stream of theory such as transaction cost economics (e.g. Geyskens, Steenkamp & Kumar 2009), ones that focused purely on dyadic relations such as joint ventures (e.g. Ren, Gray & Kim 2009), or those embracing only particular aspects of network relations such as coordination (e.g. Sobrero & Schrader 1998). I also excluded a small number with overly limited reach due to low journal relevance or impact, loosely following the approach used by Majchrzak, Jarvenpaa & Bagherzadeh (2015: 1341).

A review of the resulting 12 overviews serves to highlight common patterns with regard to network structure arguments and are analysed with regard to arguments relevant to answering the present research question. The papers are presented in Table 2 in the order of their appearance in publications. After the subsequent analysis of what these reviews reveal about theories, research foci, levels of analysis, methods, and research gaps identified in interorganisational network research, the focus is placed on the ambiguities of networks identified by the same in the light of the research gap addressed by this study.

Author(s)	Title	Journal	Year
Oliver	Determinants of Interorganizational Relationships. Integration and Future Directions	Academy of Management Review	1990 Vol. 15 No. 2
Grandori & Soda	Inter-firm Networks: Antecedents, Mechanisms and Forms	Organization Studies	1995 Vol. 16 No. 2
Gulati	Alliances and Networks	Strategic Management Journal	1998 Vol. 19 No. 4
Oliver & Ebers	Networking Network Studies: An Analysis of Conceptual Configurations in the Study of Inter-organizational Relationships	Organization Studies	1998 Vol. 19 No. 4
Gulati, Nohria & Zaheer	Strategic Networks	Strategic Management Journal	2000 Vol. 21 No. 3
Barringer & Harrison	Walking a Tightrope: Creating Value Through Interorganizational Relationships	Journal of Management	2000 Vol. 26 No. 3
Borgatti & Foster	The Network Paradigm in Organizational Research: A Review and Typology	Journal of Management	2003 Vol. 29 No. 6
Brass et al.	Taking Stock of Networks and Organizations: A Multilevel Perspective	Academy of Management Journal	2004 Vol. 47 No. 6
Provan, Fish & Sydow	Interorganizational Networks at the Network Level: A Review of the Empirical Literature on Whole Networks	Journal of Management	2007 Vol. 33 No. 3
Zaheer, Gözübüyük & Milanov	It's the Connections: The Network Perspective in Interorganizational Research	Academy of Management Perspectives	2010 Vol. 24 No. 1
Parmigiani & Riviera-Santos	Clearing a Path Through the Forest: A Meta-Review of Interorganizational Relationships	Journal of Management	2011 Vol. 37 No. 4
Majchrzak, Jarvenpaa & Bagherzadeh	A Review of Interorganizational Collaboration Dynamics	Journal of Management	2015 Vol. 41 No. 5

Table 2: Overview of reviewed network research reviews

2. 3. 4. 1. Theories in interorganisational network research

Interorganisational network research is a growing body of literature and is grounded in several different theories which, as some authors claim, may have led to the term 'network' becoming slightly blurred (Grandori & Soda 1995: 184). The authors covered here identify several theories used in the emerging "Network Paradigm in Organizational Research" (Borgatti & Foster 2003: 991), and some (e.g. Grandori & Soda 1995; Barringer & Harrison 2000; Parmigiani & Rivera-Santos 2011) position them loosely along a continuum featuring economics-based approaches at one end and social-science oriented approaches at the other. The economics approaches include: industrial organisation economics, organisational economics, game theoretic negotiation analysis, neo-institutional approaches such as transaction costs theory, resource-dependence based views such as the resource-based view or the knowledge-based view and strategic choice. Historical analyses, arguments from evolutionary theory and population ecology are used by both economics researchers and social-science oriented scholars, but apparently only play a minor role in interorganisational network research. The social science-oriented approaches constitute (neo-) institutional theory, stakeholder theory, learning theory – including (co-)exploration and (co-)exploitation, social cognition, group processes, and the social network approach with a notably structure- and position-focused "Social Network Theory" (Grandori & Soda 1995: 191).

Industrial organization economics studies networks with a focus on the vertical and horizontal integration of companies and on the efficiency gains available through economies of scale or scope. *Game theoretic* considerations study networks as repeated cooperative games. *Organisational economics* studies networks as a hybrid form of governance between markets and hierarchies (Grandori & Soda 1995: 185-189).

An important field of economics-oriented approaches in network research is *transaction cost economics* (TCE). This approach views networking as a means of reducing transaction costs, when sustained business relations can (to some extent) reduce the need for monitoring and control that is typically required due to the uncertainty, specificity, and frequency of a transaction. The 'make or buy' dichotomy is thus expanded to position networking as an intermediate solution. Through emerging trust, networking can reduce opportunism risks similarly to a hierarchy, whilst continuing to facilitate market mechanisms such as prices within the relations and avoiding the otherwise necessary internalisation of a new economic activity. Furthermore, networking may allow firms to maintain their competitive advantage and specialisation benefits. At the same time, TCE is being criticised for neglecting factors beyond costs (Barringer & Harrison 2000: 372).

Parmigiani and Rivera-Santos (2011: 1115) subsume the above economic theories under *organisational economics* together with the related *agency theory* and the *resource-based view* and its variations *knowledge-based view* and *dynamic capabilities*. The resource-based view of the firm focuses on firms' resources (including knowledge) and their being valuable, rare, imperfectly imitable, and not substitutable (VRIN). The connected *resource-dependence view* posits that firms cooperate when required for gaining access to resources otherwise unobtainable for either partner. This can, however, make firms become dependent on other firms. Firms may also seek to gain strategic control of resources to decrease their dependence on others or to increase others' dependence on them. Networking may also allow firms to mutually take advantage of complementary assets, such as R&D developments and sales channels. Alliances themselves may be also VRIN, e.g. through achieving a high combined market power (Barringer & Harrison 2000: 373).

Gulati, Nohria and Zaheer explain that networks, or actors' positions within them, can constitute VRIN resources, e.g. network membership can enable the reception of valuable information or interorganisational trust and joint history can be valuable for cooperation and difficult to copy. Similarly, the capability of managing a firm's network relation can be a VRIN resource, particularly as it grows over time through learning from experience, and firms become more skilled at extracting value from network relations (Gulati, Nohria & Zaheer 2000: 208-209). However, the resource-dependence literature also appears to have argumentation loops: combining resources may also lead to a reduction in competitiveness when it lowers the value or uniqueness of the individual assets. Partnering may also lead firms to reduce their attention towards investing in their own assets rather than joint ones. Moreover, the resource-dependence argument neglects many other motivations as far as sharing corporate efforts is concerned (Barringer & Harrison 2000: 373).

Strategic choice is a broad economics-based perspective that essentially embraces all the above arguments of increasing efficiency, strengthening market power, increasing speed-to-market, neutralising opponents, reducing costs, entering foreign markets, accessing technology, and economics of scale and scope as motivations for partnering with other firms, but strategic choice lacks a genuine theoretical contribution (Barringer & Harrison 2000: 374-375)

Drawing on the above economic arguments, economic *historical analyses* study how an industrial landscape or technologies are shaped by networks and how networks are shaped by them, in a predominantly descriptive manner (Grandori & Soda 1995: 186). The more social science-influenced *population ecology* studies employ arguments from evolutionary theory and seek to uncover how the survival of firms and networks is influenced by the existence of networks and their properties (ibid.: 193).

Empirical support for these broad approaches taken by economics and arguments used in resource-dependence literature is described as mixed, but RBV and related arguments find more support (Parmigiani & Rivera-Santos 2011: 1115). Transaction cost arguments and resource-dependence arguments are used most frequently for connecting other theoretical arguments (Oliver & Ebers 1998: 557).

(Neo-) Institutional theory posits that external pressures drive organisations towards legitimate appearances in the light of social norms. Legitimacy can be important for creditors, customers, or other

cooperation partners. Linking with other (more) legitimate (e.g. prestigious, big, powerful, visible) organisations can result in legitimacy gains and thus be a driver of networking. As a second rationale, isomorphistic mimicry can lead a firm to engage in networking if other important firms already do the same. While the theory details networking motives clearly, it cannot explain why different forms of collaboration exist and it also has limitations regarding the outcomes. Furthermore, it conflicts with RBV explanations, since mimicry is a counterargument for networking from the RBV perspective that builds on in-imitability (Barringer & Harrison 2000: 381).

Stakeholder theory "envisions organizations at the centre of a network of stakeholders" (Barringer & Harrison 2000: 376), where the firm constitutes a "nexus of contracts" (ibid.) between the firm and its stakeholders. Networking with other (stake-holding) firms is part of the assumption of the theory. Accordingly, while many stakes need to be considered and aligned by top management, an organisation's goal is to coordinate stakeholders' interests. These may form coalitions in order raise their importance vis-à-vis others, reduce environmental uncertainty etc. In network terms, these coalitions could be considered constellations, networks, or strategic networks. Stakeholder theory raises a crucial point regarding agency problems: management may turn its attention from the principal to an external partner – a situation constituting stakeholder competition. At the same time, strict control is not only impractical, but also potentially harmful to firm performance. The related *stewardship theory*, however, contradicts this argument by pointing out the aligned interests of principals and management, also regarding interorganisational relationships. The stakeholder models have been criticised for lack of empirical testing, arguments being based on "moral correctness" (ibid.: 377), and anecdotal evidence, rather than empirical work (Barringer & Harrison 2000: 377).

Learning theory points towards opportunities for learning from partners in inter-firm relations. Using alters as a basis for acquiring knowledge or skills that are not available in the marketplace because of their tacit character appears to Barringer and Harrison as the most cited driver of networking (2000: 378). Particularly high-tech ventures seem to rely on learning through networking. Some types of interorganisational relations such as trade associations or interlocking directorates are focused on a learning component (ibid.: 378). Research has shown that networking can be effective for learning. Seemingly, however, there exists an inverse u-shaped relationship between the number of alliances a firm enters and the amount of product/service innovations it can produce, i.e. at a certain point, partnering may demand more resources than it can produce in output.

Exploration vs. exploitation is a strong theme in the interorganisational learning field. Introduced by March (1991), exploitation is considered learning with a concentration on optimisation, e.g. cost reductions of known practices (local search), whereas exploration is linked with beneficial discoveries beyond present knowledge. Parmigiani and Rivera-Santos apply this distinction to interorganisational relationships by categorising them into two idealised "pure" groups, one focusing activities on "co-exploitation" and one on "co-exploration" activities (2011: 1122). Accordingly, co-exploitation relations are focused on realising cost savings or asset-utilisation efficiency gains based on existing knowledge. Co-exploration is constructed as innovation-focused, experiments and joint discovery of new knowledge. In the former arrangement, partners remain more separated and relations fixed in terms of scope, with the latter arrangement more joint, reciprocal and more goal-oriented than scope-oriented. Time plays a role in the development of interorganisational learning relations, since exploration may be more important at the beginning of a new development than towards its end. *Absorptive capacity* is a theoretical concept created for studying firms' ability to acquire and act upon the knowledge they encounter. Learning abilities and absorptive capacities co-develop and cumulate over time based on experience.

While learning arguments and the exploitation-exploration nexus certainly apply with regard to theorising, their empirical measurability is somewhat lacking. The literature also neglects cost as a factor in the equation of how fruitful an alliance may be overall (Barringer & Harrison 2000: 380). Further, exploitation relations exhibit under-researched hazards of slacking, and exploration relations potentially suffer from risks of the unilateral appropriation of jointly created value or knowledge. Moreover, traces of both ideal types are likely to be found in most interorganisational relations, and the intentions of partners may even differ within one single relation, which creates some tension in terms of both practice and theory (Parmigiani & Rivera-Santos 2011: 1125).

Research on *social cognition*, as reviewed by Borgatti and Foster (2003: 998-999), is relevant for interfirm research in so far as their members may or may not recognise network structures around their organisation and make decisions based upon these (in)accurate perceptions. Such knowledge, and the processes by which people and organisations gain knowledge about networks and their structures influence actors' actions and conversely influence their cognition about their networks. The awareness of the centrality of certain actors on a network map, for example, may influence the frequency with which they develop partnerships. *Group process* studies build chiefly on social psychology, analysing the manner in which physical and social proximity and network ties influence how individuals' interaction can lead to jointly-held beliefs and shared norms in networks, commonly known as 'groupthink'. One of the main explanatory factors here is the homophily argument ('equity' with regard to organisations) which when applied to interorganisational networks means that firms might seek partners that are similar in recognisable aspects (Borgatti & Foster 2003: 999).

Contributions following a *social network approach* or "social network theory" (Grandori & Soda 1995: 191-192) study the emergence, development, and effects of network structures and positions. Particular foci include structural equivalence, centrality or cliques that are studied often with a focus on predicting future states of networks (Grandori & Soda 1995: 192). Tie-strength and frequency, time horizon of cooperation, and emerging trust have been found to influence networks' ability to achieve their goals (Parmigiani & Rivera-Santos 2011: 1116). Further, social capital (including brokerage and closure) and social embeddedness arguments can be counted towards the theories stemming from the original network research approach. However, some review authors (e.g. Zaheer, Gözübüyük & Milanov 2010) maintain that the network approach remains a methodological rather than a theoretical lens.

Barringer and Harrison conclude their review by pointing out that none of the theoretical foundations is sufficient on its own, and, in many situations, more than one will be applicable to some extent (2000: 395). Covering networks from a range of perspectives is both an advantage and disadvantage: While networks' empirical existence (and their scholarly analysis) can certainly be justified in the light of more than one theory, the blur of theories can also lead to 'theory confusion' and false claims of exclusivity of explanation. Similarly, Zaheer, Gözübüyük and Milanov attest that no single theory exists to explain interorganisational linkages, which leads to a "lack of coherence and parsimony" (2010: 63), that network research addresses multiple levels of analysis, and that connections exist between these levels. This vagueness invites us to deem the theories non-exhaustive, as other reasons for firms' networking may still exist, e.g. managers' personal friendships etc.

Many studies use more than one theory, as underlined by Oliver and Ebers' (1998) study. They make 158 network studies their empirical subject matter and use network analysis and statistical measures to link theories, concepts and approaches in interorganisational network research in an effort to integrate the heterogeneous field. They reveal that resource-dependence perspectives and studies based on the (social) network approach account for more than half of the studies considered. Most articles are empirical and more than half embrace arguments on multiple relations and not only dyads. The authors link the theories by means of structural network analysis. They find that the theories that most frequently connect other theories by bridging (highest Betweenness centrality) are transaction costs and population ecology, followed by resource-dependence. The authors identify four research foci in interorganisational network research: 1. contingent decision-making with resource-dependence arguments; 2. a focus on (social) network relations with social network theory; 3. interorganisational power structures argued by means of resource dependence; 4. a focus on governance structures and the related application of transaction cost and institutional theory (ibid.: 558ff.). On the basis of these findings, they assert that the field of network research is not as fragmented as previously claimed, instead being centred around the theoretical concepts outlined above. Oliver and Ebers draw a remarkably cohesive picture of interorganisational research. This is surprising given the heterogeneity claimed by other reviews covered in the present study. They also discern a strong focus on multi-relational studies, rather than dyads. This is equally surprising given the plethora of work on dyads, but their finding may be due to their vague definition of multi-relational as simply a "study of relations among multiple parties" (ibid.: 575). Oliver and Ebers (1998) also pay only limited attention to the extent to which these studies actually engage network structural measures and arguments that go beyond claiming a general influence of multiple ties on individual relations.

Among the theories employed by network research, not all can be readily applied to all phenomena, but considerable overlap exists, particularly for the most cited 'resource dependence' and 'knowledge sharing' which apply to many, if not most, cooperation situations. Many theories can integrate structural arguments and none is evidently more powerful than others in this respect. This is largely because structure is an emergent outcome of the activities that are explained using these theories. To this extent, the existence of structure can be explained by many theories, but its emergence and consequences are only understood by a few. Consequently, it appears plausible that some studies are informed by several theories for analysing networks in a more 'eclectic' manner. Several perspectives may often be necessary to understand a specific phenomenon holistically, particularly since networks' ties and their patterns both empower and constrain firm behaviour and outcomes (Zaheer, Gözübüyük & Milanov 2010: 63).

2. 3. 4. 2. Networking antecedents and motivations

Firms' motivations for networking are derived from the theories described above and are just as diverse. According to Oliver (1990: 242), interorganisational networking is motivated by an organisation's (i.e. the top management's) evaluation of six interacting contingencies that are integrated here with arguments by other reviews. These contingencies include *necessity*, e.g. a legal, historical or political requirement from the firm's context to enter cooperation relations (Oliver 1990: 243, Brass et al. 2004: 804); *asymmetry*, i.e. exercising power and control over organisations and/or their resources (Oliver 1990: 243-244; Zaheer, Gözübüyük & Milanov 2010: 65); *norms*, such as *reciprocity* that enable cooperation and coordination through repeated interactions (Oliver 1990: 244-245; Brass et al. 2004: 803), and create deterrence-based trust or knowledge-based trust through network closure, and the resulting high density can reduce transaction costs by eliminating the need for costly monitoring and replacing due diligence to some extent (Zaheer, Gözübüyük & Milanov 2010: 65; Gulati, Nohria & Zaheer 2000: 210ff.; Brass et al. 2004: 802); *efficiency*, improving the internal input/output ratio through networking (Oliver 1990: 245); *stability*, e.g. coping with uncertainty through dependable partners (Oliver 1990: 245-246); and *legitimacy*, i.e. the institutional incentive to partner and the signalling of reputation effects (Oliver 1990: 246; Zaheer, Gözübüyük & Milanov 2010: 65).

Further motivations can lie in creating (political) *lobbying* bodies or in aligning the interests of several of a firm's stakeholders (Barringer & Harrison 2000: 376). *Equity* refers to how firms with similar characteristics are more likely to partner than dissimilar firms (Brass et al. 2004: 904; Gulati 1998: 296-297). Gulati (1998) identifies that resource access and joint learning which Zaheer, Gözübüyük and Milanov (2010) summarise under networks as a "*source of resources and capabilities*" (2010: 65, italics in original) are the motivations chiefly used in the literature, with information the most sought-after resource (Gulati 1998: 298-299; Zaheer, Gözübüyük & Milanov 2010: 65). Brass et al. (2004) similarly discuss networking antecedents as the *motives of market* uncertainty reduction, legitimacy seeking through legitimising ties and the achievement of shared goals such as cost benefits from the synergy effects from economies of scale or scope (2004: 804).

Gulati, Nohria and Zaheer (2000) posit that because firms seek differentiation to drive their competitive advantage, they will network if it aids this overall goal. Competitive advantages can stem from membership of industry's networks with high density that entail high market power concentration, with oligopolistic coordination and tacit collusion, or a firm's central position in the network, among others (ibid.: 205-206). In intra-industry structures, strategic blocks may arise and pose mobility barriers for members and new entrants by locking-in present members or locking-out new entrants from these networks or even entire industries (Gulati, Nohria & Zaheer 2000: 206-207). As regards the strong resource-based view, networks themselves or actors' positions in the same can constitute VRIN resources, e.g. exploitable structural hole positions can facilitate the receipt of valuable information or if interorganisational trust and joint history is valuable for cooperation and difficult to copy. Similarly, the ability to manage network relations can be a strategic resource, particularly as it grows over time through learning from experience, with firms becoming more skilled at extracting value from network relations (Gulati, Nohria & Zaheer 2000: 208-209). The latter essentially constitutes a learning effects argument with potentially problematic increasing returns (Sydow, Schreyögg & Koch 2009: 700). Consistent with that argument, Gulati, Nohria and Zaheer (2000) characterise overly close ties as problematic with regard to performance. Competitive (dis)advantages can stem from lock-in and lock-out effects that occur because firms have limited resources, and forming certain ties may preclude other ties from being established. Expectations of loyalty among current members can impede or foster the formation of new ties, and switching network groups is difficult and costly. Additionally, learning races can result in some members exploiting the knowledge and other intangible resources of others (Gulati, Nohria & Zaheer 2000: 210-211.).

Oliver and Ebers (1998) found that 'antecedent for networking'-arguments in empirical network studies appear to be largely resource-based motives, but a third of the studies covered also employed network position arguments. These studies predominantly analysed firms' motivations and intentions – antecedents – followed by partner selection and lacked a focus on outcomes (Oliver & Ebers 1998: 556-568). Gulati concludes likewise and claims that an overwhelming focus of literature lies on networks' initial conditions and their formation phase (Gulati 1998: 298-299).

It becomes clear from these findings that more than one motivation may apply in empirical networks and distinguishing motivations clearly could prove challenging. Whatever the motivation for networking, however, all have an effect on network and industry structures. Furthermore, the ability of organisations to pursue the goals they derive from these motivations may differ depending on the existing and emerging structures in the relevant networks. Overall, network research is thus far clearly focused on motivations and antecedents rather than the somewhat under-researched outcomes and consequences of networks (Gulati 1998: 298-299).

2. 3. 4. 3. Networking process and governance

Surprisingly few studies describe the process of establishing a network itself. Gulati (1998) introduces an exemplary event sequence of *alliance formation*, choice of *governance structure*, *evolution* of the alliance, *performance* of the alliance and the *consequences* for firms. He posits that firms' entry into alliances is both enabled and restricted by the embeddedness in networks (Gulati 1998: 300). Moreover, a history of connecting with certain partners or general networking leads firms to be both more centrally located in networks and more frequently involved in alliances. On the other hand, treating centrality as an explanatory variable makes firms more attractive and visible as an alliance partner, and thus increases the number of alliances they enter (ibid.: 301). Here, Gulati describes a self-reinforcing mechanism: the centrality of a firm is endogenous to network structure, and since centrality exogenously leads to more relations that increase centrality once more, leading to ever more relations, a clearly self-reinforcing network process emerges.

Majchrzak, Jarvenpaa & Bagherzadeh review 22 longitudinal case studies for exhibited network dynamics based on six network characteristics. The findings include *goal dynamics* (explicit qualitative mission changes), *contract frame dynamics* (relational and transactional character of a tie), *interaction style* (cooperative vs. competitive actor behaviour), *decision-making control dynamics* (management level of decisions regarding joint work organisation), *organizational structure dynamics* (formalisation and standardisation of roles and processes), and *actor composition dynamics* (new actors joining, existing actors leaving Majchrzak, Jarvenpaa & Bagherzadeh (2015: 1346-1349).

The authors identify six distinct patterns of network dynamics that occur in the interorganisational networks covered in the long-term case studies. These patterns are:

- single changes in a network characteristic, typically attributed to external sources of influence such as actor composition changes caused by retiring organisational members;
- binary loops between the interaction style and the contractual framework, caused mainly by differences between the networking partners and the composition of actors, e.g. different cultures of actors newly joining a network which increases the reliance on contractual relations;
- parallel multisource effects on a single network characteristic caused by changes in e.g. a combination of actor composition, decision-making control and organisational structure that occur simultaneously and affect the interaction style;
- positive multi-characteristic loops are patterns where differences between the cooperation partners lead to positively-reinforcing interdependent changes in three relational characteristics, such as contractual framework, interaction style, and decision-making control, aided by the emergence of mutual trust, for example;

- negative multi-characteristic loops where, conversely, differences between actors developed into conflicts that fuelled negatively-reinforcing interdependent changes between the actors, i.e. decreasing trust, more reliance on top-down control, competitive relational style etc.;
- multiloop flows where several of the above feedback loops occurred simultaneously.

Overall, dynamics of at least one of the kinds identified were exhibited by the majority of cases, leading the authors to conclude that interorganisational networks "are exceedingly unstable" (Majchrzak, Jarvenpaa & Bagherzadeh 2015: 1339), while noting that this is typically not considered problematic. Rather, the authors note that researchers in the case studies analysed named single changes, binary loops, and negative multi-characteristic loops as criteria for 'unsuccessful' relations, while positive and multi-characteristic changes and multiple loops were considered 'success' criteria (Majchrzak, Jarvenpaa & Bagherzadeh 2015: 1356). Interestingly, this implies that the more complex types of interdependent changes in relational characteristics allow for accommodating change more easily, and also exhibit greater potential for continuity in the relationship – a (counterintuitive) indication of stability through iterative changes that point towards path-dependent dynamics.

Gulati (1998) discusses different governance forms of inter-firm networks and finds that while there are several formal contractual methods, knowledge-based trust from a specific relationship and deterrence-based trust from dense networking, reputation effects and shared norms function as effective means of overcoming opportunistic threats to the relationship and are thus a powerful 'lubricant' for alliances (ibid.: 303-304).

According to Provan, Fish and Sydow (2007), *governance* [9]is a scarcely studied aspect of whole networks but was found to be influenced by reputable actors in a network who manage or coordinate activities. Coordination occurs either informally, through emerging network structures, norms of reciprocity and trust, or more formally through contracts, rules and regulations. In this latter guise, it typically affects dyads rather than the whole network. When governance influences the whole network, it typically does so in three ways: as a) shared governance, where all involved organisations contribute to decision making or through a lead organisation that can be b) informally established as a hub firm or c) formally appointed as a network administrative organisation (NAO). This formal leader function is typically not carried out by a 'normal' network member as an additional managing task, but rather by an entity dedicated solely to network management (Provan, Fish & Sydow 2007: 504).

[9] In their review on contractual governance of dyadic collaboration agreements, Schepker et al. (2014) identify a shift in scholarship from studying contractual details towards the coordination function of contracts and their adaptation to changing alliance conditions.

2. 3. 4. 4. *Networking forms and levels of analysis*

The forms or types of networking among companies depend on governance choice and relations' purpose and can subsequently assume several different forms. Reviewers identify differing degrees of arrangement formality and closeness among forms of cooperation. Grandori and Soda (1995: 200) identify the looser social networks based on interpersonal relationships without formalisation. *Board interlocks* (also termed interlocking directorates) are one example where organisations are networked by identical members on several firms' governing bodies. Evidence suggests that they influence corporate acquisition behaviour, pay structures etc. mainly because of uncertainty reduction and information access (Borgatti & Foster 2003: 996). Grandori and Soda also count *contractual relations*, such as sub-contracting towards social networks, and further distinguish these into symmetric, i.e. equality-based, and asymmetric, i.e. centrally governed relations (Grandori & Soda 1995: 200). Parmigiani and Rivera-Santos (2011: 1121) add the contract-based vertical relations buyer-supplier relations which resemble a value chain definition and looser cross-sector partnerships (2011: 1121).

Borgatti and Foster's term '*network organizations*' describes how firms integrate their economic exchange activities into trust-based social relationships in order to use trust networks as a cost reduction mechanism between markets and hierarchies. Some of the articles reviewed thus consider it an independent organisational form. However, Borgatti and Foster find the benefits of this research stream questionable and its terminology confusing (2003: 995).

Barringer and Harrison consider *networks* as *constellations of organisations* that are based on social rather than legal contracts. Research often finds that organisations group around a 'hub' firm that steers activities and relationships while allowing the other members to focus on their specific contributions and competences. These structures arise when market uncertainty and/or task complexity is/are high and often in knowledge-intensive industries (Barringer & Harrison 2000: 388). While advantages (speed to market, market power, learning, blocking competitors etc.) exist, disadvantages exist, too: e.g. the increasing difficulty of managing the network as membership grows, strong reliance on (increasingly) powerful hub firms, and a related reduction in knowledge transfer (ibid.: 389).

Bureaucratic networks are more formalised network forms and include symmetric networking, e.g. trade associations and consortia, the latter of which are less formalised but centrally staffed and managed, while the asymmetric forms of licensing and franchising are by definition governed primarily by one of the contractual partners (Grandori & Soda 1995: 201-203). *Licensing* is purely contract-based and, while franchising models could theoretically involve cooperation relations among network members (exceeding the typical analytical focus on the franchiser-franchisee relation, e.g. framed as a principal-agent problem), no reference was made with regard to this.

Consortia and *industry blocks* are similar to networks though typically not managed by a "hub firm" (Jarillo 1988: 32), but by a formally created leadership organisation. Activities are often focused on

R&D efforts and typically appear in technology-oriented industries and involve the setting of (technical) standards. They also often transcend firms, including non-profit organisations such as government, research facilities and even NGOs into networks. Advantages of consortia are rapid learning in the pre-competitive phases of an industry development, and cost sharing in contexts in which investments would prove too costly for a single firm. Moreover, consortia allow for risk-sharing and lobbying. Disadvantages include dissolution, if firms lose interest at later stages, management problems because of a lack of attribution of competences to the leadership organisation and finally anti-trust issues should state agencies begin to perceive the existence of consortia as a problem due to their potentially monopolistic power, for instance (Barringer & Harrison 2000: 391).

Trade associations are defined as non-profit entities created for the motivations of lobbying, training, legal and technical advice by firms of the same industry. They can set standards regarding products and services and thus avoid state intervention by regulation. While their existence seems to be widespread, trade associations have apparently not been the subject of extensive (network) research. Issues identified, however, are that members may free-ride, be too open about trade secrets, or lose influence to bigger firms that follow their own agenda rather than the industry benchmark (Barringer & Harrison 2000: 391).

Barringer and Harrison (2000: 383) further add *joint-ventures* and *alliances*. Joint-ventures, and the often equity-based variants, form a vast part of the strategic management stream of alliance research and can be counted towards the more tightly coupled cooperation agreements. However, joint-ventures do not satisfy the above definition (2. 3. 3) of interorganisational networks exceeding two entities.

Alliances are somewhat looser, cooperative arrangements entered into by firms that do not result in new legal entities. They are often focused on marketing and, similar to consortia, they offer risk- and cost-sharing while creating pools of resources and knowledge among members, or distributions channels and market access. Research has focused on similarities between partners as an explanation of failure or success and on governance issues such as control, opportunism, and trust. However, misunderstandings, opportunism and distrust can emerge due to the more informal norms of these alliances compared to joint-ventures or consortia (ibid.: 391).

Parmigiani and Rivera-Santos find that some forms of cooperation such as joint-ventures or (research) alliances have been covered comparatively well in research while networks, trade-associations and consortia have been neglected (Parmigiani & Rivera-Santos 2011: 1109). In addition, studies have generally concentrated on (dis)similarities between forms more than they have on (dis)similarities within forms of relationships, and their delineation often remains of limited precision overall (ibid.: 1121). Moreover, from a scholar's external perspective, it may be difficult to ascertain whether a network is a consortium, alliance block, trade association or alliance because even *if* the goals of an interorganisational venture are formally stated, members' actions may diverge from these goals and thus transcend the definitions in the literature. Overall, the degree of formalisation varies and tends to decrease as the number of partners in a networking form increases with alliance blocks, for instance, relying chiefly on social rather than formal contracts.

As the types of networking arrangements vary, so do the levels of analysis. Broadly speaking, the analytical levels covered in the literature reviews are the ego-level, dyads, strategic groups, and whole networks. Oliver & Ebers point out the large swathe of the literature that studies only one firm at the organisational (i.e. ego) level of analysis and how networks and their structures affect that ego and/or its properties (1998: 556). The second most studied level is the dyad, not least because of the strong joint-venture focus in strategic research. Due to its focus on dyads, according to Gulati (1998) much of the research on strategic networks thus "represents an undersocialized account of the firm" (Gulati 1998: 295). Far fewer studies incorporate triads or more complex networking types such as strategic grouping of firms. There are some notable exceptions, e.g. work on *strategic blocks* by Gomes-Casseres (1996), similarly *consortia* (e.g. Browning, Beyer & Shetler 1995) or the economic geography research on *regional clusters* (e.g. Sydow, Lerch & Staber 2010). Even fewer studies analyse the 'whole network level', and this can certainly be deemed under-researched (Provan, Fish & Sydow 2007: 480-481). Some light was shed on whole networks through research on industry organising processes (e.g. Manning & Sydow 2011) and public management research on the control of public service administration networks (e.g. Provan & Kenis 2007). Still, the literature has neglected this important level of analysis. It requires further investigation, because it can reveal "how networks evolve, how they are governed, and, ultimately, how collective outcomes are generated" (Provan, Fish & Sydow 2007: 480) particularly with regard to the influence of network structure and the potential problems in networking. Moreover, due to its ability to integrate arguments across the organisational, group, network and industry levels, network research has a methodological advantage over other social sciences perspectives because it can more easily "bridge the micro-macro gap" (Borgatti & Foster 2003: 1001).

2. 3. 4. 5. Network dynamics: mechanisms and properties

Grandori and Soda introduce the term 'mechanism' to the network discussion by emphasising that these are "mechanisms of coordination that are used to **sustain** inter-firm cooperation" (Grandori & Soda 1995: 193, emphasis added). Mechanisms and network properties with causal implications found in networks are often discussed under the umbrella term of *network dynamics*. Network structure constructs can be categorised into organisation level constructs (in-degree/out-degree, Closeness and Betweenness centrality, multiplexity, brokerage and cliques) and unique network level constructs (density, fragmentation, structural holes, governance, centralisation, cliques). In research practice, the former are often used as explanatory variables for the existence of the latter (Provan, Fish & Sydow 2007: 480). The following four subsections show relevant properties, constructs and mechanisms with regard to the development dynamics of interorganisational networks.

A) Properties

Brass et al. find that "In sum, interorganizational networks are created by some of the same mechanisms that create interpersonal networks, as well as by distinct mechanisms" (Brass et al. 2004: 807). They stress a particular difference in interorganisational networks that is inter-firm competition. This element makes networking among firms more complex than networking in social networks. Other influential mechanisms of social networks find less meaningful application, such as homophily and kinship. As mechanisms, Brass et al. identify *imitation* as the mimetic adoption of ideas and practices from legitimate partners that diffuse through network connections, especially for similar firms; and mutual *learning* from network partners in proximity leading to innovation, particularly in R&D projects. *Structural holes* and *closure* and *strong* vs. *weak ties* are identified as influential network properties for survival, performance, and growth, and likewise the centrality of actors and the degree of centralisation of a network in general (Brass et al. 2004: 805-807).

Gulati (1998: 301) attributes to centrality the properties of a self-reinforcing mechanism: a firm's centrality, as a measure of its prominence in a network, is endogenous to network structure. Centrality in t_0 signals attractiveness for networking partners not least through high visibility, and thus exogenously leads to more relations for that actor in t_1. These new relations then increase that actor's centrality in t_2, leading to a virtuous (or vicious) cycle of ever more relations – a clear self-reinforcing network process is at work. High (but theoretically also low) network centrality can be a property actively sought by actors, e.g. when high in-degree centrality for a company whose business model relies on being widely known bears significant influence on its performance. Research at the ego level finds that centrality (and thus implicitly network size) positively affects firm performance and its absorptive capacity (Zaheer, Gözübüyük & Milanov 2010: 66).

Gulati (1998) further stresses the importance of history in the imprinting of networks' initial conditions on their future development. Prior ties can influence the creation of existing and new ties and shape the future choice of networking partners. Furthermore, past structures can influence present and future ties and their performance more than present ties (Provan, Fish & Sydow 2007: 502). Notably, Gulati identifies another feedback loop active in interorganisational networks, namely "the manner and extent to which firms [are] embedded [are] likely to influence certain key decisions (Gulati 1998: 294), such as the frequency of allying, the choice of partners and the development of alliances over time. Gulati introduces time as an element in relations and stresses that being embedded in relations influences both new and existing relations. This once again underlines that network relations invariably exhibit both endogenous and exogenous properties (ibid.: 297).

Provan, Fish and Sydow (2007: 502) point out that structural analysis in whole network research chiefly embraces density, centralisation, and cliques as constructs. Cliques occur frequently, and their existence can influence network effectiveness (Provan, Fish & Sydow 2007: 502). Such 'small-worldness' of a network, i.e. the division of a network into dense cliques and loose links to other cliques, enhances firms' and the cliques' innovativeness and knowledge transfer (Zaheer, Gözübüyük & Milanov 2010: 69). Cliques are formed based on past and existing ties and can occur horizontally and vertically. In addition, former cooperation partners can turn into competitors and vice versa. High network density can lead to aligned collective strategies of members, despite horizontal competition, as in the 'alliance constellations' or 'strategic blocks' argument of Gomes-Casseres (1996). Such broader network structures and their dynamics over time can lock firms into path-dependent courses of action. Moreover, when actors are reflecting and aware of such dynamics, it allows them to engage in path creation (Gulati 1998: 297). Research shows that these structures influence information flows, that network density increases over time and that it is impossible to maximise both density and centralisation simultaneously in a strategic manner. A trade-off between centralisation and differentiation also exists, indicating that diverse activities are more difficult to coordinate than more focused activities (Provan, Fish & Sydow 2007: 502-503).

B) Mechanisms

Mechanisms and constructs that exist in interorganisational networks in connection with other theories include resources, rules and norms that are created and used within the network and the influence of key players' practices, which can lead to the development of a 'dominant logic' (Provan, Fish & Sydow 2007: 503). One example is the legitimacy-seeking or norm-induced mimetic *imitation* of practices of network partners (e.g. Parmigiani & Riviera-Santos 2011: 1126). Similarly, Borgatti and Foster point out that *knowledge management* and group process research found that networks can lead to the development of homogenous beliefs, practices, attitudes, and norms and describe how s*ocial cognition* may (or not) lead organisations' members to recognise network structures around their organisation and base decisions upon such perceptions (Borgatti & Foster 2003: 998-999). Since organisations are abstract constructs they cannot 'think' themselves, but the individuals that deal with interorganisational networks on behalf of their organisations are all but immune to such processes. Hence, commonly held beliefs such as 'groupthink' can emerge from close interorganisational relations.

In a similar vein, Grandori and Soda (1995) identify *sequential joint communication and decisions*; *social control* through group norms, reputation and peer control; *integration of managers' roles; common staff and centralised coordination structures*; *hierarchy and authority*; *planning, control, selection and incentive systems* such as joint property rights in R&D; *shared information systems and infrastructure* such as IT; and the extent of *formalisation* of the relationship as binding learning effects with increasing returns.

A further stabilising element is *trust* that can develop between networking partners over time, but Grandori and Soda do not consider it a mechanism, but rather an outcome of relations (1995: 194-199). Parmigiani and Rivera-Santos (2011) agree that trust emerges from long-term stable interorganisational relationships and facilitates the achievement of cooperation goals. Trust can become a stabilising factor for network relations, since partnering with other trustworthy individuals reduces transaction costs and makes the attainment of networking goals more likely, among other aspects (Grandori & Soda 1995: 198; Parmigiani & Riviera-Santos 2011: 1116-1117; Majchrzak, Jarvenpaa & Bagherzadeh 2015: 1354). Thus, repeated ties make a continuation of relationships at the dyadic level more likely (Zaheer, Gözübüyük & Milanov 2010: 65). However, how readily the various trust concepts can be applied to an interorganisational or whole-network level of analysis remains open to discussion (Provan, Fish & Sydow 2007: 509).

Arguments regarding the network property of *embeddedness* draw attention to the situation in which repeated or long-standing business relations become integrated into the social networks of organisational members. Henceforth, these can develop their own logic and mechanisms and influence business decisions, e.g. selecting joint-venture, sourcing, purchasing or partners etc. (Borgatti & Foster 2003: 994-995). This can increase firm performance as long as this embeddedness does not become too strong, because then the lack of diversity of information can mean higher risks of external shocks (Zaheer, Gözübüyük & Milanov 2010: 66; Hagedoorn & Frankfort 2008).

C) Social capital

One 'big' concept from social networks that finds application in interorganisational network research is 'social capital' (Borgatti & Foster 2003: 994). With the structural holes arguments of Burt (1992) and the closure argument of Coleman (1990) as the two main variants, Borgatti and Foster define this type of capital as having valuable ties or positions among ties of alters and posit that it can explain power structures in networks (e.g. Borgatti & Foster 2003: 993-994). Zaheer, Gözübüyük and Milanov (2010: 67) define the variants of social capital as the extent to which an actor can gain information, timing, or control benefits from brokering between two others (structural holes) or, conversely, closure as the density of an ego network that increases trust and thus cooperation and knowledge sharing within (closure), as well as the extent to which actors may have identical ties or identically structured ties (structural equivalence). The structural holes and closure should not be seen as conflicting, but rather considered as complementary (an argument discussed in more detail in Sections 2. 5 and 2. 6). Moreover, reputation is a means allowing reputable actors to exercise a level of control over the development of the network, even without direct control over resources (Provan, Fish & Sydow 2007: 503). Reputation and peer control arising from closure can thus lead to positive incentives for creating more closure (e.g. Zaheer, Gözübüyük & Milanov 2010).

Borgatti and Forster present a division of social capital into the two mechanism categories 'structuralist' and 'connectionist' (i.e. focusing on structural topology or resource-flow content of relations). Together with their typology of the explanatory goals 'performance' and 'homogeneity' (e.g. the dis-/advantages of social capital or the diffusion of ideas that changes actors), this leads to the four typologies 'structural capital', 'resource access', 'convergence' and 'contagion' of research on network consequences (see Table 3 below; Borgatti & Foster 2003: 1004).

Structural capital research is concerned with actors' positions and the dis-/advantages arising for them in consequence, their strategic way of dealing with these and the resulting outcomes. (Social) resource access studies analyse the resource flows in networks, whereas convergence and contagion studies deal with the spreading of ideas, norms, and beliefs, but focus their attention on actors either being shaped by their network environment or through the direct interaction with others (Borgatti & Foster 2003: 1004).

Typology of research on consequences of network factors	**Dependent variable**	
	Social capital (performance variation)	*Diffusion (social homogeneity)*
Structuralist (topology)	Structural capital	Environmental shaping
Connectionist (flows)	Social access to resources	Contagion

Table 3: Typology of research on consequences of network factors (Borgatti & Foster 2003: 1004)

There are several indications that social capital also has a 'dark side', in which social ties imprison actors in maladaptive situations or facilitate undesirable behaviour (Borgatti & Foster 2003: 994; Gargiulo & Benassi 2000; Gulati & Westphal 1999; Portes & Sensenbrenner 1993; Putnam 2000). Finally, claims are made that social capital arguments strongly overlap with both resource access and power/control arguments (Zaheer, Gözübüyük & Milanov 2010: 65). Hence, network relations can exhibit a restricting force. Certain relations may lock-in firms to unproductive or otherwise problematic relations, or existing relations among network members may lock them out of other, more fruitful ones, e.g. through internal norms such as reciprocity (Gulati, Nohria & Zaheer 2000: 211).

D) Causality and endogeneity of network mechanisms

Lastly, an important question regarding network properties, effects and mechanisms is that regarding the direction of causality (Borgatti & Foster 2003: 1000). Researchers and practitioners alike find it difficult to solve the 'chicken-or-egg' question of network constructs: e.g. is a firm successful in connecting with relevant partners because it already had high network centrality, or is the high network centrality instrumental in the pursuit of suitable cooperation partners? In fact, both may simultaneously be the case because, as Gulati (1998: 306) pointed out, network structures and constructs exhibit endogeneity over time and, frequently, a recursive relationship. Empirical studies of networks commonly suffer from their cross-sectional design and resulting lack of additional data time points for answering the question of the recursivity of constructs. Accordingly, Majchrzak, Jarvenpaa & Bagherzadeh call for methodological advances and the use of computational simulations that allow for the study of feedback loops and can thus accommodate recursive dynamics (2015: 1358). The recursivity of network mechanisms leads the discussion to the ambivalence of network constructs and the problems that network research often encounters (and creates) in Section 2. 3. 4. 8.

2. 3. 4. 6. *Performance and outcomes of networks*

Borgatti and Foster find that while the majority of network research (in line with its structuralist heritage) deals with outcomes rather than antecedents, the situation in interorganisational research is in reverse. They attribute this to diversity in the field and lack of a unified research agenda of e.g. 'network change' (Borgatti & Foster 2003: 1001). The relatively scarce research on the performance of alliances characterises performance as poor overall (Gulati 1998: 307) with often dramatic failure rates, e.g. a 50-70% failure rate of interfirm business alliances (Barringer & Harrison 2000: 368). Unfortunately, many studies (like Barringer & Harrison 2000) leave failure undefined or conflate termination with failure. This is problematic for two reasons: firstly, equating termination with failure "fails to distinguish between natural and untimely deaths [of alliances]" (Gulati 1998: 307). Some alliances may discontinue because of having reached their previously defined goals rather than ending in failure. Secondly, equating continuing cooperation with success is equally unjustified, because relations may continue for reasons of inertia or increasing exit costs etc. that would imply the opposite of a successful cooperation (ibid.). Gulati explains the conflicting evidence through problems in the data stemming from inaccessibility, measurement issues from output reporting asymmetry and/or lack of measurability in financial terms, e.g. in the case of learning (Gulati 1998: 307).

Despite these problems, research claims that performance advantages may stem from firms' ability to manage a network, from relations being positioned closely in a network, due to knowledge- and deterrence-based relational trust and simplified communication. Further evidence suggests that more strongly embedded ties with longer durations encourage firms to make non-recoverable investments. Such alliances perform better and terminate prematurely less often, particularly under conditions of high uncertainty (Gulati 1998: 308). Similarly, Majchrzak, Jarvenpaa and Bagherzadeh (2015: 1356) find that researchers considered more complex network dynamics (i.e. feedback loops) to be more successful than less complex dynamics. As moderating factors, firms' ability to reap benefits from their network relations depends on the frequency of past alliances and their position in the network. Apart from financial or learning outcomes such as innovation, ties with legitimate partners in well-connected networks have further been found to increase firm survival rates (Brass et al. 2004: 806). Provan, Fish and Sydow (2007) characterise the results of networking as focused mainly on learning, effectiveness, or efficiency in business contexts. Most research can be attributed to the (at least implicit) assumption that networks exert a positive influence on network outcomes (Provan, Fish & Sydow 2007: 505). While centrality in a network or clique can help the growth of firms, the consequences of tie strengths are found to be mixed, depending on industry, and even brokerage and cohesion were found to work together. Decentralised networks appear to increase performance better than centralised ones, particularly when they are structured like small-world networks (Brass et al. 2004: 807).

However, some risks also exist, such as the empowerment of competitors, firms' overembeddedness or developing risk aversion due to embeddedness (Brass et al. 2004: 805-807). Provan, Fish and

Sydow (2007) point out a potential emergence of cartels and the instability of competitive advantages based on network structures. They see failure occurring more often in intentionally created rather than emergent networks. There also appears to be tension between more stabilising actors at the core of the network and more destabilising ones at its periphery. Negative outcomes also include undesired flows of information or imitation, e.g. isomorphism and domination, or informal leadership despite a contrary appointed role (Provan, Fish & Sydow 2007: 505-506).

The answer to the question of the extent to which firms' networking activities lead to value creation thus remains unclear. Gulati (1998) attributes this to the fact that most studies' level of analysis is the relational rather than network level and to a lack of studies on the structural embeddedness of firms. He also underlines the need for research into the effect that membership of certain networks has compared to membership of others, and the effects of certain positions in these networks (Gulati 1998: 308).

2. 3. 4. 7. Methods of interorganisational network research

A large share of network research utilises elements of the SNA method set, e.g. algorithms to measure density or centrality. Other methods used to study interorganisational relationship are mainly cross-sectional quantitative studies that typically use network variables from SNA as input variables for regression analyses. Oliver and Ebers (1998) analyse network studies regarding the methodology employed and identify the dominant approach as "empirical, quantitative cross-sectional studies [..] with a focus on multiple (rather than dyadic) ties" (1998: 566). Qualitative methods that focus on the exploration of networks find far less application. The requirement for future research is thus to close the gaps by shedding light on the processes and outcomes of networks, e.g. by employing qualitative approaches (ibid.: 567-568). The picture drawn by Provan, Fish and Sydow (2007: 509-510) is similar. They discuss how the difficulties and resources (in time and money) involved in measuring empirical networks over longer time periods, the literature's focus on dyadic arguments, and the need for multi-method perspectives on networks may have led to this cross-sectional and quantitative method focus (ibid.: 510-511). Moreover, Oliver and Ebers argue that network research is located along a continuum of (social) network approaches focusing on network structure and actor positions at the one end, and a governance perspective employing institutional analysis while focusing on actor properties at the other (ibid.: 568-570).

Surprisingly, network research has employed simulation methods even less, the many reviews that noted its wide-ranging applicability notwithstanding. The present study employs both one of the lesser used qualitative methods – particularly for its ability to produce fine-grained process development data – and the simulation method because it can produce time-dense data beyond the typically used two-time points of empirical network analysis, and because the simulation method successfully deals with endogeneity and the necessarily recursive nature of network structure and feedback loops.

2. 3. 4. 8. Gaps, ambiguities, and avenues for (this) study

This section points out important gaps in the present interorganisational network literature that this research seeks to close and demonstrates relevant ambiguities in extant research findings. It concludes by addressing the 'dark side' of networks that research has identified to be similar to or even amount to network path dependence before I discuss how the present study seeks to address these points thereafter.

A) Gaps

The review papers reviewed above uncover several gaps in the research that have not yet been addressed sufficiently. Oliver (1990) indicates that the conditions leading to interorganisational relations are still to be studied and attributes the gap to the literature's focus on joint ventures (Oliver 1990: 260). Grandori and Soda (1995) argue that antecedents have been well studied, including several mechanisms for sustaining inter-firm relationships, but that networking consequences and dissolution are largely uncovered (Grandori & Soda 1995: 205). Oliver and Ebers (1998) counter that research (still) concentrates a great deal on the antecedents of interorganisational relationships, but they agree that there is a strong lack of studies on their outcomes (Oliver & Ebers 1998: 566-568). Brass et al.'s (2004) review considers only the antecedents and consequences dichotomy and thereby neglects the development dynamics and processes of networks.

However, Gulati (1998) was one of the first to consider networks' structural embeddedness and in particular their dynamics as directions for future research because it can shed light "on the path-dependent processes that may lock [firms] into certain courses of action as a result of constraints from their current ties" (Gulati 1998: 311). Provan, Fish and Sydow (2007) agree with Gulati that research needs to increase its understanding of longitudinal processes and dynamics as they are the processes that lead to networks' existence, dissolution, or stability. There are also open questions regarding the tension between a dynamic network and stability in a network and the consequences of networks for their individual network members and groups of members (Provan, Fish & Sydow 2007: 507-509). Gulati, Nohria and Zaheer (2000: 206) concur, adding that a focus on network positions and structures, particularly regarding *strategic sub-groups*, remains underdeveloped for the study of (intra-)industry structure. The often-stated lack of studies on these aspects can be attributed to the difficulties in studying long-term developments empirically and in measuring the effects precisely. Also, effects that are positive for one member might be detrimental to others and vice versa, thus rendering the many mean effects-oriented studies and methods overly superficial. Consequently, the authors stress that a discussion about suitable measures, levels of analysis, and relationship structures is needed (Provan, Fish & Sydow 2007: 509-510).

Both Barringer and Harrison (2000: 396) and Provan, Fish and Sydow (2007: 504) find that research on the practices of network governance is rare while the governance of consortia varies broadly, and that research needs to address the effect of governance on effectiveness, failure, or success (if such criteria can be objectively established).

With regard to levels of analysis and network types, whole network level research appears to be lacking across the board (Provan, Fish & Sydow 2007: 480). In their two-by-two matrix, the authors categorise network research along the dimensions of dependent and independent variables. The fourth quadrant of this matrix is termed "Whole networks or network level interaction" (ibid.: 482). Provan, Fish and Sydow suggest future research to examine how network properties and structure affect the effectiveness of certain network structures such as structural holes, the ability of structure to predict behaviour and outcomes, how (government) policies may shape and constrain structure and, in general, which factors affect the development of different network structures.

A Typology of Interorganizational Network Research		
Independent Variable or Input Focus	**Dependent Variable or Outcome Focus**	
	Individual Organizations	*Collectivities of Organizations*
Organizational variables	Impact of organizations on other organizations through dyadic interactions	Impact of individual organizations on a network
Relational or network variables	Impact of a network on individual organizations	Whole networks or network-level interactions

Table 4: A typology of interorganisational network research (Provan, Fish & Sydow 2007: 482)

Parmigiani & Rivera-Santos (2011: 1128-1129) claim that researchers need to pay more attention to context and relational diversity and thus ask for more research on certain forms of interorganisational relations, e.g. consortia-like networks. Zaheer, Gözübüyük and Milanov (2010) emphasise that too few studies in the extant literature cross the boundaries of levels of analysis or study more than one mechanism. An example of this could be Gulati's (1998) study, which introduced a multi-level view of analysis where alliances are based on interpersonal networks. Given that several different mechanisms might simultaneously be active at different levels, research may produce spurious findings or biased explanations if the interaction of these different mechanisms and their effects are neglected (Zaheer, Gözübüyük & Milanov 2010: 70-74). This holds especially for research on social capital where e.g. the (lack of) cognition regarding network structure occurs at a different level than the structure itself.

Methodological issues that remain unaddressed in the extant literature include the issue of (double) endogeneity and the difficulty of differentiating levels of analysis and dependent and independent network variables as suggested by Provan, Fish and Sydow (2007: 482; see Table 4 above). This is due to the interaction between mechanisms, effects, and levels of analysis (Zaheer, Gözübüyük & Milanov 2010: 70-74). Research should thus analyse how mechanisms may work across different levels and occur simultaneously and over periods of time. Examples include the effects of density or signalling – much-neglected aspects at both ego and network level (see Table 5, below). Both density and signalling are of importance for this research project because membership of an industry block serves important signalling functions for both the network and the individual firms, and density plays a strong role in the development of path dependence network processes. A related question not yet answered satisfactorily concerns firms' awareness of network structures and their ability to strategically manipulate these in their favour, e.g. by preventing or furthering closure/brokerage positions etc.

Theoretical mechanism	**Levels of Analysis**		
	Dyad	*Ego*	*Network*
Resource access	Strong Ties → Tacit Knowledge Transfer Weak Ties →Explicit Knowledge Transfer Uzzi & Lancaster (2003) Exploitation Context → Strong Ties Exploitation Context → Weak Ties Rowley et al. (2002)	Degree Centrality → Information Ahuja (2000), Shan et al. (1994) Degree Centrality → Capabilities and Learning Powell et al. (1996), George et al. (2001) Structural Holes → Information Burt (2004), Zaheer & Bell (2005) Structural Holes → Capabilities and Learning McEvily & Zaheer (1999)	Interorganizational Networks → Regional Success Saxenian (1994) Interorganizational Networks → Effective Knowledge Transfer Singh (2005), Almeida & Kogut (1999)
Trust	Strong Ties → Trust Gulati (1995) Trust → Performance Zaheer et al. (1998)	Closure → Trust Ahuja (2000), Rowley et al. (2000) Centrality → Trust Ingram & Roberts (2000)	Interorganizational Networks→ Regional Success Saxenian (1994)
Power/Control	Power Imbalance → Tie Formation Bae & Gargiulo (2004) Mutual Dependence → Constraint Absorption Casciaro & Piskorski (2005)	Structural Holes → Bargaining Power Burt (1992)	Interorganizational Relationships → Strategic Blocks Nohria & Garcia-Pont (1991)
Signaling	Future Research	Bonacich Centrality as Status Benjamin & Podolny (1999), Gulati & Higgins (2003), Jensen (2003)	Future Research

Table 5: Interorganisational research framework (Zaheer, Gözübüyük & Milanov 2010: 64)

B) Ambiguities

As the reviews show, some of the research on interorganisational networks is contradictory or ambiguous. In very general terms, networks can be positive for firms or negative, and involvement in them carries certain risks or side-effects.

Network membership can allow firms to access resources that are otherwise not in their possession, but once access has been gained, it can also lead to network partner dependence based on a dependence on that resource, particularly when said resource is market access or power. Network membership itself, or a certain position in a network, can constitute a VRIN resource and the management of strategic cooperative links can be a competitive advantage (Ireland, Hitt & Vaidyanath 2002: 440). However, being a network member can also reduce the competitiveness of members due to (unintended) sharing (Barringer & Harrison 2000: 373), and certain diseconomies may exist that together with dependencies exert a binding force on network members (Dyer & Singh 1998: 672). Communication in networks can have positive (mediating) effects on firm performance if it can effectively reduce opportunism among strategically relevant partners (Möller & Seiter 2008: 20-21). Similarly, certain advantages have been attributed to the emergence of interorganisational trust between organisations, such as enhanced performance through partially substituting formal governance mechanisms and reducing conflict (Gulati & Nickerson 2008: 17-18). Moreover, learning from past relations and the resulting trust appear useful in the creation of new ties and decisive for their success, particularly in non-equity cooperation, but may also limit individual firms' performance, increase risk aversion and lead to overembeddedness (Brass et al. 2004: 802), one of the network problems discussed below.

Relating more closely to network properties and structure, certain network positions, such as hubs or brokers that occupy structural hole positions, can prove beneficial (Bae & Gargiulo 2004: 853). If recent rather than in the past, structural hole positions allow actors to reap financial benefits from their network, but only for a limited time (Soda, Usai & Zaheer 2004: 903). Furthermore, large ego networks may be ambiguous since an increase in size may be met with resource and capability restrictions (Zaheer, Gözübüyük & Milanov 2010: 72). Soh, Mahmood and Mitchell showed that a firm's high ego network centrality allows it to receive information, but it can accelerate both corporate success and failure in consequence (2004: 914-915). Knowledge and information sharing in very dense networks may also have downsides when this exceeds levels that permit the protection of proprietary knowledge (Zaheer, Gözübüyük & Milanov 2010: 72) or when it leads to learning races (Gulati, Nohria & Zaheer 2000: 211). Partnering with actors in similar positions in a strategic block can mitigate the entry of competition to a local market, but such arrangements may become locked-in due to inertia (Nohria & Garcia-Pont 1991: 122).

In a similar vein, Zaheer, Gözübüyük and Milanov (2010) point towards "trade-offs" found in network research. They pose the general question regarding the effects of structure and see a potential 'dark side' of social capital, i.e. balancing "the benefits of trust and embeddedness with the cost of lock-in and inflexibility" (2010: 71). However, by focusing on how organisations try to strike such a balance, research neglects the understanding of the mechanism that leads to lock-in situations initially.

C) Problems

The focus of this research lies on certain problems that arise in networks and may be problematic for or even detrimental to firms that are members of that network. These problems have been given several different names, and their main arguments are outlined in this subsection in roughly ascending order of severity of the issues that the phenomena pose to member firms.

An initial aspect is that networks have a development history. Ties are created over time, and the creation of new ties is influenced by existing ones. History matters for network development because firms that had allied in the past are likely to repeat or continue this cooperation (Gulati 1995: 643), especially if they have a similar centrality in the network (Gulati & Gargiulo 1999: 1476ff.). This situation can be problematic insofar as such structures may hinder firms' individual pursuit of economic interests, and because the (network coordination) costs associated with occupying a position of high centrality may sometimes outweigh the latter's benefits, for example (Tsai 2001: 1002).

Beyond network historicity and continuity, network structures appear to have some kind of "network memory" in that past network structures may have stronger effects on performance than present ones (Soda, Usai & Zaheer 2004: 903) as time becomes a contingency factor. Marquis (2003: 681-682) found that past networks can impose local norms on firms and even on new entrants to a network. Not only may history influence firms' future networking choices, but historical ties may also be difficult to resolve and place constraints on firms, e.g. when they are trapped in a position outside of a structural hole (Kim, Oh & Swaminathan 2006: 72). Such 'network inertia' reduces firms' structural autonomy, constrains access to resources, and makes dissolving inauspicious network ties more difficult (ibid.: 713). Gulati, Nohria and Zaheer (2000) even stress a "potential dark side [.. that] may lock firms into unproductive relationships or preclude partnering with other viable firms [because] a firm's network or relationships is a source of both opportunities and constraints" (Gulati, Nohria & Zaheer 2000: 203-204). Zaheer, Gözübüyük and Milanov (2010: 72) additionally point out the implicated, potentially undesirable signalling effects that may occur when leaving particular relationships.

When firms are allied in strategic groups, such as alliances, constellations, blocks, cliques, or consortia, this can be beneficial to them because they create capability synergies or may provide resource access (Gomes-Casseres 1996: 38). However, if these structures are too loosely managed or coordinated, and interdependence of partners low, benefits may not arise, causing partners to leave the group (Barringer & Harrisson 2000: 390-391). Conversely, if cooperation is too close, however, these structures have also been reported to bear the risks of becoming rigid and locked-in (Nohria & Garcia-Pont 1991: 122), especially since they have been found to be generally more structurally stable than other network shapes such as stars (Vanhaverbeke & Noorderhaven 2001: 13). While not only this is problematic for firms, market regulation issues may also exist, such as antitrust investigations when members cooperate more closely and achieve oligopolistic coordination (Gulati, Nohria & Zaheer 2000: 206-207).

Cooperation that becomes very close within a network's strategic group may lead to further problems for its members. One of these is overembeddedness, which can occur at the three levels "environmental, inter-organizational and dyadic" (Hagedoorn & Frankfort 2008: 503). Environmental embeddedness refers to a firm's connections within its broader economic or industrial surroundings. Interorganisational embeddedness refers to relationships within strategic groups or blocks where dense cooperation ties are typical. Dyadic embeddedness denotes the repetition of relations with one and the same network partner (ibid.: 506-509). Being increasingly embedded in such relations is described as having many advantages at first, but over time, the benefits and growth of valuable new partnerships follow an inversed u-shape curve (ibid.: 511). Notable here is that the three levels of embeddedness can concur and often increase simultaneously (ibid.: 519-520), also recursively influencing each other.

Beyond this tipping point, the fruitfulness of embeddedness can turn into overembeddedness. At the dyadic level, partner dependence increases with tie duration and multiplexity and creates issues that concur with the typical resource-dependence arguments and information or learning disadvantages or diseconomies (ibid.: 515). Interorganisational overembeddedness emerges when firms become trapped in "densely-connected sub-networks" (ibid.: 516) due to loyalty expectations and network norms of cooperation and cognitive lock-in of the member firm (ibid.: 517). At industry level, overembeddedness is more abstract and refers to a saturation of partnering capabilities coupled with the environment's expectations that firms 'cannot go it alone'. Being overly embedded in a social fabric can have the consequence of reduced ability to enter new relations with new partners and restrictions in partnering or diversifying outside the industry (ibid.: 518-524).

Uzzi (1997) found that becoming too embedded further reduces diversity and a firm's ability to adapt, as well as creating isomorphism among network members (1997: 57) when "diligent commitment, [..] expectations of reciprocity and social pressure to perform" (ibid.) or even indebtedness (Soda & Usai 1999: 294) create a rigid social structure and increase the costs of maintaining ties. This "paradox of embeddedness" (Uzzi 1997: 35) can become problematic through an "unexpected loss of a network's core organization, or more generally, a deep and sudden structural change in resource flows" (ibid.), particularly because it restricts firms in moving beyond known partners and makes firm survival more difficult.

Another phenomenon of network lock-in and lock-out dynamics occurs in rather dense networks (Gulati, Nohria & Zaheer 2000: 203) in which many companies are connected to one another. Such constellations can naturally have a positive side in terms of opportunities, access to resources, learning and economic returns. However, they can also have negative implications. From a social capital theory perspective, an actor's control is typically deemed higher in networks in which they occupy a position of bridging structural holes, since it allows them influence in the flow of information. Dense networks, however, permit another type of control that allows the partners in a firm's network to control that firm's actions to a certain extent. While this may be positive for the alters of the firm, it may not necessarily be so for the firm itself, since it might require the deployment of more resources than preferred on certain relationships (Gargiulo, Ertug & Galunic 2009: 326). This normative control has two facets in that apart from the cooperation control benefits for the alters of a firm, it may restrict said firm's ability to choose its networking partners and, overall, seems to provide more benefits to small firms rather than big ones (ibid.: 330-331).

Social capital has further implications relating to constraint. From an individual firm's perspective, social capital in the form of resources available through network partnering has enabling effects at the start of alliance creation (Duysters & Lemmens 2003: 52). These very benefits may paralyse firms over time (ibid.). This is the case when network groups are formed which become very dense, i.e. closed, too closed for members to choose freely with whom to cooperate (if at all). The reasons behind such a situation are primarily local search, the trust emerging through the high density of the network and the norms and social cohesion which make investment in existing relations more likely (ibid.: 52-53). The constraining effects of these networks stem from a replication and/or continuation of ties in a (sub-)group and a resulting decrease of technological diversity and homogenous information, behaviour, and beliefs. Inertial forces emerge from a reduction of search efforts beyond the local domain since resources are ultimately limited, learning and innovation are impeded (ibid.: 55-57; see also Li & Rowley 2002) and cognitive processes create common mental models and groupthink and can lock actors into unproductive but stable network relationships (Zaheer & Soda 2009: 6). Furthermore, strategic inflexibility and (sub-)group dependence arises not only for the locked-in members of the network but also in terms of a lock-out for potential newcomers that could provide new input for the established players (Duysters & Lemmens 2003: 65).

Overall, ambiguity and discord in the academic debate appear to exist as regards whether bridging ties, i.e. social capital from brokerage, or network closure, i.e. social capital from cohesive ties, are beneficial or detrimental (Ahuja 2000a: 451-452). Walker, Kogut and Shan (1997) avoid the dispute between the two schools of social capital thought and introduce their own version by modelling social capital as structural equivalence. They define structural equivalence as "firms that are structurally equivalent have relationships with the same other firms in the networks" (Walker, Kogut & Shan 1997: 115) – essentially a 'homophily' argument. This definition is conceptually quite distant from both Burt's structural holes' conceptualisation and Coleman's closure arguments, since it measures neither structural holes nor closure via density, for example, as will be discussed in depth in Section 2. 5. With this specification, their finding is that interorganisational networks become path-dependent because their members recreate structures that were established at an early point in an industry's history, and because early partner choice has a strong impact on future cooperation partners (1997: 120). As to why this reproduction occurs, the authors remain vague. Overall, they conclude that such path-dependent developments can be explained by their social capital conception and that network structure need not to reach its optimum and has inertial influences on members (1997: 122).

In this manner, they 'only' explain that structure is stable and rigid, but not why, and particularly how this rigidity came about. Unfortunately, the conceptualisation of social capital as structural equivalence measured via a comparative static approach and the two time-point restriction of the empirical data in this study clouds the view of the process development leading to firms' path dependence. Furthermore, their use of path dependence remains at a purely metaphorical level. Nevertheless, it is surprising that neither the network approach community nor the path dependence community has remedied these shortcomings since 1997. Still, the three authors must be credited for making the connection between interorganisational network research and path dependence as the central phenomenon. Furthermore, it is their paper which identified one driver of path dependence, namely social capital, albeit in a fashion unsuited to revealing the process dynamics unfolding beneath.

2. 3. 5 Summary and approach of this study

Interorganisational network research can be characterised as fairly diverse. Several theories are employed in the research of interorganisational cooperation because no single theory can capture all phenomena. However, many of the studies connect their theoretical reflections through resource or information access (resource-based view) and learning arguments that, together with transaction cost reasoning, serve as the main theoretical bridges between approaches. These also serve as two of the most widely-used arguments regarding firms' motivation for networking. Other arguments include the attainment of economic power through the creation of industry blocks and joint projects such as R&D. Allying with other firms can take many (legal) forms along a continuum of contractually 'closer', e.g. joint ventures, and contractually 'looser' variants such as industry blocks or regional clusters. The levels of analysis differ correspondingly, ranging from firms' ego-networks to groups, subgroups and, much less frequently, entire network structures.

With regard to mechanisms and properties of networks, findings indicate that partnering with prominent firms in a network, i.e. those with high centrality, can lead to a self-reinforcing process that consolidates the property of centrality, and many empirical network constellations are grouped around such central "hub firms" (Jarillo 1988: 32). Networks exhibit historicity in their development, with new ties building on older ones and network cliques forming among actors who frequently cooperate, which gives rise to the emergence of reputation-based trust between the cooperating entities. Social capital in its 'structuralist' or 'connectionist' guises can explain certain network structures and developments, and it appears to have a 'dark side' in the sense of constraining network members in partner choice and strategic flexibility, a factor that might explain the reported low performance of interorganisational ventures.

Methods and methodologies employed in interorganisational network research chiefly take the form of the quantitative cross-sectional approach in which certain network variables, e.g. centrality, is captured and used as an explanatory variable in a regression model. Network research faces the challenges of endogeneity, simultaneity, and heterogeneity (Zaheer, Gözübüyük & Milanov 2010: 72), yet the frequently-employed cross-sectional quantitative approaches are limited in data depth and time density, thus forcing researchers to tread paths unsuited to addressing these issues. Computer simulation as a network study approach that can overcome these hurdles has failed to play an important role in interorganisational research to date, despite offering the additional advantage of facilitating the study of network dynamics in a controlled environment.

The main gaps and unaddressed ambiguities revolve around the outcomes, processes, and dynamics of networks, and especially the 'dark side' of networks. Network dynamics have been flagged as a major gap in network research that is rarely addressed given the cross-sectional approach of much empirical work, with some exceptions studied by Majchrzak, Jarvenpaa and Bagherzadeh (2015). Since much research focuses on dyads, whole network level and sub-group level remain the most understudied network levels in the research. The 'dark side' of networks captures all phenomena where networking or networks' properties exhibit problems for the participants. Almost every potentially positive structure or mechanism seems also to hold potential for negative consequences. This is because the interplay between social structure and actions may "put a firm on an irreversible path-dependent trajectory of future development [… which is] structurally shaped" (Gulati 1995: 646). Some of these phenomena have been identified as network imprinting, inertia, overembeddedness, lock-ins, and path dependence.

While all these are more or less meaningful characterisations of firms' problematic structural situations in the context of interorganisational networks, these studies lack a systematic understanding of the path-dependent process which leads to the aforementioned problematic situation, despite adopting some of its terminology. To properly address the ambiguity of network structure and understand the problems, a thorough process perspective of network path dependence is necessary that exceeds two data points in time (such as Kim, Oh & Swaminathan 2006: 706.) Furthermore, the reviews discussed above are clear in their identification of the negative consequences of certain network structural situations, but imprecise in their definition or operationalisation of network path dependence phenomena. Dense network sub-groups are among the most beneficial yet concurrently the most dangerous network constellations in terms of their effects on participant firms. Nevertheless, not much is known about their emergence despite the fact that a lock-in to problematic structure is most frequent in these situations. It follows that, networks' structural embeddedness and, in particular, their dynamics, need to become a research focus because they can shed light "on the path-dependent processes that may lock [firms] into certain courses of action as a result of constraints from their current ties" (Gulati 1998: 311). These gaps and ambiguities have been alluded to several times during the time-frame covered in the literature review, yet do not appear to have received sufficient attention in the management literature given the remaining, as yet unaddressed, questions (Gulati, Noriha & Zaheer 2000; Zaheer, Gözübüyük & Milanov 2010: 72-74.).

This situation can thus be understood as an urgent appeal for the study of networks' over-stability, i.e. path dependence in interorganisational networks. The present research seeks to close the gaps by providing a systematic understanding of the network path dependence phenomenon is concerned, addressing the call for research on the 'dark side' of networks. It proposes a new understanding of and contributes a driving mechanism for network path dependence, and sheds light on the network dynamics involved. By addressing both the whole network level and the sub-group level, this research also concentrates on two rarely studied levels of analysis in interorganisational network research.

It would appear that such a systematic understanding of path dependence in interorganisational networks cannot emerge from interorganisational network research alone. Some research has addressed network path dependence (Walker, Kogut & Shan 1997), but has not provided sufficient answers with regard to dynamics leading to a lock-in, nor suitable data required to explore the validity of such a theoretical claim. The field requires some additional theorising. I suggest that a solid process lens on network path dependence can be deployed to improve our understanding of the phenomenon. Such a perspective is offered by the theory of path dependence that has been neglected in network research thus far, with the exception of borrowing its terminology. The theory of path dependence in its adaptation to interorganisational networks offers a systematic understanding of a social mechanism-based lock-in to unfavourable situations. Although it has not embraced network structure arguments to date, it is compatible with network reasoning.

The theory of path dependence forms the focus of the next Section 2. 4. Initially, I provide a brief outline of its history and foundations in economics (David 1985; Arthur 1989), before concentrating on its adaptation to organisational theory by Sydow, Schreyögg and Koch (2009). Their approach fills the gap left by network scholars to a great extent. It offers a mechanisms-based reasoning that helps to uncover detrimental dynamics that can emerge with or without actors' awareness. It identifies drivers of these mechanisms and gives a specification of different phases of a dynamic process, as well as providing a more systematic definition of a lock-in situation than offered by interorganisational network research thus far. Path dependence research lacks a network structural mechanism driving the path dependence trajectory at a whole-network level. I will remedy this omission in path dependence theory by integrating social capital reasoning in Section 2. 5.

2. 4 The theory of path dependence

"The fundamental problem of possibly locking-in a regrettable course of development remains" (Arthur 1989: 128).

Research has long identified the phenomenon of network path dependence by using path dependence in a more or less metaphorical way as the 'history matters' argument (Arrow 2004). Much more precision than is currently offered in interorganisational network research is required in order to gain a systematic understanding of how positive feedback in social structures and the processes based on these can increasingly lock-in social settings to one of several possible unfolding outcomes. Path dependence theory offers a systematic view of these self-reinforcing processes, its properties and mechanisms and it is a powerful tool for the study of network structure dynamics and lock-ins. But what actually is path dependence?

Vergne and Durand summarise path dependence as the notion of "increasingly constrained processes that cannot easily be escaped" (Vergne & Durand 2010: 736). Path dependence has become an important finding and line of reasoning in organisational scholarship (Sydow, Schreyögg & Koch 2009: 689) and in the disciplines of "sociology, economics, psychology, history, political science, or economic geography" (Vergne 2010: 1758). Its popularity[10] is largely owed to the theory's main contribution of re-introducing history into the study of organisation and other domains. Nonetheless, it appears that the theory, or rather its usage in research, lacks definitional precision (Ackermann 2001: 9), and some claim that it has become "one of those many constructs for which ten different people would have ten different definitions" (Vergne & Durand 2010: 1758). This is hardly surprising, given the broad range of its applications. Furthermore, Vergne and Durand argue that scholars have conflated or confused the lock-in as the outcome of the process with the process itself (2010: 729). Such vagueness and definitional confusion may have contributed to the imprecision in the usage of the path dependence construct by the few interorganisational network scholars dealing with the phenomenon (e.g. Walker, Kogut & Shan 1997).

In order to avoid such confusion and in order to underline the explanatory fruitfulness of path dependence theory, I firstly outline its foundations and central properties (David 1985; Arthur 1989). Secondly, for an application within organisational research, I introduce the most influential adaptation of the concept to organisational and interorganisational settings (Sydow, Schreyögg & Koch 2009) with the constitutive explanatory elements of a path-dependent process. After describing each

[10] Sydow, Schreyögg and Koch (2009: 689) cite almost one paper per issue in three leading organisational journals between the years 1995 and 2008.

property or element, I apply these to an interorganisational network setting and discuss the applicability and implications for (interorganisational) network research. Lastly, I discuss two important criticisms of path dependence, and conclude the chapter with a discussion of social mechanisms which exhibit the potential to drive path dependence processes. Here, I stress the gap in path dependence research that will subsequently be filled by social capital theory as a path dependence mechanism.

2. 4. 1 The foundations of path dependence

Neo-classical logic posits that fully rational agents make perfectly informed decisions. Hence, they cannot make inferior choices, and decentralised markets always achieve the best solution in terms of the best product or service becoming the market standard. In this model world, no situation can arise that would ultimately result in an inefficient market outcome.

In stark contrast, David (1985) shows in his seminal article that markets do not always achieve the best, i.e. efficient, solution in a state of equilibrium. He argues that the product or service which can most efficiently or effectively fulfil its task for consumers will not automatically become the most successful in the marketplace, and that such a situation can be irreversible. For critiquing neo-classical economics, he used the – by now famous – case of the QWERTY keyboard layout as an illustration to show how “historical accidents” (David 1985: 332) can shape agents’ choices to favour an inferior product.

The historical accident alluded to in this case was that the QWERTY keyboard layout allowed sales personnel to quickly type their brand name ‘Typewriter’ since all letters required for it are in the first row of the keyboard. This feature mattered insofar as it allowed a demonstration of how the supplier Remington & Sons had invented an allegedly superior technology in which the keys and typebars were much less prone to jamming, hence allowing higher typing speed (David 1985: 333).

If this were true, it would explain the success of the QWERTY keyboard layout and even be in keeping with the neo-classical reasoning. However, David shows evidence to the contrary: typists perform more slowly on QWERTY than on the competitive Dvorak Simplified Keyboard (DSK), for example (David 1985: 333-334). Furthermore, and yet more puzzling, the requirement for jam-reducing keyboard layouts disappeared through advances in technology: first through more advanced mechanics and later through the electrification of typewriters. Ultimately, the use of modern PCs (and nowadays touchscreen devices) should have led to a steep advance in alternative keyboard layouts, e.g. of DSK, if its superiority holds[11] or other competitors that existed (David 1985: 334). Yet, even today almost all keyboard layouts continue to follow the QWERTY layout from the year 1873

[11] This was contested most strongly by Liebowitz and Margolis (1990) and Kay (2013) with contrary findings.

or its geographic adaptations.[12] It follow that, over time, the cumulative choices by market actors resulted in an inefficient market outcome, because an inferior product (or service) became so 'successful' that it still constitutes a very strong market standard (David 1985: 335).

David makes the combination of two mechanisms responsible for this situation: (1) *technical-interrelatedness* is the term he uses to describe the need for compatibility or complementarity between the software (the typists' typing skills) and the hardware (the typewriter layout), and demand on one of them would lead to an increase in demand for the other; and (2) system economies of scale that decrease overall costs through a de facto standardisation and learning that becomes easier through increased usage and cheaper through decreased typewriter variety (David 1985: 335). David deems this situation as quasi-irreversible since the investments made in the standard cannot be recovered and the skills not unlearned. David thus speaks of a "lock in" (1985: 335) of the system to the market standard. Overall, these seemingly random historical events can lead to a literally global lock-in to an inefficient solution.

2. 4. 2 Path dependence considered formally

While David (1985) remained on the level of an explanatory narrative, Arthur (1989) reveals an abstract mathematical model that shows how increasing returns are responsible for lock-ins. Just like David, Arthur uses technical standardisation as an illustrative case, because such cases are prone to path dependence. Arthur assumes a system in which adopters with heterogeneous preferences (R and S agents) choose between two competing standards A and B. Arthur posits three return regimes: constant, diminishing and increasing returns (Arthur 1989: 118-119).

Under constant returns, agents make their choice in a random sequence (from an external observer's perspective), thus resembling a statistical random walk process. Previous agents' choices have no impact on another's choice and the market share will end up split among 50% each (Arthur 1989: 117). Under diminishing returns, the more a technology becomes adopted, the lower the utility for earlier and new adopters. Such a development necessitates technology switches that result in a process that appears to have "reflecting barriers" (Arthur 1989: 121) and with a shared adoption market outcome.

[12] With the advent of touchscreen devices at the beginning of the 21st century, this layout is in theory replaceable and indeed new alternatives have been created (e.g. SwiftKey www.swiftkey.net, Minuum http://minuum.com/). However, even their layout design is still strongly influenced by the QWERTY legacy and these layouts are very far from notable market successes.

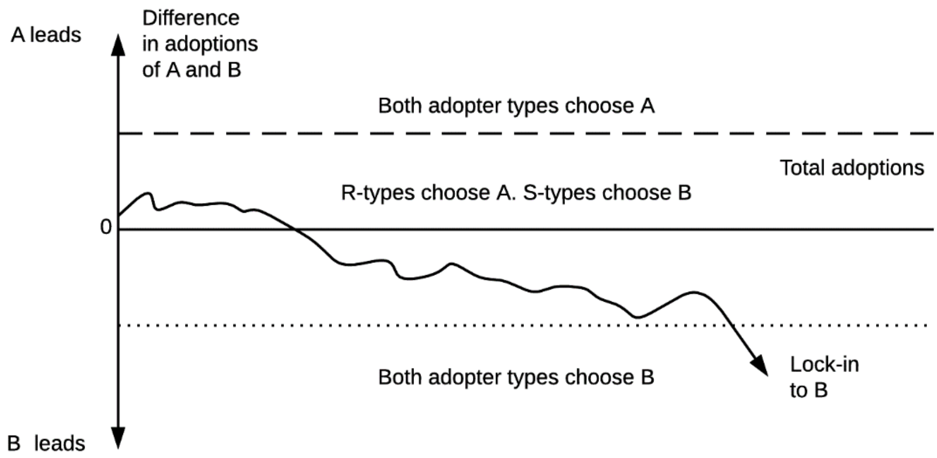

Figure 3: Technology adoption under increasing returns (adapted from: Arthur 1989: 120)

The most interesting case is a market adoption process with an increasing returns regime. If a technology exhibits increasing returns, it becomes more attractive than competitors if more agents had already previously made the same choice. A prominent example of such a situation is the telephone network system with its direct network effects referred to in 2. 2. 2 as an example of how economists employ networks. Here, every further user to a system increases the system's utility for both the actors who made their choices previously and the new adopters. In the event that one technology has more adopters than others but is not necessarily more advanced, all or most adopters still switch to the technology with more users, despite its inferiority. In this case, a market exhibits a path-dependent process. What is important here is that at the beginning of the process there are multiple equilibria (in this example: two) with regard to market outcome. However, the history of market choices influences the full adoption of only one dominant technology in the long-run.

It follows that whichever factors influence these choices at an early stage in proceedings can have a strong impact on a market decision. Influences can stem e.g. from regulation through subsidies or taxes, first-mover advantages or from technological sponsorship in case a sponsoring firm employs penetration pricing and forfeits early returns or even accommodates losses in return for expected future returns (Arthur 1989: 121-123; Arthur 1990: 93). In the case of technological standards, an important feature of a path-dependent process is that early adopters of a technology can see their utility reduced in the future even if their technology is superior, because a future inferior standard may arise that renders old investments void. In such a case, early adopters pay a price for their willingness to choose early on in the process. Since these processes are not as rare as one might expect, particularly as far as technological standards are concerned, many users expect a market lock-in to a later de facto standard, thereby slowing down their adoption. This behaviour is one factor contributing to the so-called S-curve trajectory of technological adoption that empirically holds for many technologies (Geroski 2003: 44). In addition to the QWERTY case, several other standard-setting technological path-dependent processes occurred, e.g. alternating current (David & Bunn 1988; David 1992), nuclear power station technology, internal combustion engine-driven automobiles, the US colour TV system NTSC (Arthur 1989: 126); software operating systems (Dobusch 2008; Shapiro & Varian 1999; Arthur 1996), the JVC VHS vs. Sony beta video system (Liebowitz & Margolis 1995b: 218-222) and semiconductor lithography technology (Sydow et al. 2012) among others.

In addition to introducing this formal model of path dependence, Arthur identified several properties of a path-dependent process. This case of increasing returns is presented vis-à-vis the properties of the other two regimes (Arthur 1989: 121) in the following Table 6.

Properties of the Three Regimes				
	Predictable	*Flexible*	*Ergodic*	*Necessarily path-efficient*
Constant returns	Yes	No	Yes	Yes
Diminishing returns	Yes	Yes	Yes	Yes
Increasing returns	No	No	No	No

Table 6: Properties of a path-dependent process (Arthur 1989: 121)

Here, Arthur formally defines several properties that mark a market process as path-dependent. These features will be reviewed in the subsequent sections. A path-dependent process exists because of increasing returns and is neither predictable nor flexible; it is *per definitionem* non-ergodic and it may not be (path) efficient. It is, of course, this latter property and the unique combination with the other properties that distinguishes increasing returns situations from the other return regimes. It is also the very property that gives path dependence theory the critical edge in contrast to neo-classical economics. I discuss these properties in more detail below when outlining the adaptation of path dependence theory to management and organisational phenomena.

Arthur, Ermoliev & Kaniovski (1987) further provided a mathematical model of non-linear path dependence with the Polya urn model (1987: 295). This model resembles the process of withdrawing single balls from an urn that at the start of the process contains an equal number of balls of two colours. Upon drawing one colour, the drawer then returns the ball and adds to the bowl one more ball of the same colour. While, at the beginning, the chance of drawing one colour was exactly $p=0.5$, this balance is now tilted in favour of the colour first drawn in $p=0.5\ +1$ ball. At the next drawing, it is thus more likely that drawing would reveal another ball of that colour again, thus adding a further one, ever increasing the odds for this colour to be drawn. Continuing this process over time, one colour would become so dominant in the process that it crowds out the balls from the other colour entirely. Path dependence, then, is the result of such a non-linear process because the outcome depends upon the initial drawing of events in an unpredictable, non-ergodic way that leads to inflexibility but does not (necessarily) satisfy the inefficiency criterion.

2. 4. 3 The adaptation to organisations and management

Path dependence theory arose in historical economic studies and focused on persistence and positive feedback mechanisms that can lead to lock-ins at market level. Schreyögg, Sydow and Koch (2003) and Sydow, Schreyögg and Koch (2009) extend the theory to the analysis of phenomena in organisation and management research settings. They do so by providing a process model that conceives of path dependence as a three-stage process and define its properties by adapting those of David (1985) and Arthur (1989). The main reason for extending path dependence theory to management topics is that strategic and organisational processes are prone to becoming inert or persistent even in the light of calls for change. Furthermore, these issues have been described in management and organisation research before, but not systematically. Thus, concepts such as groupthink, imprinting, routines, core rigidities, cognitive constraints etc. lack a true process perspective that argues more precisely than an all-embracing *past* dependence as argued by other scholars (Sydow, Schreyögg & Koch 2009: 690).

The first stage of a path-dependent process, the preformation phase, is characterised by a more or less broad scope of actions. However, "history matters in the Preformation Phase, too" (Sydow, Schreyögg & Koch 2009: 692) in that when initial decisions are made, these are embedded in a cultural, organisational and context with routines, habitual practices, and rules. Thus, history always matters in the sense of informing (and potentially biasing) agents, but the process nonetheless remains contingent. Based on this initial imprinting, small (or bigger) events occur. These have previously been described as essentially random (David 1985: 335), or chance (Arthur 1989: 118). In an organisational context, random decisions or actions are unlikely. In contrast to markets, organisational actors make strategic choices that have intentions or goals. Considering them to be random (as in the foundations of path dependence studies), would not be justified. However, the actions or decisions are still non-deterministic with regard to the final outcome since actors are not able to foresee all consequences of their actions, including the unintended ones, and the events are thus small in their significance, though not necessarily in scope. Over time, these choices and actions can accumulate in the unintended (or by later theoretical extension: intended) initiation of a reduction of the available scope of action for the actors involved. At the end of this first stage, there is a bifurcation point that the authors (following Collier & Collier 1991) term "critical juncture" (Schreyögg, Sydow & Koch 2003: 263) where it becomes deterministic to the degree that it diminishes the range of available options as perceived by the actors.

The second stage of the process after the critical juncture, the (path) formation phase, begins with a now more limited scope of action than at the start of the preformation phase. Most centrally, the second phase sees the development of at least one positive feedback or self-reinforcing mechanism (Sydow, Schreyögg & Koch 2009: 693) that reduces the likelihood or ability of actors to deviate from their previously chosen courses of action. David (1985) considered increasing returns to be the central self-reinforcing mechanism, because of its utility-increasing property. While this mechanism may exist, it alone is too restrictive a conceptualisation in an organisational context and there are frequently other self-reinforcing mechanisms at work (Sydow, Schreyögg & Koch 2009: 693), which I will discuss below. What remains important about positive feedback mechanisms, however, is their effect: they narrow down the available scope of action. This is the case in examples of increasing returns in which unit after unit attained makes attaining further such units easier. The logic remains the same for all other positive feedback mechanisms: over time and with more usage of an action or decision pattern, its use invariably becomes more attractive. The problematic aspect of this situation is that habituation of an action or decision pattern, together with high investments or start-up costs (ibid.: 694), means that the situation becomes increasingly irreversible.

This irreversibility becomes manifest if developments culminate in the third and final stage in the path-dependent process: the lock-in phase (ibid.: 694). This stage is marked by the emergence of a dominant choice or action pattern that is no longer questioned by the actors engaging in it; hence actors reinforce the pattern. This situation in itself would not necessarily be problematic if actors would indefinitely profit from this lock-in. Paradoxically, it may actually be actors' rational intention to enter this lock-in, because initially it promises higher benefits than potential problems. In addition, in the absence of external shocks such as economic or environmental change, problems may not necessarily occur, or may not occur for individual actors, but rather at a higher level of social aggregation such as organisations, interorganisational networks, clusters, regions, economies, or society at large (Schreyögg, Sydow & Koch 2003: 266). Moreover, this adverse situation may not necessarily exist at all points in time, rather it may offer short-term (individual) benefits (and thus fit in well with utility-maximising rationality arguments) but exhibit its problems only at the horizon of a long-term perspective (Sydow, Schreyögg & Koch 2009: 695).

However, external shocks are more or less inevitable and only a matter of time in a dynamic economic environment. Lock-ins prove problematic when actors find themselves bound to a single solution and stop recognising other available options which maybe more profitable/effective/efficient or even required for survival in the light of external shocks. However, because of sunk costs, high switching costs or managerial cognitive lock-in, deviations from the chosen course of action are increasingly eschewed. We can thus speak of a potential or arguable inefficiency in the case of path dependence lock-ins where future developments induce a "dysfunctional flip" (Sydow, Schreyögg & Koch 2009: 695). This signifies a further social context in which the emergence of structure has both an enabling as well as a constraining element, as similarly argued in the case of networks above.

This lock-in can go so far that a strategy develops around defending and sustaining this chosen pattern of action (Burgelman 2009: 233-248). The difficulty in the lock-in situation lies in actors' recognition of the pattern of action that drives it, because it inhabits a deep structure that is typically not readily accessible for reflection (Sydow, Schreyögg & Koch 2009: 695). A high intensity of actors' involvement often entails (escalating) commitment to known action or decision patterns, groupthink, fixed mental models, and emotional, strategic, or resource barriers to switching. These are factors that often go hand in hand with path dependence, despite also being, strictly speaking, alternative causal explanations (Sydow, Schreyögg & Koch 2009: 689-690; 696ff.). Figure 4, below, depicts the three-stage model of organisational path dependence.

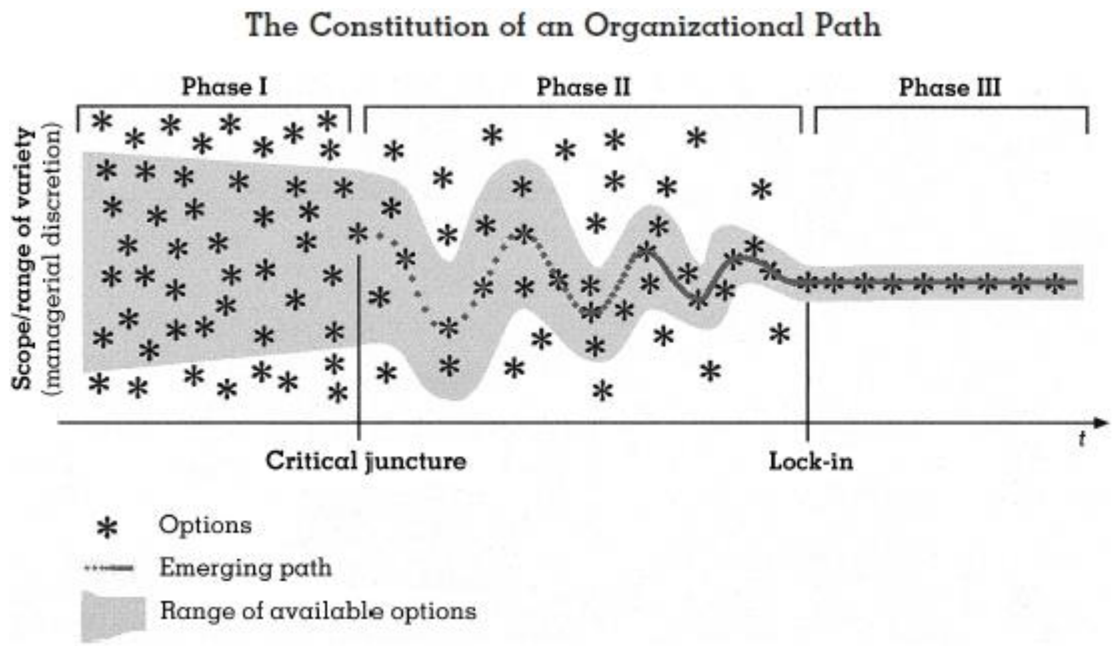

Figure 4: Berlin model of organisational path dependence (Sydow, Schreyögg & Koch 2009: 692)

In line with David (1985), Arthur (1989), and also Schreyögg, Sydow and Koch (2003), Sydow Schreyögg and Koch (2009), and Vergne and Durand (2010), I thus define path dependence as a stochastic process that unfolds in three stages and whose development is contingent (non-ergodic) and unpredictable during the preformation phase, where supposedly small events lead to a critical juncture and trigger a self-reinforcing dynamic that culminates, in the path formation phase, in a deterministic, inflexible lock-in to an (at least potentially) inefficient, ineffective, dysfunctional or otherwise adverse situation, choice, or mode of action that cannot easily be reversed.

2. 4. 4 Path dependence elements and interorganisational networks

These properties of path dependence are discussed below, and also applied to interorganisational networks, allowing us to identify the relevance of these properties and their significance for a study of path dependence in interorganisational networks.

2. 4. 4. 1. Small events

Small events are actions, decisions or other historical accidents (David 1985: 332) that essentially equate to the 'history matters' argument. They are perceived as small in hindsight, but they constitute something of a necessary condition without which path dependence could not exist (Schreyögg, Sydow & Koch 2003: 268). Small events are the triggers of a path-dependent process of developments and it is their sequence that defines the course of action over time. Initial small events add up to a critical juncture from which a positive feedback (or self-reinforcing) dynamic is triggered.

Page (2006) identifies a misunderstanding in the roots of path dependence. Accordingly, a theoretical misunderstanding leads to the conflation of chaos theory (sensitivity to initial conditions) with (early) path dependence (sensitivity to outcomes) that characterises a deterministic dynamic system in which the trajectory of its development is subject to strong influence from its initial conditions. Path dependence theory, in contrast, does not employ this deterministic tendency, but allows for early decisions and (small/random/or even intentional: Kay 2013: 1176) events to shift the probability of possible futures. The result, then, is a process that remains stochastic but is also biased, in varying degrees, to favour one possible future over another. This is more realistic than the chaos theoretical perspective of the physical world, because in the reality of the social world, 'everything is contingent' ("…aber auch anders möglich" Luhmann 1987: 152: "also possible in a different way," translated from German by the author). Path dependence, then, is exactly that, a social process, dependent on the developing path unfolding over time rather than merely dependent on initial conditions.

With regard to interorganisational networks, small events could be the entrance of new actors to a network, new relations that form (within it), new constellations of actors that emerge, or new network properties that arise, e.g. the centrality of an actor that becomes more prominent etc. The critical juncture with regard to the process could be a relation or network that becomes reinforced over a relatively short amount of time, or a particularly important actor or relation within a given network that becomes relevant for its overall development.

2. 4. 4. 2. Unpredictable development

It is an important property of a (potentially) path-dependent process that when it is analysed, it proves to be non-predictable from an external observer position at its outset (Arthur 1989: 118). If the long-term outcome is already foreseeable *ex ante* or at the beginning of the process, it can no longer be considered stochastic and therefore would be predictable. Furthermore, a fully predictable process would be deterministic from the start and, given the problematic nature of the lock-in, may well be avoidable, thus rendering the process not path-dependent in a stricter sense. Processes that are predicable would not display any puzzling lock-in outcome which would require a novel explanation. It follows that Arthur rightfully identified non-predictability as one of the defining properties of the path-dependent process. Upon further scrutiny, however, unpredictability can only play a role in the first stage of the process, because it is there that the situation is actually more or less open (Sydow, Schreyögg & Koch 2009: 691). As the process develops, a self-reinforcing dynamic exercises its constraining power as far as narrowing down the available options is concerned, and the outcome becomes more and more predictable, possibly culminating in the lock-in to a single option, making the situation fully deterministically-dependent on its past and predictable from that moment onwards.

The development of interorganisational networks is unpredictable insofar as, at the beginning of a process, it remains unclear to what extent relations, properties, constellations, or positions will remain stable, i.e. persist over lengthy periods of time. It is also not obvious whether a network will become locked-in or whether new entrants and exits of actors will occur and what effect these will have. Such developments cannot be predicted by theory, beyond any speculative (and probably overly reductionist) claim of a general continuance.

2. 4. 4. 3. Non-ergodicity

David (1985: 332) deemed path-dependent processes non-ergodic as early as the 1980s. In non-ergodic processes, not only are several outcomes of the process possible from the beginning of their sequences, but “history [also] selects among the different alternatives” (Sydow, Schreyögg & Koch 2009: 691). This implies that, conversely, different (minor) events can, with high probability, lead to the same outcome in ergodic, thus not path-dependent, processes (Arthur 1989: 118). In general, in non-ergodic processes it is the precise historical sequence of events that produces the outcome, not any other random order of other or identical events (Schreyögg, Sydow & Koch 2003: 251). Such a process may still be *past-dependent*, but not path-dependent in the sense that events build upon each other and are logically connected. In that sense, the non-ergodicity criterion occupies a middle ground between the process being deterministic and fully random or erratic (Ackermann 2001: 11; Schreyögg, Sydow & Koch 2003: 261). Small events, non-predictability, and the directly connected non-ergodicity can be summarised as the ‘history matters’ principle of path dependence theory. If the history of a development process does not matter, situations may be puzzling, but they are not path-dependent.

Interorganisational networks exhibit non-ergodicity *per se*. The process of networking is not fully deterministic. Relations once formed do not continue to exist for all eternity. Nor is the process erratic, because actors do typically *choose* their networking alters, at least to some degree, even if the network is managed by a network administrative organisation (NAO). Historical sequencing is also important: e.g. only by establishing a tie at a time t_0 can the then increased property of centrality of these actors influence a subsequent establishment of a relationship between the now more central actor and a new entrant at time t_1. In general, all network or actors’ properties that are influenced by network development can only follow a temporal logic where the property depends on the past and influences the future. Furthermore, new entrants, actor and network properties or constellations can only emerge or develop if they follow this temporal logic, since it cannot be assumed that all the actors which become locked-in are directly involved in co-producing the process leading to the lock-in.

2. 4. 4. 4. *Inflexibility and lock-in*

Certainly, the lock-in is one of the most conspicuous features of a path-dependent process (David 1985: 334). The lock-in was termed "inflexibility" by Arthur (1989: 118) and negatively defined: flexibility exists in a market situation if taxes or subsidies can encourage the market to favour one alternative; if it cannot, flexibility has become eliminated (Arthur 1989: 118). Lock-in is thus defined in terms of lack of flexibility arising after the critical juncture has occurred. The difficulty in analysing path-dependent processes sometimes lies in identifying this critical juncture, but the inflexibility is more clearly marked by the narrowing down of available options than by a complete disappearance of scope for alternative actions. Such a lock-in can be marked by a combination of managerial cognitive restrictions, resource-based, normative, political, and organisational lock-in (Sydow, Schreyögg & Koch 2009: 694). In organisational settings, a lock-in cannot be understood as fully deterministic as the early theorists posit for markets. Rather, it is important to conceive of it as a fixed mode of action or choice pattern that reinforces the lock-in (potentially without intention) but allows for some minor variation (Schreyögg & Sydow 2010: 8). It thus does not exert total rigidity, but a strongly narrowed-down degree of flexibility from which drastic deviation does not occur, only minimal variation in its reinforcement practice.

Lock-ins in an interorganisational network situation can and have been conceived of as relational lock-ins, network lock-ins and (sub-)group lock-ins. Relational lock-ins are chiefly portrayed as resource-based dependence on certain networking partners (e.g. Gulati, Nohria & Zaheer 2000: 203-204). This type of lock-in arises due to a developed or ex-ante existing dependence on a resource that this partner brings into the relationship, for instance. The more specific this resource is, the more severe this lock-in will be from a strategic point of view for the participant firms. (Sub-)group lock-ins occur at a higher level of social aggregation. (Sub-)groups are defined as the alliances, consortia or alliance blocks which develop around the creation of common standards or platforms in technology industries. If a (sub-)group offers a resource, market access, market power etc. upon which an actor or its members depend, this can cause (additional) relational lock-ins.

A further type of network lock-in can be the lock-in to a certain network position in the network's overall structure. A firm continually in the position of a structural hole broker between two otherwise unconnected networks may benefit from the information control advantages of this position. If, however, this firm would benefit more from being strongly connected in order to access a particular resource such as trust between network members, for instance, it would be a detrimental lock-in if networking practices, norms or other structurally reinforcing mechanism kept it in its place. The same could also be imagined in reverse: a firm connected in a dense network being unable to exploit its information advantage, because it cannot assume a brokerage position if there are no structural holes to fill or other firms occupy this position and defend their advantages.

Moreover, it is also possible that a firm can become locked-in to the overall network of which it is a member. However, since it is difficult, if not impossible to draw identifiable lines around network boundaries, such a position is hard to observe in practice. It is, however, theoretically possible in situations with clearly defined boundaries (e.g. in controlled environments, such as a computer simulation experiment) to identify whole network lock-ins, as in situation in which no exits or entries from the network (sub-)groups, or even networks relations at large, occur.

2. 4. 4. 5. Positive feedback mechanisms

An additional, if not the most important, *conditio sine qua non* for a process of path dependence is the existence of a positive feedback mechanism. Sydow, Schreyögg & Koch (2009: 698) place it at the heart of the path dependence explanation, because positive feedback mechanisms are a crucial part of what distinguishes path dependence theory from other related constructs. David introduced positive feedback mechanisms like the increasing returns regime (David 1985: 335) that drives the lock-in through "*technological interrelatedness, economies of scale*, and *quasi-irreversibility* of investments" (David 1989: 334, italics in original). Similarly, Arthur (1989: 121) argues that increasing returns is strictly necessary for the emergence of path dependence, but he fails to discuss any mechanism other than economic increasing returns. Arrow (2004) disputes the need for this to exist at market level, deeming the irreversibility of (capital) investments alone sufficient for the existence of path dependence (Arrow 2004: 28). While I disagree with such a path dependence definition that denies the necessity of a positive feedback mechanism, I agree with the notion that the increasing return logic is not the only social mechanism that can drive path dependence, and I maintain that "what is really required to sustain a path is a mechanism that decreases the relative attractiveness of alternatives" (Vergne & Durand 2010: 743). Therefore, I adopt Schreyögg, Sydow and Koch's (2003) understanding of a 'positive feedback' mechanism as a necessary ingredient for a path-dependent process (Sydow, Schreyögg & Koch 2009: 698).

Moreover, there is a subtle but crucial difference in the definition of increasing returns, self-reinforcing mechanism, and positive feedback mechanism. The increasing returns logic was borne out in studying the market level but is too limited when dealing with path dependence at the organisational and, more importantly, the interorganisational network level. Here, other mechanisms which can lead to path dependence also exist, which often work simultaneously or consecutively, because "in complex social systems, multiple positive feedback loops are always at work" (Vergne 2013: 1192). Therefore, I adopt the 'positive feedback' definition for such dynamics. An additional advantage of this definition for the study of organisational phenomena of path dependence is that it permits explanations that transcend the economic utility-oriented reasoning of strict increasing returns regimes (Schreyögg, Sydow & Koch 2003: 269). In this sense, increasing returns are a special case of positive feedback mechanisms, and *positive feedback* can be considered something of an umbrella term for all different forms (Schreyögg & Sydow 2010: 6). What remains a common feature of all cases of positive feedback is that the dynamics, be they economic, social, structural, emotional, or cognitive in nature, are necessarily self-referential and recursive, i.e. they are enhanced through adoption and increased adoption leads to more enhancement, also via further supportive decisions and potentially even other mechanisms that lead to even more adoption and enhancement overall (Schreyögg, Sydow & Koch 2003: 270).

The positive feedback naming also engenders a more active role of agency in the creation, existence and furtherance or facilitation of the dynamics than the increasing returns definition (David 1985; Arthur 1989), or the self-reinforcing alternative that seems to allow almost exclusively for mechanisms that develop fully without agent's actions and/or behind their backs (e.g. North 1990; Mahoney 2000; Pierson 2000). This is absolutely not to argue that self-reinforcement does not occur. On the contrary, part of the positive feedback dynamic typically becomes self-reinforcing, but primarily at the later stage in the dynamic, and even this may be intended by some of the actors involved.

However, by stressing the 'self'-reinforcement of the dynamic, such a definition could be understood as too restricted to allow for agency and too focused on the later stage of the process where the mechanism has become *self*-reinforcing. At the outset, a positive feedback process may not yet be *self*-reinforcing, instead being reinforced by agents, potentially even consciously and intentionally, e.g. in the case of learning (Schreyögg & Sydow 2010: 6-7). Over time, it can become *self*-reinforcing and even if this flip may be intended by agents. However, it still holds the potential for agents to lose control over the dynamic that they (think they) had at the beginning. Thereafter, the self-reinforcement takes over at an advanced stage in time, ruling over the influence that agents can exert on the dynamic – the dysfunctional flip that results in the lock-in. The strength of this extended 'positive feedback' conceptualisation is thus its focus on the social aspect of social mechanisms and the causal relations between actions, events, processes, and structurally restricting aspects, explicitly allowing for agency and not only an abstract, seemingly uninfluenceable, market-level mechanism.

In the following subsections, I review several different mechanisms that exhibit positive feedback and can thus cause a "dynamic [to]eventually flip[s] over into rigidity" (Sydow, Schreyögg & Koch 2009: 698). Accordingly (ibid.: 698-701), these are learning effects, complementarity, adaptive expectations, coordination effects, accumulation effects and lastly, self-reinforcement, and are then applied to interorganisational networks. These mechanisms are important because they can drive lock-ins at an (inter)organisational or strategic level. These mechanisms may occur independently, but can also work in combination, thus resulting in an arguably more severe lock-in than when active on their own.

A) Adaptive expectations

Adaptive expectation effects are based on individuals' (or organisations') perception-based expectation of what others will do or like (David 1985: 335; Arthur 1989: 123). This concept posits that, contrary to neo-classic economics, actors do not build fixed individual preferences, but rather make them dependent upon what they perceive or expect others will choose, because actors "wish to end up on the side of the winners" (Sydow, Schreyögg & Koch 2009: 700). Agents' need for basing their decision on what others are doing stems from insecurity, since they have no predictive knowledge of what the solution favoured by the majority will eventually be. Hence, they feel more secure in building preferences based on what others are likely to choose. The positive feedback in this mechanism stems from the logic of a self-fulfilling prophecy (Sydow, Schreyögg & Koch 2009: 700): the more people expect a particular solution to become dominant and behave accordingly, the more it becomes dominant. Examples can be found in the organisational context, in which expectations about others' (in)action can lead to organisational processes that anticipate such (in)action, complement it with incentives and thus produce and reinforce it (Schreyögg, Sydow & Koch 2003: 269). A further example is the situation in which early adopters or lead users can influence the decisions of innovation followers by making their choices at the beginning of a diffusion process (Meyer 2012: 86). As early adopters make their choices, diffusion followers may base their expectations on these choices of early adopters and build their preferences on these choices. At a higher level of abstraction, we then find "expectations of expectations" (Luhmann 1995, quoted in Sydow, Schreyögg & Koch 2009: 701) that are reinforced by the display of expectations through behaviour.

In interorganisational networks, while (adaptive) expectations about other's behaviour or preferences could in theory influence the networking relation choices and preferences of other actors, I am unaware of any study that has attempted to measure the expectations (with regard to networking) and their effects on networking. One applied example where expectations do play a role in interorganisational networks would be the frequently-observed strategic construction of industry consortia that seek to set (technological) standards, not only for their members, but beyond at market level. These consortia, alliances, or alliance blocks (e.g. Gomes-Casseres 1996; Vanhaverbeke & Noorderhaven 2001) are established by their members for the purpose of shaping internal (e.g. through cohesive network relations, related technological choices, shared mental models, norms etc.) and external (e.g. accumulated market power, innovative power, financial prowess etc.) expectations as to the winners of an alliance block competition and thus actively attempt to create a self-fulfilling prophecy.

B) Learning effects

David introduced the concept of learning effects early on (1985). In the context of technical interrelatedness, he writes of the acquisition of skills that constitute the software which needs to be compatible with the hardware of the QWERTY typewriter (1985: 334-335). With more precision, Sydow

Schreyögg and Koch (2009: 700) define learning effects as "the more often an operation is performed, the more efficiency will be gained with subsequent iterations." This increasing ease and quality of the performance, coupled with decreasing effort, can come to exert restrictive forces, because the way in which the operation is performed becomes more attractive over other options. Actors consequently engage primarily in exploitative learning rather than explorative learning, with the result that the exploitation drives out exploration in the mid- to long-term (Schreyögg & Sydow 2010: 7). The situation in which an organisation stops searching for alternatives 'outside the known box' and stops engaging in double-loop or deutero learning (Argyris & Schön 1996) becomes problematic when the incremental increases are no longer innovative or are rendered ineffective through external environmental changes. Leonard-Barton pointed out that even the perceived core competence of an organisation can experience a dysfunctional flip and turn into a "core-rigidity" (Leonard-Barton 1992: 111) that prevents a formerly innovative firm from developing further innovative products.

From the above review of interorganisational network studies, it has become apparent that learning theory is not only used frequently for studying interorganisational relations, but that learning is also a major motivating factor leading firms to partner with others. A situation in which learning effects become a driver of a path dependence lock-in can potentially occur when an interorganisational relationship exists mainly for the purpose of "co-exploitation" (Parmigiani & Rivera-Santos 2011: 1122). In this sense, a firm's absorptive capacity which targets the exploitation of learning effects may lead to a lock-in of that firm, because learning and absorptive capacity co-develop and can result in partner-specific or even network group-specific absorptive capacity (Cohen & Levinthal 1990; Lane & Lubatkin 1998).

Furthermore, learning races taking place in locked-in networks can become problematic, especially if one actor exploits the knowledge of others (Gulati, Nohria & Zaheer 2000: 211-212). Here, it is quite clear that this focus is intended by the partners involved and only turns into a dysfunctional mechanism when it drives out the necessary exploration and becomes a narrow, simplistic behavioural pattern that turns from success into failure (Sydow, Schreyögg & Koch 2009: 700). Additionally, with the growths of network or (sub-)group size, explorative learning and knowledge transfer become more difficult due to resource restrictions, and this may also exert a restrictive learning effect on participant firms (Barringer & Harrison 2000: 389).

Moreover, firms also learn from their past relations with certain partners or about partnering in general. When experiences accumulate from learning with one partner, from one type of relation or from one learned network management skill, it is likely that firms will exploit this knowledge and continue to engage in related behaviours. In this case, such a mechanism may limit individual firms' performance, increase their risk aversion and lead to network overembeddedness (Brass et al. 2004: 802).

C) Unit accumulation effects

While, strictly speaking, all positive feedback mechanisms concern the accumulation of certain properties of a system, under the present section, entitled 'unit accumulation effects', I summarise all effects that build on the accumulation of units, such as money. This type of positive feedback includes the classic supply-side economies of scale returns introduced by David (1985: 334). Economies of scale on the supply side of the market model refer to a situation in which the production of a certain product and/or service becomes cheaper as the output amount of this product and/or service increases (Ackermann 2001: 59-61). Increasing output amounts permit a distribution of the fixed production costs over an increasing unit volume, meaning that the fixed costs per output unit decrease proportionally with the increase in output. Together with learning and reduced wastage, economies of scale exert a strong self-reinforcing logic.

Capital and, with a negative sign, debt as the cornerstones of the present economic regime also display properties of positive feedback. An interest accruing to capital/debt, if not withdrawn, increases the capital/debt base on which the interest payment/demand for the subsequent period is calculated. Provided there is again no change in the amount of money saved or owed, this compounded interest can *ceteris paribus* exert a strong positive feedback effect on capital/debt. Over longer periods of time, the effect of compound interest can thus substantially increase capital or debt (Price 1772: 19) through "self-expanding growth" (Hudson 2000), rendering compound interest quintessentially a self-reinforcing mechanism.

Network effects or 'network externalities' are an accumulation effect explored above while discussing economics scholars' use of networks in their reasoning (cf. Section 2. 2. 2). Direct network effects refer to the effect exerted by a product's or service's user base size on the utility of existing and new users of that product or service. A prevalent example of direct network effects is the telephone system, in which the utility of all users rises with the addition of other users to the network. Indirect network effects are similar in their logic, except that not only the direct size of the user base matters, but rather the size of available complementary products or services and their user base. This case is discussed more in detail in the subsequent subsection on complementarity effects.

D) Complementarity effects

David used the term "*technical interrelatedness*" to describe the phenomenon of complementarity effects (David 1985: 334, italics in original). It refers to the situation in which one product or service is complemented by another product or service. One of the most typical examples of such instances is "economies of scope" (Sydow, Schreyögg & Koch 2009: 699). Economies of scope create synergies that allow firms to spread fixed costs over several products/services and enable piece cost reductions as a result, as opposed to spreading them over an increasing amount of a product's/service's unit output *per se*. In organisational settings, these complementarities may not only stem from synergies between products or services, but also from complementing resources, rules, incentives, or practices (Sydow, Schreyögg & Koch 2009: 699).

Indirect network effects (see Subsection C, above) exist when the size of a product's or service's user base is influenced by the size of the user base of a *complementary* product or service and thus necessarily works together with unit accumulation effects. A well-received example of this situation is the dependence of media players such as VHS, DVD, or Blu-ray players and recorders on the availability of compatible content and recording media (Liebowitz & Margolis 1995b: 218-222). The success of one of these is directly related to the success of the respective complementary other (Meyer 2012).

Complementarity effects are also a very strong driver for creating interorganisational networks, because firms often seek synergies through economies of scope when sharing the production or development of products or services with network partners (Zaheer, Gözübüyük & Milanov 2010: 65). The strongest driver for this behaviour seems to be sharing or pooling of resources when they complement each other and the intention to learn from one another (Barringer & Harrison 2000: 391). Relations can be used to establish the complementarity of products or services in the indirect network effects case. Then the networking between e.g. media player manufacturers and content media providers can be considered a relational manifestation of the complementarity of products/services.

In this sense, relations themselves can become complementary when a longer-standing relation to one partner, e.g. a supplier of important parts, creates a synergetic relation with a relation to one customer that relies upon a specific property of a product/service produced by the firm in the middle. Arguably, network situations of bridged structural holes (Burt 1992) could be considered to exploit such a complementarity of relations. Lastly, learned network management skills can become complementary to a firm's other skills, resources, or practices. Here, incentives may exist to further pursue a synergetic skill or resource combination, rather than exploring other options.

E) Coordination effects

Coordination effects are created through the emergence of rule-based behaviour, e.g. certain institutions that reduce transaction costs through the widespread adoption by agents (Sydow Schreyögg & Koch 2009: 699). Following the established rules makes social or economic interactions easier, less risky, and cheaper and thus allows for an improvement in actor's utility compared to a situation without the coordination rules. The adoption of such rules becomes more attractive the more agents adopt them. Coordination thus exhibits positive feedback when adoption increases in a manner analogous to economies of scale (ibid.). Vivid examples of coordination effects comprise the convention that coordinates the side of road where cars drive to reduce accidents (David 1994: 209), or the working time hours that have developed over time to allow for the smooth conducting of business within organisations, among organisations, and between companies and customers (Sydow Schreyögg & Koch 2009: 699). However, Ackermann (2001: 52-53) posits that coordination effects differ from the game-theoretic conceptualisation of coordinating prisoner's dilemma moves. They do, however, represent collective action problems, since the emergence of coordination rules cannot be attributed to the actions of individuals but must be attributed, instead, to collectives.

Coordination effects in interorganisational networks can develop through the interaction of actors and generate a so-called 'dominant logic' of interaction (Provan, Fish & Sydow 2007: 503). This can result in the norm-induced mimetic adoption of practices from network partners (Parmigiani & Riviera-Santos 2011: 1126). Coordination through social cognition can lead to groupthink, a group-based homogeneity of beliefs that, like dominant logic and shared practices, becomes reinforced through widespread adoption (Borgatti & Foster 2003: 998-999). Firms' reputation and interfirm trust that arise in interorganisational networks can have coordination effects, e.g. when they enforce rules such as reciprocity or other group norms (Gulati, Nohria & Zaheer 2000: 211). Their positive feedback stems from situations in which partnering with trustworthy others reduces transaction costs and repeatedly eases a future repetition of a relation (Grandori & Soda 1995: 198; Parmigiani & Riviera-Santos 2011: 1116-1117). In dense networks, normative control bears potentially negative consequences for a firm's control over its own resources and relations, particularly for larger firms (Gargiulo, Ertug & Galunic 2009: 326-331). Shared resources, joint structures (e.g. shared staff), centralised coordination structures (e.g. network administrative organisations), or aligned incentive systems can similarly exert the binding force of coordination effects (Grandori & Soda 1995).

F) Positive feedback in (interorganisational) networks

Some positive feedback effects in networks have already been described above as part of the other effects. Learning from partners and from partnering, direct and indirect network effects, complementary and synergetic relations, or coordination effects from norms and trust arising in interfirm interaction can exhibit positive feedback loops which increase the likelihood that the relations, exploitation of joint knowledge, synergies practices, norms, or other resources will be continued as opposed to discontinued and other options pursued. However, there are also positive feedback mechanisms unique to the network as an organisational form. One of these is network centrality.

Centrality is a measure of an actor's prominence in a network. The centrality of an actor is endogenous to network structure, i.e. it is affected by and affects the network: a firm's (high) centrality in t_0 signals its (high) attractiveness to networking partners since centrality is highly visible to alters. These potential partners are (typically) attracted or at least informed by this high visibility and tend to favour partnering with such a central actor. Centrality thus leads to more relations for that focal actor in t_1. These new relations then increase that actor's centrality in t_2. This potentially leads to a virtuous (or vicious) cycle of ever more relations for a central actor (Gulati 1998: 301). High network centrality may further be a property actively sought by companies whose business model depends on being widely known or well connected, i.e. high in-degree centrality in the network. Indeed, research at the ego level underlines that centrality (and thus implicitly network size) positively affects firm performance and its absorptive capacity (Zaheer, Gözübüyük & Milanov 2010: 66), providing the incentives to attain positive feedback as regards the property of centrality. Centrality as an explanatory mechanism for path dependence in interorganisational networks is limited, however, since it is a network actor property that exerts positive feedback, but fails to incorporate a relational perspective that can explain a lock-in to (sub-)groups.

Apart from centrality, social capital has been offered as a positive feedback mechanism that may explain path dependence in interorganisational networks (Walker, Kogut & Shan 1997). Its conceptualisation remains limited, as indicated above, due to missing an explicit dynamic beyond two time-steps. Moreover, the authors operationalised it as structural equivalence which may help explain actors' lock-in to certain network positions but cannot be used (without further modification) to explain the over-stability and potential lock-in of whole interorganisational networks based on developing stable (sub-)groups which is of interest in the present study. Social capital does, however, exhibit positive feedback effects much like the accumulation effects in monetary capital, an aspect helpful as regards the concept used for the purposes of this study. I develop and introduce this positive feedback mechanism of social capital in the next main section (Section 2. 5, below). Before that, however, the discussion of path dependence will be concluded with a discussion of two further important and disputed features.

2. 4. 4. 6. Questions of agency: strategy and inverted U-shaped curves

David (1985) and Arthur (1989) conceived of path dependence as revolving around the existence of increasing return regimes – an abstract economic property that requires no human action beyond simply following the path. Similarly, institutional scholars have argued that such patterns develop behind actors' backs and are 'self-reinforcing' (e.g. North 1990; Mahoney 2000; Pierson 2000). In fact, some critics of path dependence even diagnose a lack of "an explicated theory of agency" (Garud & Karnøe 2001: 7). The stressed 'self' of the mechanism together with the alleged lack of agency of the original conception leads some to ask where agency should be located, since it is a crucial element required by the methodological individualism of most OMS approaches. Indeed, one could also ask why actors would (willingly) engage in a practice or mechanism that potentially has problematic consequences. There are several answers to this question:

A) The Founders

David and Greenstein (1990) pointed out that even in the case of abstract increasing returns regimes, the existence of influential technology sponsors indicates strong elements of agency as displayed in the strategic behaviour of corporate actors (David & Greenstein 1990: 12-14). However, even the positive feedback definition, while allowing for an active level of agency in the creation, facilitation, existence, and furtherance of a positive feedback dynamic, still includes the dysfunctional flip that may be problematic for actors. One explanation for this is that the deciding agents are not fully rational (in the neo-classical economic sense) and, as such, they are “not concerned with whether the larger system that might (and was) being built around what they were doing would be optimized by their choice” (David 2000: 29). In this way, they can actively contribute to a developing positive feedback mechanism that at a later stage of development may become self-reinforcing. Foray (1997) concurs and reasons that decisions by actors “are accidental [only] in the sense that the decisions taken initially did not take into account the possible persistence and durability of the choices made before the introduction of some dynamic complementarities into the system” (Foray 1997: 746).

B) Garud and Karnøe’s Path Creation

An interesting perspective on the question of agency is the idea of path creation (Garud & Karnøe 2001; Garud, Kumaraswamy & Karnøe 2010: 760). Path creation is an extension of path dependence theory that integrates the fact that agents are often aware of the practices or mechanisms in which they are engaging. In this way, the historical accidents established by David (1985: 332) become less accidental, and more significant small events bearing the marks of significant strategic influence, but not unbounded strategic choice by entrepreneurs (Garud & Karnøe 2001: 2). The active creation of paths is a process described to require a step of a mindful deviation from a former mode of action (Garud & Karnøe 2001: 6). The process leading to the creation of a path is described as having several steps: a cultivated experimental breakthrough leads to a mobilisation of minds that is actively supported by so-called ‘boundary spanners’ which generate momentum for the new idea to take hold and initiate a virtuous cycle of a development trajectory over lengthy periods of time (Garud & Karnøe 2001: 12-22). One of the mechanisms employed in this mindful deviation is *bricolage*, a concept which refers to a novel recombination of resources. Furthermore, the idea of distributed embedded agency (borrowed from the literature on the social construction of technology) is used to explain how cumulative actions by different actors unite to exert their power of creating a virtuous path (Garud & Karnøe 2003: 278-281).

C) Assessment of path creation

While the creators of the path creation extension claim much novelty, the idea of distributed agency and strategic interaction are not new, as pointed out in subsection A on Founders above. The inventors of path dependence theory included the strategic activities of agents in the path-dependent process at the outset. In fact, the historical report on the original path dependence case about the development of the QWERTY keyboard not least included the strategic placement of all letters required for typing the word TYPEWRITER in the first row of the keyboard (David 1985: 333). While this decision certainly bears the characteristics of a small event in the sense outlined above, the engineered positions of keys are undeniably an instance of active agency. Moreover, the training of typists is undeniably a conscious choice of agents who knew they would gain typing speed advantages by training on the system. What these agents did not see (or perhaps did, but they wanted their system to dominate the market) was that a (potentially) better standard (DVORAK) existed but could not gain market dominance due to the strong learning effects and the interrelatedness of the skills learned with the hardware that forced the learning investments into an irreversible lock-in at market level.

In that sense, the involvement of many actors which ultimately lead to the lock-in were distributed agency, rather than coordinated. Taken together, the novelty of Garud and Karnøe's (2001; 2003; Garud, Kumaraswamy & Karnøe 2010) path creation extension lies not in the reintroduction of agency into path dependence theory, contrary to the authors' claim; agency was always part of path dependence. What they offer is an additional explanation and understanding of the process by which agents may intentionally bring about and stabilise positive feedback processes, i.e. mindfully deviating from former actions, making conscious choices that lead to the emergence of momentum through boundary spanning.

D) When virtuous cycles turn into vicious cycles

What Garud and Karnøe do not explain is the point in path genesis at which actors lose control over these dynamics and become locked-in unintentionally. In fact, they claim that path creation is an alternative that can avoid a lock-in altogether (Garud & Karnøe 2001: 7). They claim expertise only for the field of technology, but since they base their arguments on organisational practices, these must also hold up against criticism from organisational research. Such research, however, has found that actors tend to lose control over positive feedback cycles even if they believe they have succeeded in creating a beneficial dynamic at the start of the process (Sydow, Schreyögg & Koch 2009). What actors do not anticipate is the dysfunctional flip which occurs when the dynamics become limiting rather than enabling factors, even when the actors have profited from their existence for some time. As a prominent example, economies of scale are clearly virtuous. When, however, the exploitation of economies of scale gains more prominence than innovation – the activity by which firms survive (or not) in competition – then such exploitation patterns experience a dysfunctional and problematic turn. More generally, this point in time can be characterised by an inverted U-shaped curve.

At the beginning of the path-dependent process, the mechanism or dynamic can be intentionally created, supported, or facilitated by actors, since they initially (think they) profit from the same. Over time, however, the development of benefits from the process experiences a plateau – the lock-in – at which point benefits are reduced over time until problematic situations arise, and the formerly beneficial dynamic can become a liability. This is what happens behind the backs of actors mainly due to lack of (resources for) reflection or perhaps precisely because of the nature of distributed agency. In short, success turns into failure (Sydow, Schreyögg & Koch 2009: 700).

2. 4. 4. 7. Questions of (in)efficiency

The original definition of path dependence not only required the existence of historicity and a positive feedback mechanism ending in a lock-in. A further constitutive element of the definition was that lock-in was inefficient at market level (David 1985: 333; Arthur 1989: 121). In terms of the economic origins of path dependence, this inefficient lock-in is the particularly puzzling part of path dependence phenomena and also what lent the theory its explanatory power to describe why markets do not always achieve the best, i.e. efficient, outcomes, contrary to the claims of classical economics.

A) Criticism by Liebowitz and Margolis

Making inefficiency such an integral part of the theory has led to some criticism of path dependence. Most fervently, Liebowitz and Margolis (1990: 22) characterise path dependence (or 'excess inertia' as the terminology they adopt at first) as a particular type of market failure. They claim that the transaction cost economics framework can readily explain why a suboptimum standard may exhibit persisting market dominance in the face of better alternatives: the costs of communicating with other agents (1990: 4). Only because these costs are too high, agents cannot communicate to all others to make optimum decisions in situations of technical complementarity (ibid.: 2-3). However, since these suboptimum situations offer opportunities for entrepreneurs to exploit, the surviving standard must consequently be the "economically fittest" (ibid.: 5). Not only does this argument bear certain dangerous tendencies towards *post-hoc* reasoning or ideological arguments (Arthur 2013: 1187), it also provides no systematic understanding of why a suboptimum standard may persist. The authors then provide arguments suggesting that the Dvorak keyboard is actually not superior to QWERTY and claim path dependence to be built on a false and inaccurate empirical premise (ibid.: 23). Nevertheless, they concede that the QWERTY standard may, after all, not be "the fittest that can be imagined" (Liebowitz & Margolis 1990: 8), thus rendering their own argument vague or even entirely mistaken (Arthur 2013: 1187).

In a later paper, apart from rejecting all path dependence examples presented in the literature thus far, Liebowitz and Margolis (1995b: 224) further claim that the theory of path dependence is incomplete and restrictive as a model. They consider the theoretical implication of the inefficiency part of the theory and present three different degrees of path dependence based on the question of whether they are inefficient lock-ins and whether they could have been known in advance.

Accordingly, *first-degree* path dependence exists in the case in which initial conditions or decisions matter as far as the future of the dynamic process is concerned, but no inefficiency exists, since information is perfect and agents can incorporate all implications of their decision on long-term efficiency into their decision making (ibid.: 206-207). *Second-degree* path dependence exists when inefficiencies result from the dynamics which were not foreseeable in the beginning and could thus not be taken into consideration by the agents, i.e. agents make a costly error (ibid.: 207). This argument already marks a notable departure from the neo-classical model of economic actors which have perfect information at all times, even though Liebowitz and Margolis claim that only third-degree path dependence violates the neo-classical model (ibid.). *Third-degree* path dependence exists similarly when agents' errors lead to the inefficiency of the outcome and that this outcome is remediable, i.e. it was already avoidable at the beginning or later, but this better outcome is not achieved (ibid.). However, this outcome remains remediable if strategic or institutional rent-seeking actors are present who intervene, or if agents are willing to pay the 'upgrade price' to the better solution (Liebowitz & Margolis 1995b: 224). The two critics further maintain that their rejection of path dependence criticism revolves around the idea that indirect network effects are a rare case and that scholars lack rigour in their methodology and empirical reasoning for path dependence (Liebowitz & Margolis 1994).

B) Reflections on the inefficiency of the path dependence lock-in

It should first be noted that the critique by Liebowitz and Margolis was itself subject to strong criticism (Ackermann 2001: 81). Arguments against their rejection include they do not fully recognise the difference of path dependence compared to typical network effects models (David 2001: 23) and that they are seemingly obsessed with the inefficiency criterion and neglect other important properties of path dependence that are required explanations for the potential inefficiency (David 2007: 105). Furthermore, David (2007: 102) rejects the criticism that path dependence should automatically be equated with market failure. Similarly, Arthur (2013: 1187) stresses that "lock-in and optimality are separate issues."

A further distinction must be made insofar as the efficiency debate revolves around the Pareto-efficiency conceptualisation of market economics. The Berlin model of organisational path dependence (Sydow, Schreyögg & Koch 2009), however, offers a model of "[o]rganizational settings [that] cannot readily be equated with markets and monopoly" (ibid.: 694). Consequently, inefficiency is not necessarily the right criterion to determine whether or not a path dependence lock-in is problematic. Foray (1997: 742-744) considered that, even in the case of the market level, a lock-in would already be problematic if it is 'only' *potentially* inefficient. He advanced beyond Liebowitz and Margolis' critique of economic efficiency by identifying three sources of inefficiency: persistence of obsolete intentions (i.e. the difficulty of changing, due to sunk costs and the lack of coordination between actors); premature standardisation (premature rejection of better alternatives when early standardisation occurs, e.g. in cases of complementarity effects); and an excess of diversity (a lock-in that occurs while several options remain possible choices, but are rendered impossible by high switching costs among installed bases and isolated user groups (Foray 1997: 745-748). He argues further that "inefficiency not only derives from the persistence of obsolete intentions [..], but can also be generated by the fact that there is no guarantee that the intrinsically better technology is selected" (Foray 1997: 749). This argumentation is very much in line with that of organisational path dependence theorists.

These require the "strategic inefficiency" (Sydow et al. 2012: 159) of a chosen course of action or its "actual or potential inefficiency" (Schreyögg & Sydow 2010: 7). What remains important is that this lock-in, contrary to the market level monopoly situation, is not fully deterministic, but should instead be understood as a quite limited corridor of possible actions (Schreyögg, Sydow & Koch 2003: 272-273). A fully-deterministic understanding would be too restrictive for the social and organisational context, in which a certain degree of variation always remains possible (Schreyögg & Sydow 2010: 8). In contrast, organisational paths should be understood as restrictive, quasi-deterministic, deeply embedded, and as exhibiting a predominantly social influence (Sydow, Schreyögg & Koch 2009: 695). Whether the outcome is efficient or inefficient according to whichever of the many possible interpretations is considered to lie outside of the theory (ibid.). What remains is that positive feedback-driven lock-ins bias the potential and risk for a dysfunctional flip, reducing flexibility and can, because of its singularly focused action pattern, become problematic, e.g. in the event of external shocks or even when the action pattern becomes ineffective as far as achieving its original goal is concerned, but nonetheless remains embedded.

To answer the question of inefficiency, one would also have to answer the question regarding the point in time at which a lock-in becomes inefficient. The duration for this has not been clearly defined, but indications exist that inefficiency can also be interpreted as a "long run suboptimality" (Vergne & Durand 2010: 474-475). It is thus not a short-term phenomenon, but instead occurs over a lengthy period of time. Additionally, a path could be subject to path-breaking or dissolve if the positive feedback loop reinforcing it is discontinued (Sydow et al. 2012: 158). Whether scholars are looking at the right time horizon and at the right moment in time when identifying an organisational path dependence lock-in through path constitution analysis consequently remains open to discussion. There remains a certain risk that an identified lock-in is only of a temporary nature. However, given the Berlin model's focus on (self-reinforcing) positive feedback mechanism, it is arguably not (only) the lock-in that is the most important property, but also the feedback dynamics, since they may stay in place even if a lock-in is reduced to some extent.

A more pressing question with regard to the problematic nature of lock-ins is: for whom is it problematic or inefficient, and concerning what frame of reference? In the case of market-level path dependence where Pareto-efficiency is the determining answer, this may seem rather straightforward. For organisational path dependence, a view of the micro level is required. The social entity facing the problematic lock-in could be an individual organisation with strategic path dependence issues, people within that organisation that are affected by organisations' path-dependent practices, a group of connected firms that have stopped innovating yet continues cooperating, or an entire industry that is affected by a path-dependent reinforcement of a particular production or distribution system, for instance. All these levels are possible, and the frame of reference for establishing the problematic nature varies accordingly. In many cases, this frame of reference will be a more adequate practice/structure/process/allocation of resources/strategy etc. than currently employed. Since many actors involved and trapped in self-reinforcing path-dependent dynamics may not even recognise these alternatives themselves, the superior alternatives necessarily remain at an argumentative level that scholars must use in order to establish whether a process really exhibits this at least potentially problematic nature of the lock-in.

In conclusion, an important note that remains from Liebowitz and Margolis' criticism is the warning not to automatically claim the existence of path dependence for all empirical cases of positive feedback (Ackermann 2001: 79). However, inefficiency is not a constitutive feature of path dependence since a positive feedback-driven dynamic with historicity is already problematic when actors' (strategic) flexibility is reduced quasi-deterministically. Burgelman (2010: 233-248) and Breznitz (2010: 13-34) similarly warn scholars against applying path dependence to too many differing phenomena, a practice which runs the risk of conflating divergent arguments and creating confusion. Consequently, this not only weakens path dependence arguments themselves, but also creates a term, like a catch-all phrase, too general to offer substantial explanatory power and precision. In summary, "path dependence does not imply suboptimality, it *can* lead to it" (Vergne 2013: 1192, italics in original).

C) Dysfunctional flips in interorganisational networks

Knowledge and information sharing that increases with learning effects can also have downsides in dense networks where the learning effects exceeds levels that would allow for the protection of proprietary knowledge (Zaheer, Gözübüyük & Milanov 2010: 72). Furthermore, learning effects can make firms not only path-dependent but also paralyse their network actions when groups of learners are formed that become too closed for members to freely choose whom to cooperate with (Duysters & Lemmens 2003: 52). In these cases, the learning effect-driven focus on local search, the emerging trust, norms of reciprocity and social cohesion make investment into existing relations more likely than outside searches, decrease technological diversity and lead to homogenous information, behaviour, and beliefs.

Inertial forces emerge from a reduction of search efforts beyond the local domain, learning and innovation are impeded (ibid.: 55-57), cognitive processes create common mental models, and groupthink can lock actors into unproductive but stable network relationships (Zaheer & Soda 2009: 6). Furthermore, strategic inflexibility and (sub-)group dependence arises not only for the locked-in firm members but also for newcomers in terms of a lock-out of certain knowledge (Duysters & Lemmens

2003: 65). Moreover, when firms remain in a relation without continually checking for better outside options, such behaviour can prove problematic in the sense that success in relationships can breed failure, e.g. with regard to the performance of involved firms in the long run.

2.4.5 The missing link: a positive feedback mechanism in interorganisational networks

Sydow, Schreyögg and Koch's (2009) three-stage model for the analysis of path-dependence places particular emphasis on the study of positive feedback mechanisms, e.g. coordination effects, learning effects, complementary effects, and adaptive expectation effects. These are important, because they drive a path's trajectory from more or less small events towards lock-in at an organisational or strategic level. The strength of this conceptualisation is this focus on social mechanisms and causal relations between events, processes, and structural aspects.

With regard to interorganisational networks, however, such a mechanism (apart from those of learning, coordination and centrality as outlined above) has not been developed systematically. While several papers have pointed out situations of lock-in (e.g. Gargiulo & Benassi 2000; Hagedoorn & Frankfort 2008), describing mechanisms including resource allocation practices (Burger & Sydow 2014) or co-specialisation (Schmidt & Braun 2015), a more focused social-*structural* dynamic leading to a lock-in remains underexplored.

One suggestion for a such structural dynamic has indeed been made by Walker, Kogut and Shan (1997), who address persistency in interorganisational networks. In their paper, they argue that an interorganisational network development, where an existing network is reproduced over time, becomes path-dependent. They do not, however, make full use of path dependence theory. Compared to the three-stage model, they remain at a rather metaphoric level, mainly employing the 'history matters' argument. Their paper does, however, identify a social mechanism that they claim is responsible for path dependence in networks: social capital.

Although they find that the empirical phenomenon of network reproduction can be adequately explained using the theoretical construct of social capital, their understanding of the dynamics remains superficial, since the study employs a comparative static methodology rather than one that can trace the process unfolding over time. In consequence, these authors underutilise the concept of social capital. Furthermore, while their study can explain the reproduction of ties over two time points, it does not explain the extent to which (or if at all) social capital exhibits the positive feedback loops inherent in path dependence theory. Consequently, how far social capital can be understood as a positive feedback mechanism that drives the emergence of a path-dependent trajectory remains both unclear and undiscussed, beyond Walker, Kogut and Shan (1997) suggesting so.

2. 5 Social capital

"The concept is about the value of connections"
(Borgatti & Foster 2003: 993).

Social capital has been singled out as a candidate for a positive feedback mechanism that can explain the finding of interorganisational network research that firms become path-dependent within the network (groups) or positions (Walker, Kogut & Shan 1997). Social capital theory stems from the realm of sociology, and social network research in particular (Borgatti et al. 2009: 894). Despite, or perhaps precisely because of its present application across many academic disciplines, it is not a clear-cut concept (Adler & Kwon 2002). Social capital appears to share this situation with the concepts of networks and path dependence discussed above. Similarly, a clarification and recapitulation of the main four conceptualisations (and proponents) will serve here both to provide an understanding of the concept(s) and, more importantly, as a metaphorical expedition as regards what the concept has to offer as far as explaining path dependence in interorganisational networks is concerned.

2. 5. 1 Introduction to social capital

The coining of the term 'social capital' has been attributed to the American educator Hanifan (Aulinger 2005: 250; Iseke 2007: 33-34), but only became established as a scientific concept by the scholars Bourdieu, Putnam, Coleman, Burt, and to a lesser degree Granovetter. Most likely due to Putnam, who studied society at large and whose work had political ambitions and implications, the term has found a way into mainstream societal dialogue. On the way to 'success', however, the concept lost much of its scientific precision, not least due to "variability, contextuality, and conditionality" (Bankston & Zhou 2002: 286). Some scholars even see a "looming danger that the free flow of understanding, application and interpretation of social capital may soon reach a point where the term might be [..] rendered meaningless as a scientific concept" (Lin, Cook & Burt 2001: vii).

Nonetheless, social capital has become one of the 'big' theories in social networks scholarship that also find application in interorganisational network research (Borgatti & Foster 2003: 994). While the social capital in interorganisational networks depends on the existence of networks, networks and social capital <u>cannot</u> readily be considered the same thing (Todeva & Knoke 2002: 349). Since its several different notions and interpretations are to some extent rather incompatible, we need to clarify what is meant by this concept. What holds for all interpretations is that, at an abstract level, social capital serves as a term to identify the value of social connections (Borgatti & Foster 2003: 993). This positive connotation of the social world as 'capital' is not unproblematic, since capital also has a flip side denoted as 'debt'. This aspect plays a role in Bourdieu's conceptualisation of social capital, which is the first of four to be reviewed below. Following his and Putnam's, I then focus on two conceptualisations most useful for the present purpose, namely social capital as brokerage and social capital as network closure, and discuss their application in OMS, their issues and criticism.

2. 5. 2 Broader social capital conceptualisations

Social capital can generally be understood as a metaphor for the value of social structures such as connections and networks (Riemer 2005: 58). However, two of the prominent theories chosen as a focus here are more network-structurally formalised in their reasoning and thus more applicable when answering the present research question. The first two conceptualisations abstract more strongly from network structure (but not from social structure) and are briefly presented here for the sake of completeness, differentiation, and overall understanding of the social capital debate.

2. 5. 2. 1. Convertible social capital (Bordieu)

Bourdieu engages in a broader macro-sociological or even philosophical debate in political economy about the forms, nature and properties of capital and capitalism theory. This debate was originally initiated by the German philosopher Karl Marx (1867) and continued by the American economist Gary S. Becker (1964; 1993; cf. also Lin 2001: 4-6) and is currently experiencing a strong revival (Piketty 2014). As such, Bourdieu's aim in this debate is quite abstract and he targets less of a formal definition than a philosophical foundation. In the tradition of this debate, it comes as no surprise that he defines that generally "Kapital ist akkumulierte Arbeit" (Bourdieu 1983: 183) – "Capital is accumulated labor" (Bourdieu 1986: 241).

Social capital, then, exists as a form of capital (Bourdieu 1983: 185; 1986: 243) next to economic capital – capital in the form of property rights, for instance, that readily converts into money, (Bourdieu 1983: 185; 1986: 243) – and cultural capital which akin to Becker's (1964) human capital concept represents the time and effort invested in self-improvement, this frequently measured in institutionalised educational certificates which can yield its own (economic) returns (Bourdieu 1983: 185-190; 1986: 244-248).

Social capital abstractly consists primarily of social obligations (Bourdieu 1983: 185; 1986: 243). More specifically, it is constituted by the "actual or potential resources which are linked to possession of a durable network of […] relationships […] or in other words to membership in a group" (Bourdieu 1983: 190-191; 1986: 248). Following this definition, social capital accrues to an actor if they can access, mobilise, or otherwise make use of obliging social connections. In this sense, an actor's social capital is constituted by the social debts (obligations) other people have with that actor. As long as social capital is maintained in symbolic and/or material transactions, the social capital that actors have available depends primarily on the size of their network (Bourdieu 1983: 191; 1986: 249). Since group membership is the defining criterion for an agent's access to the social capital, group entry and the delegation of group representation to one agent are the two most strongly contested aspects of Bourdieu's social capital (1983: 192-193; 1986: 250-251).

The practices of maintaining the borders of the group and continuity in the relational work of agents ensure the reproduction of social capital for all group members (1983: 193; 1986: 250). Groups typically acquire names for their group in order to signal the social capital available to the outside world and provide internal and external identification for members (1983: 193-194; 1986: 252). The possession of social capital is not only closely related to economic and cultural capital. It can also be converted into cultural or more typically economic capital at certain conversion costs in transformational effort (1983: 195-198; 1986: 252-255). Furthermore, some kinds of profits, goods and services may only be attainable on condition that the social capital has received investments of sociability for long periods of time in good faith. This means that investing agents have no means of guarantee or contract providing some kind of return, but rather a sense of "nonspecific indebtedness" (1986: 252).

Bourdieu's abstract definition is relevant insofar as it outlines properties for social capital. It exhibits features of economic capital with a form of interest or return accruing to the member agents. Moreover, it allows a form of ownership or at least appropriability by individual agents that establishes access to certain resources, goods, services, or other returns that are subject to membership of a group providing a sense of identification for its members. Social capital thus exists at the individual level of agents, but only comes about due to the meso-level group of social connections of individuals. Thus, regarding social (network) structure, groups are an important focus for the analysis of Bourdieu's social capital conceptualisation since it is there that social capital accrues to individuals.

2. 5. 2. 2. Social capital as a societal property (Putnam)

In "Bowling Alone" (1995; 2000) – politically speaking a rather controversial work – Putnam portrays a decline which took place in US civic society. In Putnam's understanding, social capital is the basis for explaining this decline. His book can be deemed politically motivated and has normative ambitions with regard to societal solidarity (Godechot & Mariot 2003: 5). At the beginning of the book, Putnam introduces a conceptualisation of social capital that is rather different to Bourdieu's. While Putnam's debate is targeted at the macro-sociological level like Bourdieu's, his conceptualisation of social capital, in contrast, is too.

In the first chapter of his book, he posits that "the core idea of social capital theory is that social networks have value [… and] affect the productivity of individuals and groups" (Putnam 2000: 18-19). This productivity of individuals can provide "civic virtue" (ibid.) and is in turn based upon the norms of reciprocity and trust which Putnam claims are highest in densely connected societies and low in looser societies with more isolated individuals. Social capital, then, is described as simultaneously a public and private good in the sense of specific and generalised reciprocity (ibid.: 20), and more importantly, generalised trustworthiness (ibid.: 21).

Putnam considers social capital the 'social lubricant' that is drawn from mutual trust and reciprocity in social relations (ibid.: 21). He further distinguishes two dimensions of social capital as bonding (exclusive, or inward-oriented), and social capital as bridging (inclusive, or outward-oriented) (ibid.: 22-23). This distinction appears somewhat blurred, with the exclusive form drawing more on specific reciprocity, and inclusive social capital drawing more on generalised reciprocity and on information diffusion of the type famously identified by Granovetter (1973; 1974). Overall, social capital according to Putnam's definition is a property of (American) society that aims to explain the functioning of community in the civic society or lack/decline thereof. Rather than an individual's resource (as in Bourdieu's definition), social capital's benefits are generally available to all members of a society that has social capital, although some may be disconnected from direct access to its benefits, e.g. due to network structure.

It remains that, in Putnam's terms, "social capital is to some extent merely new language for a very old debate in American intellectual circles" (Putnam 2000: 24). Yet these conceptualisations of a 'sense of community' are frequently drawn on in the study of a plethora of issues that deem social capital synonymous with a productive functioning of civic society. Examples include public health discussions (e.g. Poortinga 2005), education (e.g. Kim & Schneider 2005), community studies in behavioural studies that rely on complex measurement (e.g. Onyx & Bullen 2000), the economic development of countries (e.g. Francois & Zabojnik 2005)[13], and organisational research on identity (e.g. Davenport & Daellenbach 2010).

2. 5. 3 Network structure-driven social capital conceptualisations

The two social capital conceptualisations by Burt and Coleman are more structural in that they explicitly draw their conceptualisations from the structural properties of networks and network positions, rather than just their general existence.

2. 5. 3. 1 Social capital as structural brokerage (Burt)

Like Bordieu, Burt's conceptualisation of social capital focuses on the individual, but without the necessity for a reference group as Bourdieu conceptualises. In this way, Burt's concept is rather different from Putnam's and also from Bourdieu's since he argues strictly at the micro-sociological level

[13] Sobel (2002), for example, analyses the potential virtues of Putnam's social capital definition for economic research.

of the individual and their immediate relations. Burt is also the only scholar who directed his definition of social capital and the research on it directly at an OMS audience of scholars, whereas the other conceptualisations have been used in OMS but did not originate there.

Burt (1992; 2001; 2005) introduces the definition of social capital as brokerage. Accordingly, social capital accrues to an actor who is in the structural position to connect ('broker') between otherwise isolated actors or groups within a network or market (2005: 11-18). Furthermore, "social capital is a function of brokerage opportunities in a network" (Burt 1997: 340), i.e. it draws its value from these opportunities. In this way, Burt acknowledges that social capital from brokerage depends on the existence of ties with other individuals (1992: 9), because a focal actor has relationships with at least two other social entities which have no other direct connection between themselves. This structural situation is called a 'structural hole' because it denotes the position of the connecting actor, which, if empty, would leave a hole in the potential connections of the network. The ability of an actor to bridge this hole allows them to exploit the brokerage potential arising from this position. Doing so leads to a competitive advantage for the broker relative to others and makes social capital just as important as financial or human capital (1992: 10). The advantage of social capital stems from having some degree of control over the flow of information, resources or cost reduction benefits through the information gained in the bridging process (Burt 2001: 4-7).

While the resulting network "bridges are a by-product of pursuing other ends" (Burt 2005: 28), incentives exist for a broker, e.g. estate agents, investment banks or head-hunters, to keep the two parties they connect essentially separated, since this allows them to capitalise on their (information) advantage or rather on the structural (information) disadvantages of the two otherwise unconnected actors (Burt, Hoghart & Michaud 2000: 124). Brokerage can thus form a type of business strategy that revolves around the recognition, exploitation, and maintenance of the structural hole situation.

At its core, then, Burt's social capital "is a metaphor about advantage" (Burt 2000: 346-347). Moreover, it accrues to a focal individual for the exact opposite reason to Putnam's or Coleman's conceptualisation (with the latter discussed below): it exists because others do not have access to it, but depend on the bridging individual for certain social transactions. In this sense, bridging and the related advantages are similar to power arguments, albeit power drawn from (the lack of) social connections rather than from financial, political, or human capital and it is exercised through control (Burt 1997: 342). Burt's social capital is thus of an exclusive nature and can only accrue to a lucky few, rather than benefit an entire group with the exception of permitting connections between the otherwise unconnected actors. Moreover, this potentially advantageous situation is precarious since it depends on the other parties not being otherwise connected. If they connect directly without the brokering agent's involvement, this broker's advantage ceases to exist.

Burt later (2005) extends his definition of social capital to include the type stemming from the network closure (drawing on the definition introduced by his mentor Coleman earlier – see below). Burt defines it as "closed networks [..] create advantage by decreasing risk that would otherwise inhibit trust" (Burt 2005: 95). Thus, he introduces relational risk as a factor in the consideration of social capital to the extent that alleviating risk of trusting another actor is the main function of this social capital from closure (ibid.: 108-9). Like brokerage, social capital from closure accrues to the individual in the form of reputation within a (sufficiently) closed network and "where that trust is an advantage, closure is social capital" (Burt 2005: 109). This part of the definition is problematic in the sense that it makes social capital's advantageousness a criterion for its existence, thereby neglecting a 'dark side' of social capital such as social debts, or the potential downsides of being strongly monitored by other network members.

It follows that his measure for the strength of social capital from closure constitutes the degree of connectedness, as "the more closed the network, the more likely that misbehaviour will be detected and punished" (Burt 2005: 97). This definition exhibits a deterrence-based trust/reputation mechanism much in line with the research on interorganisational networks (see Gulati 1998: 303; Gulati, Nohria & Zaheer 2000: 210.; Brass et al. 2004: 802; Zaheer, Gözübüyük & Milanov 2010: 65). Burt also discusses the potential pitfalls of such closed networks becoming (overly) stable, e.g. the decay of stable relations over time, the building reputation mechanism leading to a re-enforcement of the status quo and resulting in echo chambers of "ignorant certainty" (Burt 2005: 197-222).

2. 5. 3. 2. Social capital as structural closure (Coleman, Burt)

Coleman laid the foundations of his social capital conceptualisation in a study of economic sociology in which he claims that social capital can explain differences in educational attainment, i.e. human capital (1988). There he argues, similar to Bourdieu, that these two are closely related. He later introduces social capital as a counterpoint to the "fiction [..] that society consists of a set of independent individuals [.. as] expressed in the economic theory of perfect competition in a market" (Coleman 1990: 300). Using this contextualisation, Coleman connects his debate to those of (economic) philosophers Thomas Hobbes (1651), Adam Smith (1776), and Albert Hirschman (1977), and criticises the invisible hand approach of classic economic theory.

Incorporating the connected ideas of Granovetter (1985), Lin (1982) and De Graaf and Flap (1988) in the field of weak ties research, as well as Bourdieu's notion of convertibility of capital types, Coleman first embraces a view that, not dissimilar to Putnam (2000), considers social capital a boundedly-fungible set of entities that facilitate certain (social) actions and is embedded in the connections of actors within a social structure rather than in individuals (Coleman 1990: 302-304). After stressing the difference between physical, human, and social capital's forms of embodiment, levels of abstraction and complementarities (ibid.: 394), Coleman defines social capital as: "The function identified by the concept 'social capital' is the value of those aspects of social structure to actors, as resources that can be used by the actors to realize their interests" (Coleman 1990: 305).

At first glance, this definition appears to be similar to the conceptualisation of Bourdieu. Coleman elaborates that social capital is based upon a system of generalised trustworthiness that social obligations will be repaid in the future (Coleman 1990: 306-7). This theorisation is in turn based upon the general theory of social exchange that Coleman lays out in the first chapters of his book (1990: 119ff.) and in that he differs strongly from the much more abstract definitions of Bourdieu (and also from that of Putnam). On the contrary, Coleman rejects the private appropriability of social capital: "As an attribute of the social structure in which a person is embedded, social capital is not the private property of any of the persons who benefit from it" (Coleman 1990: 315). In this way, Coleman's and Bourdieu's approaches differ with regard to their meanings and their epistemological bases but share the aspect that they are often applied in research without much context (Coradini 2010).

Coleman then identifies several sources, or rather forms, of social capital: *obligations and expectations* when doing favours to others can work as a kind of social insurance (Coleman 1990: 310); *information potential* from using social contacts as knowledge resources (ibid.); *norms and sanctions* when groups reward actions in the interest of the collective rather than those in favour of individuals (Coleman 1990: 311). He also immediately points out the constraining function of this form of social capital in that it limits individuals' pursuit of individual interests (ibid.). Given that this is a rather contradictory property when considering his definition as social capital being useful for pursuing actors' interests (1991: 305), Coleman underlines the two-sided coin of social capital. Another form of social capital stems from *relations of authority* where an actor has been endowed with certain rights of control over others to alleviate free rider problems, for instance; *appropriable social organisation* where the creators of voluntary social organisations further their creators interests, although it is often dissolved into the other forms mentioned; *intentional organisation* creates social capital when social groups are created for the purpose of producing social capital, this contrasting somewhat with the typical case in which social capital arises from actors' pursuance of other goals (Coleman 1990: 313).

Coleman's manifold forms of social capital have been criticised as less precise than others (Wald 2011: 102), for making "heroic assumptions" (Matiaske 1999: 174), and for being abstract and requiring further specification for empirical measurement (Iseke 2007: 40) in the sense that he does not deliver the necessary theoretical clarity on the forms of social capital (Aulinger 2005: 266). Some of the assumptions are indeed not unproblematic, e.g. since Coleman follows a more or less rational actor model, as in the neo-classical economic theory, he himself criticises. The level of abstraction and some other assumptions are explained at length in Coleman's broader social theory through social exchanges that differ from economic exchanges by lacking a concrete exchange token such as money, for example. The empirical measurement of most theory-derived parameters involves an operationalisation step to turn them into variables, and this does not seem to be unique for Coleman's theory.

The criticised clarification and diversity of social capital forms can be explained when re-considering Coleman's definition as outlined above. These forms are the types of resources that become available through membership of these social networks and the given (empirical) context. On the contrary, then, Coleman should be congratulated for offering a more inclusive set of theoretical parameters which share the common denominator that they are all resources accruing to actors as a result of participation in a network. In this way, almost all nuances present in the above theorists' conceptualisations can be encapsulated by Coleman's model of social capital, with the exception of Burt's individualistic view on structural holes.

In a manner similar to Putnam's conceptualisation, Coleman further argues that social capital has the properties of a public good, because these properties are available to all members of a social structure that enforces norms and sanctions internally rather than only to the individuals that bring these structures about (Coleman 1990: 316). However, Coleman's definition becomes much more focused on and specific regarding social structure than either Bourdieu or Putnam. He posits that the closure of networks is a prerequisite for the emergence of social capital of all the above forms. Moreover, they profit from and can best be maintained when network closure among members is high or increases over time (Coleman 1990: 318). Closure of a network can be understood as high density in the network (Burt 2001: 37; Riemer 2005: 107) because it relies on the ability of actors to enforce norms of desirable behaviour through sanctions, and this is most effective when many actors in a network are connected (Coleman 1990: 275-276), again drawing on a deterrence-based mechanism like his student Burt (2005). Consequently, the more actors are connected within a network, the more can they enforce norms of desirable behaviour. While this abstract resource is the social capital described above, the structural property of a closed network can be considered a high structural density. In Section 2. 1. 3, density was defined as the number of established links among actors divided by the number of all possible links within a given network. Hence, according to Coleman's argument, the more this term approaches the value of 1, the more social capital should be available to the members of that network or connected actor group. In this reasoning, he explicitly includes the closure of systems of organisations such as firms where e.g. the closure of a network of suppliers to one company can lead to the emergence of valuable social capital and also to the problematic collusion of interests (Coleman 1990: 320). This shows that Coleman does not naively point towards the benefits of closure, but that he also already considers the possibility that problematic "inflationary or deflationary spirals in the placement of trust" (Coleman 1990: 318) may emerge in closed networks.

Three further properties are relevant to the maintenance of social capital among network members: *stability of social structure*, since the benefits of social capital arise from its close network structure, the more temporary the network relations or membership of agents and the more often disruptions occur to structure, the more difficult the repayment of obligations and thus the less incentives to network in the first place (Coleman 1990: 320). Moreover, frequent interaction such as communication appears necessary for maintaining the relations that carry the social capital since it depreciates when the relations die out (Coleman 1990: 321); *ideology* in the sense that a strongly connected group becomes cohesive with regard to its values and norms and alienation can thus be detected at an early stage (Coleman 1990: 321); and the *absence of overly resource wealthy* ("affluent") members of the network, since it makes them less dependent on the fulfilment of obligations from and for members of the network and would allow them to free-ride. Vast differences in the dependence of network members on the network would thus appear to reduce a network's social capital. As a result, a structurally overly well-connected actor in a group could potentially weaken the social capital available to the entire group of network members.

Overall, Coleman's main argument is that social capital exists for all actors that are members of a network with many internal relationships. Particularly high closure in a network generates high network density that leads to the internal cohesion of a network and can serve as a structural measurement tool. Connections between, at best, all members of a group should lead to the strongest social capital available to members. Questions remain regarding the issue of how closure emerges or is produced and maintained. Conceptual ideas to address this issue are described below when a more process perspective on social capital is discussed (Section 2. 6. 1).

In sum, the four extant social capital conceptualisations can be broadly categorised along the dimensions of appropriability and structural foundation as follows:

Social capital Categories		**Ownership / Appropriability**	
		Individual	*Group*
Structural orientation	*Structural*	Burt	Coleman
	Non-structural	Bourdieu	Putnam

Table 7: Four major social capital conceptualisations

2. 5. 4 (Other) Social capital conceptualisations in OMS

OMS research that incorporates social capital arguments often utilises parts of one or sometimes several of the above conceptualisations. In general, OMS research is marked by a lack of a common understanding of social capital. Examples of (re-)interpretations include extending conceptualisations such as Nahapiet and Goshal (1998), empirical interpretations, e.g. Maurer and Ebers (2006), as well as a wholly integrative attempt by Adler & Kwon (2002), and a structure-based specification (Lin 2005).

Nahapiet and Goshal (1998) characterise social capital as "the sum of the actual and potential resources embedded within, available through, and derived from the network of relationships possessed by an individual or social unit. Social capital thus comprises both the network and the assets that may be mobilized" (Nahapiet & Goshal 1998: 243). This definition attempts to integrate the conceptualisations of Burt and Bourdieu, in which both the network itself and the resources in it count as resources for a member actor. Nahapiet and Goshal further introduce three dimensions of social capital: the structural, the relational and the cognitive, while conceding that these are highly interrelated and hence difficult to separate analytically (Nahapiet & Goshal 1998: 243). The structural dimension refers to the (empirical) network structure pattern, configuration or morphology, and properties such as density (Nahapiet & Goshal 1998: 244). The relational dimension comprises the properties of (typically) interpersonal ties that include emotional attachment and bonding through trust, trustworthiness, norms, obligations, and expectations (ibid.). The cognitive dimension includes shared languages and codes that develop within the relations (ibid.). Among these three dimensions, however, structure is the one that reflects and provides the foundation for the other dimensions (Wald 2011: 114).

In their empirical study of biotechnology start-up companies, Maurer and Ebers stress social capital's resource aspect in an almost Bourdieu-like manner as "an asset available to individual or collective actors that draws on these actors' positions in a social network and/or the content of these actors' social relations" (Maurer & Ebers 2006: 262). They find that closure and brokerage can work simultaneously, but at different levels of analysis, and that they can profoundly influence both firm's adaptability and the three levels of social capital (Maurer & Ebers 2006: 288-289). Similarly, Biedermann (2007) embraces the three dimensions and points out that social capital can be active at several interacting levels of analysis including the individual and companies (ibid.: 26) and stresses the co-evolutionary nature of these (ibid.: 44).

Adler and Kwon (2002) seek to integrate a social capital conceptualisation that crosses disciplines and encompasses many aspects of the above conceptualisations (2002: 18). After a solid review of the extant literature, they offer a working definition of social capital as "the goodwill available to individuals or groups. Its source lies in the structure and content of the actor's social relations. Its effects flow from the information, influence, and solidarity it makes available to the actor" (2002: 23). This conceptualisation attempts to integrate both the collective and individual appropriability and the three dimensions as introduced by Nahapiet and Goshal (1998). However, this conceptualisation comes at the cost of integrating network structure less firmly since it essentially considers social structure as a source of other resources, but not the structure as a resource itself as well (see also Aulinger 2005: 284).

By contrast, Lin (2005) theorises a more network-oriented view of social capital. Defining the latter as "resources embedded in a social structure which are accessed and/or mobilized in purposive actions" (Lin 2005: 12), Lin emphasises social structure, individuals' ability to access resources embedded in the same and the prerequisite of purposeful behaviour in order to reap the benefits of these resources (ibid.). This view highlights the fact that network structure and positions within the social structure constitute a key element in identifying social capital (Lin 2005: 13). While Lin claims that

Coleman's definition of social capital via its effects is tautological (2005: 9), Lin cannot fully circumvent this self-referential and inductive nature of network relations himself when he argues that the utility of e.g. a network bridge partly defines the success of an individual's action and thus social capital available from an ego-network's relations (2001: 13). Nevertheless, Lin and his colleagues Fu and Hsung (2001: 57ff.) also suggest a measurement device for social capital with their 'position generator' – a tool that unfortunately only serves to identify the social capital of individuals and cannot readily be applied to organisations, other than that they might themselves be a source of social capital for agents within.

The notion of an organisation's social capital can be integrated within the social conceptualisation of Nahapiet and Goshal (1998), Adler and Kwon (2002), and Maurer and Ebers (2006) more meaningfully. However, Lin's (2001: 14) focus on certain network positions and structures which form part of the resources that constitute social capital is very important, since it explicitly considers the network measurement concepts of structural holes, closure, tie intensity, density, size, closeness, eigenvector etc. as part of the resources that become available to the individuals and group participants in a respective network (Lin 2001: 14-15). In this way, Lin integrates network structure and positional properties more thoroughly than the other conceptualisations.

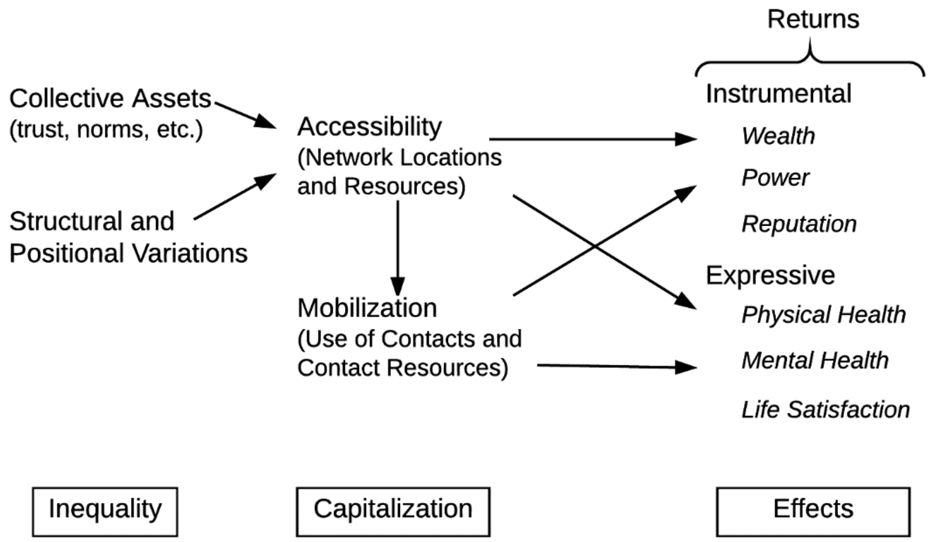

Figure 5: Social capital according to Lin (1999: 41, Fig. 1).

As indicated earlier (Subsection 2. 3. 4. 5.C), in their review of different network mechanisms in (inter-)organisational research, Borgatti and Foster (2003: 993-994) define social capital quite generally as referring to the value of an ego's network connections or an ego's position among its alters and the resulting power structures. They divide social capital into two mechanism categories 'structuralist' and 'connectionist' (i.e. focusing on structural topology or the resource-flow content of relations). Together with their typology of the explanatory goals 'performance' and 'homogeneity' (e.g. the dis-/advantages of social capital or the diffusion of ideas that changes actors) this leads to the four typologies of research on network consequences, namely 'structural capital', 'resource access', 'convergence' and 'contagion' (see Table 3 above; Borgatti & Foster 2003: 1004). Structural capital research is concerned with actors' positions and their dis-/advantages from the same, their strategic way of dealing with these and the resulting outcomes. (Social) resource access studies analyse the resource flows in networks, whereas convergence and contagion studies deal with the dissemination of ideas, norms, and beliefs, but focus their attention on actors either being shaped by their network environment or through the direct interaction with others (Borgatti & Foster 2003: 1004).

Zaheer, Gözübüyük and Milanov (2010: 67) define social capital in three ways: as the benefits an actor can gain from information, timing or control advantages through brokering between (at least) two others (structural holes); or conversely, as closure measured in the density of an ego network that increases trust and thus cooperation and knowledge sharing within the network (closure); and as the extent to which actors have identical ties or identically structured ties (structural equivalence). According to Provan, Fish and Sydow (2007: 503), the structural holes and closure should not be seen as conflicting, but rather as complementary (an argument similar to Burt's) and that reputation allows reputable actors to exercise a level of control over the development of the network, even without direct control over resources. Others have conceptualised hybrid forms of social capital relying on both cohesive local groups with advantages of closure and brokers that bridge those groups (Baum, Rowley & Van Liere 2006). Empirically, they found that in such small-world networks, closure can more readily substitute for brokers' connections than vice versa and that hybrid constellations outperform more puristic ones (ibid.: 23-24).

2. 5. 5 Ambiguity in the findings on social capital

While social capital has typically been used to denote something positive (hence the coining of the term 'capital'), some recent research has also considered potential negative effects of social capital which may relate to the general discussion on its ability to drive path dependence in interorganisational networks, which is the objective of this research.

Positive consequences of social capital are typically considered to arise from the Colemanian argumentation of reputation and peer control resulting from closure. Such closure can lead to positive incentives for creating more closure (e.g. Zaheer, Gözübüyük & Milanov 2010). Similarly, Biedermann (2007) stresses social capital's ability to offer access to resources such as information, knowledge, know-how, and sales channels (2007: 1) as well as to exert influence and control over others and produce positive cooperative benefits (2007: 48-50).

From a Burtian perspective, brokers in a structural hole position that unite parties like a "convener" can gain access to performance advantages, and the network structure allowing for brokerage forms the social capital of the broker (Brass et al. 2004: 804). To Zaheer and Soda (2009: 4), the emergence of structural hole positions is a central feature of network structures and an antecedent of organisational outcomes. Structural holes provide opportunities for actors to "enact future structures" (ibid.: 25), but also trigger structural constraints, e.g. through past network structures that influence the development of a network. These constraints can result in a lock-in to certain network positions. Such lock-ins are driven by the historical exploitation of brokerage opportunities that appears beneficial (for some time) and the (more or less) purposive agency of actors in reproducing these structures. While the extent to which structures like brokerage positions are actively created by actors remains unclear, they appear to make it "harder for focal actors to break out of redundant network structures" (ibid.: 27) and this can lead to suboptimum outcomes.

With regard to Coleman's conceptualisation of social capital as closure, the evidence is even clearer regarding possible downsides. Scholars identify possible constraining effects of network closure. Gargiulo, Ertug and Galunic (2009) point towards control exerted by others or obligations arising from social norms such as reciprocity. These can make it difficult for actors to liberate themselves from unproductive relations, which reduces their subsequent performance (Gargiulo & Benassi 2000: 185). Such relations may lock-in firms to unproductive or strategically problematic relations and may lock them out from other, more fruitful, ones, e.g. through internal norms such as reciprocity (Gulati, Nohria & Zaheer 2000: 211). Zaheer, Gözübüyük and Milanov (2010) correspondingly conclude their debate on social capital in terms of firms' need to balance the "trade-offs" of the "dark side" of social capital, e.g. balancing "the benefits of trust and embeddedness with the cost of lock-in and inflexibility" (2010: 71). However, they do point out that, by focusing only on how organisations try to strike such a balance, extant literature has neglected the understanding of the mechanism that leads to such a lock-in situation in the first place.

Moreover, not only network relations in general may have negative consequences, but tie strength and network structure also appear to play an influential role: "Although prior networking and close ties can enhance trust, it is possible that actors can become overly embedded in their networks, become risk averse, and continue to work with others because of the strong ties" (Brass et al. 2004: 803). Such rigidity may lead actors to continue existing relations in network groups if "higher density within an interorganizational clique led to fewer exits from the clique" (Brass et al. 2004: 804). Social capital's "'dark side' can consequently lead to social ties that imprison actors in maladaptive situations or facilitate undesirable behaviour" (Borgatti & Foster 2003: 994). These problematic lock-in and lock-out dynamics as consequences of social capital seem to appear in rather dense networks (Gulati, Nohria & Zaheer 2000: 203) in which many organisations are connected to one another.

The duality of network control appears evident when considering the two conceptualisations of social capital according to Burt and Coleman: from a bridging perspective, an actor's control is considered to be higher when they occupy a position of a structural hole, since that gives them influence in the flow of information. Dense networks, however, facilitate a form of control that allows a firm's partners in a network to monitor and thus govern that firm's actions to a certain extent. While this may be positive for a firm's alters, it may not necessarily be so for a focal firm itself, since it may result in the demand that the firm expends more resources than preferred on certain relationships (Gargiulo, Ertug & Galunic 2009: 326). This normative control has two sides, in that apart from the cooperation control benefits for the alters of a firm, it may restrict that firm's ability to choose its networking partners and, overall, seems to provide more benefits to small firms rather than big ones (ibid.: 330-331).

When looking at the resources that can be accessed by virtue of social capital in a group, even these can take a negative turn. It has strategically enabling effects at the beginning of an alliance formation from a firm's individual perspective, but precisely these benefits may paralyse firms over time (Li & Rowley 2002: 1116; Duysters & Lemmens 2003: 52). This is the case when network groups are created which become very dense, i.e. closed, too closed for members to freely chose with whom to cooperate (if at all). This type of situation is caused primarily by factors including local search, the trust emerging through the high density of the network and the norms and social cohesion which make investment in existing relations more likely (ibid.: 52-53). The constraining effects in these networks stem from a replication and/or continuation of ties in a (sub-)group and a resulting decrease of technological diversity and homogenous information, behaviour, and beliefs when they "do not enhance information flow so much as they amplify existing opinion" (Burt 2005: 214). Inertial forces emerge from a reduction of search efforts beyond the local domain, since resources are ultimately limited, learning and innovation are impeded (Duysters & Lemmens 2003: 55-57) and cognitive processes create common mental models and groupthink and can lock actors into unproductive but stable network relationships (Zaheer & Soda 2009: 6). Furthermore, strategic inflexibility and group dependence arises not only for the locked-in firm members of the network, but also in terms of a lock-out for newcomers which could provide new input for the established players (Duysters & Lemmens 2003: 65; Burt 2005: 197).

Overall, ambiguity remains in the interorganisational literature of whether bridging ties, i.e. social capital from brokerage or network closure, i.e. social capital from cohesive ties are more beneficial or detrimental (Ahuja 2000a: 451-452). It is much clearer, however, that if the benefits of social capital 'turn sour' for the network members, this seems to be attributable to becoming locked-in to certain network position such as brokerage or, as more frequently pointed out, a lock-in to a dense network (sub-)group with many interconnected firms. The argumentation with lock-ins is one "speciality" of path dependence theory and, sure enough, this link has been made before.

2. 5. 6 Social capital and path dependence

Walker, Kogut and Shan (1997) attempt to circumvent the ambiguities discussed above by introducing their own version of modelling social capital as structural equivalence. They define structural equivalence as "firms that are structurally equivalent have relationships with the same other firms in the networks" (Walker, Kogut & Shan 1997: 115). As outlined above, this definition is conceptually quite distant from both the structural holes conceptualisation and the closure arguments, since its operationalisation measures neither structural holes nor closure via e.g. density. Their finding with this specification is that interorganisational networks become path-dependent because their members recreate structures that were established at an early point in an industry's history and because early partner choice has a strong impact on future cooperation partners (1997: 120). Overall, they conclude that such path-dependent developments can be explained by their social capital conception and that network structure need not to reach its optimum and has inertial influences on members (1997: 122). Likewise, Maurer and Ebers (2006: 285) find that social capital is by no means positive *per se*, and that particularly strong initial network closure can have negative effects on a firm's long-term performance. Furthermore, different configurations can have quite divergent effects, particularly when accounting for different levels of analysis and the three dimensions of social capital, actor properties and contextual factors (ibid.).

In this manner, Walker, Kogut and Shan (1997) 'only' explain that structure is stable and rigid, but not why, and particularly not how this rigidity came about. The conceptualisation of social capital as structural equivalence measured in a comparative static approach, and the two time-point restriction of the empirical data in this study somewhat unfortunately cloud the view of the process development leading to firms' path dependence. Moreover, as previously mentioned, their use of path dependence remains at a metaphorical level.

2. 5. 7 Criticism of social capital

The concept of social capital has received some criticism in the OMS literature. Much of this can be attributed to the diversity of conceptualisations that scholars present in studies (e.g. Lin, Cook & Burt 2001: vii). This diversity has led the literature to separate into two broad streams which present structural holes and closure as opposing concepts. This "bifurcation" appears unnecessary to some (Adler & Kwon 2002: 35), particularly in the light of studies that have benefitted from making the connection between the two concepts (e.g. Maurer & Ebers 2006; Walker, Kogut & Shan 1997; Ahuja 2000a). In this vein, social capital research would benefit greatly from re-aligning and producing increased dialogue between the two schools of social capital thought (Adler & Kwon 2002: 35). This appears quite necessary, since research has found rather contradictory results on the positive or negative effects of network closure (positive: Ahuja 2000a; negative: Maurer & Ebers 2006) and structural holes (positive effects: Zaheer & Soda 2009; negative effects: Ahuja 2000a). Some attempts at integrating all different conceptualisations have been made (Nahapiet & Goshal 1998; Riemer 2005: 115), but have not yet found great application within research, perhaps because their added complexity makes measurement even more difficult than it was at the outset.

The attributed lack of conceptual clarity and the interrelatedness of social structures mean that the measurement of social capital and its consequences appears to be somewhat obscured. This is based not least on the approach adopted by many researchers, that seeks to measure both the social structure and its potential benefits (Aulinger 2005: 289). While the quantification of the network structure has been aided by a host of algorithmic tools from social network analysis, the quantification of the potential positive effects of social relations appears less smooth, because focusing on a particular benefit can cloud scholars' view of other positive or negative consequences of social capital (ibid.: 290). Measurement issues in social capital research include the nominally-scaled nature of many network structure measures that often only allows a qualitative assessment rather than solid quantitative measurement; the inability to equate numerical values to social capital strength or effectiveness since the effects can be negative or positive; the multidimensional nature of network structure that causes an inability to sum any numerical values up to build an assessment of capital stocks; defining the relevant network boundaries among all possible connections, and the often-used ego-network measurement approach that only allows for the measurement of one social entity's social capital, not that of other emergence levels of social capital (Aulinger 2005: 291-292).

Further criticism centres on the issue that, conceptually speaking, some of the arguments appear tautological (Lin 2005: 9) or are conceptually and/or empirically difficult to separate, because conceptualisations and levels of analysis are interrelated (Nahapiet & Goshal 1998: 243), and because social capital necessarily crosses levels of analysis (Bankston & Zhou 2002: 285). When measuring social capital only in terms of its effects, a tautological argument appears almost inevitable (Durlauf 1999: 2). A more methodological issue is pointed out by the lack of social capital studies that trace the development of relations over time, the development and maintenance of such ties and a general lack of focus on network change (Huber 2009: 164). This lack of studies that integrate the dimension of time in analysing the long-term developments of networks in general and social capital in particular (see Ahuja 2000a for a positive exception) is partly due to social capital and network measurement issues that are even aggravated when integrating a time perspective. However, such an approach would be particularly fruitful, because the "coevolution" of social structure and social capital remains largely unexplored (Adler & Kwon 2002: 35) and because "we know very little about how social capital evolves over time" (Maurer & Ebers 2006: 268).

2. 5. 8 Summary of the social capital discussion

To briefly summarise the social capital debate, it can be broadly described as a concept capturing the idea that certain positions or social structures and the resources or activities embedded within social groups can lead to an advantage for actors who are members of such network groups. The literature puts forward several (competing) definitions of social capital and the concept is applied across different interrelated levels of analysis and for social entities ranging from individuals to nation states, and with several extensions (e.g. Nahapiet & Goshal 1998; Adler & Kwon 2002).

With regard to the network structural foundations of social capital theorising, the Burtian (1992; 2001; 2005) school of thought argues that social capital is owned by individuals and stems from brokerage in structural hole positions. The Colemanian (Coleman 1988; 1990; and Burt 2005) school posits that social capital and its benefits arise, by contrast, from the closure, i.e. high density, within a network of social entities, since it enables cooperation through effective norms and control options. These two schools of social capital scholarship remain in conflict due to respective findings to the contrary and despite attempts at synthesising. In the research on interorganisational networks, it is particularly these two definitions, though, that find application.

What has become clear is the ability of a social structure to lock-in members of a network to certain positions or social structures which can be detrimental to these network members. Evidence points, in particular, to the so called 'dark side' of social capital in which social ties imprison actors in maladaptive situations and thus turn the social structure into a liability (Gargiulo & Benassi 2000; Gulati & Westphal 1999; Portes & Sensenbrenner 1993; Putnam 2000).

For the present line of investigation, this latter literature on the 'dark side' of social capital holds the necessary parts of an explanation that help tackle the research question of how the networks in which organisations participate can become path-dependent. Social capital holds the potential as an explanatory mechanism, because it can explain how a network's structure can experience a dysfunctional flip in which the benefits of a structural situation become problematic and detrimental as time passes. Precisely this aspect of development over time and across social structural levels, however, has been largely understudied in the social capital literature to date. I shall remedy this oversight by integrating time and social structural levels within the study of social capital in interorganisational networks in the next section and develop it into a mechanism of path dependence. As part of this effort, I integrate the two network-structuralist schools of social capital thought by adding a process perspective on the synthesis of the two schools in a re-specification and extension of Burt's attempts (2001; 2005).

2. 6 Towards an integrated explanatory framework

"Each discipline of the social sciences rules comfortably within its own chosen domain so long as it stays largely oblivious of the others" (Edward O. Wilson 1998: 208).

The theory discussion thus far has followed a conceptual 'top-down' approach and involved an extensive literature review which revealed how the explanation of structural persistence in interorganisational networks lacks theoretical integration. The review first specified the macro-level phenomenon of interest as the *unfavourable excessive structural rigidity of network (sub-)groups, such as alliances, in interorganisational networks*. Having then identified the lack of a process perspective in explaining that phenomenon, I introduced path dependence as a thorough theoretical framing that characterises the development process and its mechanism dynamics. Path dependence theory's explanatory elements point towards the need for a positive feedback mechanism that can drive and maintain network-structural rigidity. Two main applicable schools of social capital thought were introduced as candidates for providing the connection between the phenomenon's aggregate network level and the individual structural actions in the network that create the structural conditions for the emergence of the phenomenon at a higher level of analysis. Studying this problematic phenomenon in the light of path dependence theory proves useful, and social capital can help elucidate its development. However, social capital as a concept lacks a dynamic, process-oriented approach primarily because its current conceptualisations neglect an explicit time perspective on structuration (Giddens 1984) in an interorganisational setting.

To remedy this situation, this section elaborates an integrated explanatory framework that works its way from the conceptual bottom up. Firstly, I reconceptualise social capital by specifying the micro-level networking actions of agents, in this case organisations within an interorganisational network, explicating implicit assumptions regarding intentions and time. Secondly, the focus is placed on the emergent positive feedback dynamics that build upon this structure and make social capital a mechanism in the sense asserted by path dependence theory. Thirdly, the mechanism and its dynamics are integrated into the stages of a path-dependent process. The section closes by recapitulating the overall process of network dynamics that create the structural path dependence phenomenon, ultimately leading to lock-in at the interorganisational network level.

In this sense, this section connects the dots already outlined above. Such an approach is necessary for several reasons. As described above (Section 2. 4. 4. 5), positive feedback is an emergent social phenomenon that is generated and maintained by agents. Only by explicating agents' micro-level decisions and networking activities and by integrating the dimension of time can we uncover the functioning of the social mechanism that exhibits positive feedback. The micro-level is the level of analysis at which the cooperation decisions and networking (inter-)actions are undertaken that lead to the emergence of interorganisational groups (alliances) at the meso-level. These alliances and their activities have their own (social capital) feedback processes which are the ingredients for the macro-level, whole-network phenomenon of locked-in path-dependent interorganisational network that can sometimes even lock-in whole industries.

Furthermore, only once we understand how the positive feedback emerges, do we gain an understanding of this social mechanism – the central element of path dependence theory. Lastly, the remaining elements of path dependence theory, namely small events, non-predictability and lock-in will be integrated within the logic of this framework so that we gain an adequate insight into the phenomenon of path dependence in interorganisational network through (sub-)group lock-ins.

2. 6. 1 Process perspective on social capital

In his work on social capital Burt (1992; 2001; 2005) argues that individual agents often have incentives to create links with other agents when these are otherwise unconnected – bridging a structural hole. Such a broker engages at least two, often several more unconnected parties. The underlying motivation of the broker is that they will typically be able to reap certain benefits from their brokerage position. As mentioned before, this structural holes' conceptualisation clashes with the conceptualisation of social capital as network closure which allows other network members to engage in social monitoring of agents as part of a deterrence-based reputation mechanism (Burt 2005: 163). Discussing this apparent conceptual tension and the solutions suggested in the literature lead us towards its resolution and integration.

Burt (2005: 164) suggests resolving this conceptual tension in three ways, e.g. by a) accepting only the version with better empirical support, by b) claiming both concepts "are equally valid but different", or by c) introducing the factors "structural autonomy" and "risk to trust" into the equation. Since available empirical support is mixed and does not reconcile the two concepts, the first option ceases. The second option remains superficial in its specification and neglects the fact that both concepts are also related e.g. through time (see below). The third option introduces factors that are not easily applicable to the interorganisational level of analysis, since network actors are organisations and Burt locates 'risk of trusting' at the personal level in teams. While it is applicable to individuals representing organisations, the factor "structural autonomy" introduces a second level of analysis: the closed group (social capital from closure) with strong *external* brokerage (Burt 2005: 139; Baum, Rowley & Van Liere's 2006 hybrid conceptualisation argues along similar lines). Despite the attempts, Burt concedes that while the two conceptualisations may be resolvable in terms of network *content* and for effects on individuals, the tension cannot so readily be resolved with regard to network structure, which is of interest here (Burt 2005: 163).

For the case of interorganisational networks, we thus need other means of resolving this conceptual tension, especially as far as network structure is concerned. In this discussion, Burt and Coleman indicate the following two ideas, which successfully expound on the suggestions above.

2. 6. 1. 1. *Closure as a by-product of brokerage*

Burt identified that closure may also occur in networks in which brokers fill the gaps created by structural holes. This closure can occur as a by-product of brokerage activities when brokers connect otherwise unconnected actors who forge connections among each other over time. Burt even argues that brokerage opportunities are often best realised if they occur in a network that combines "brokerage reach with a closed, reputation-inducing, structure among select peers and subordinates" (Burt 2005: 27). The potential downside is that the broker loses command of the structural hole position in the network and, with it, many of the resultant advantages.

With this argument – the two concepts are both valid, but different – Burt attempts reconcile brokerage and closure. His solution lies in introducing different levels of social aggregation and a degree of hierarchy "peers and subordinates" (2005: 27). This is a team-specific solution and builds on a concrete case study. More generally, then, actors' ability to generate the links that span structural holes between groups or actors relies on the existence of closed – dense – networks of strong, trusting relationships *within* the groups that they connect (Burt 2005: 95-97). In this way, he considers it a critical property – critical to realising the value of structural holes (Burt 2001: 52). This notion is a delicate argument that is not easy to uphold with regard to network structure, however, since, for the trust to emerge, high density in a network is a prerequisite - precisely the network property that makes the existence of structural holes rather unlikely.

2. 6. 1. 2. *Closure as a strategy*

Several indications exist that not only can brokerage be exploited strategically, but network closure can also be pursued by firms as a strategy for gaining several interorganisational advantages. For instance, Coleman points out that firms can enact closure through dense cooperation ties (to create social capital), allowing the firms to align their interests. This can lead to collusion, which is beneficial to firms in a closed network (Coleman 1990: 320), potential legal and social implications notwithstanding. Furthermore, a high degree of closure can limit access to the public good of social capital (locking others out) and its contained resources, such as information to the network members, and reduce opportunities for free riders. This can function because closed networks remove the possibility that defaulting behaviour can go unnoticed: "The more closed the network, the more likely that misbehaviour will be detected and punished" (Burt 2005: 97). Actors fearing reputation loss within a network must adopt its norms of cooperative behaviour, e.g. exchange reciprocity, in order to maintain their reputations upon which they rely for building beneficial relations. Thus, incentives for closing a network exist in situations where shared norms of behaviour control and mutual trust are beneficial for actors' cooperation.

Moreover, incentives for connecting more, and repeatedly, within the known network, exist. These new or recurring ties can increase closure by making new connections within the network and thereby increasing its density or by stabilising existing links with similar results. Such incentives for internal (re)connecting arise from the generalised trust in the repayment of social obligations within the network; from investments that actors have already made in the internal relations and whose 'obligational debts' would be forfeited when leaving the network or decreasing its density by connecting to the outside. The positive effects ascribed to such a strategy of closure are based upon factors including information access advantages (Coleman 1990) through increased trust, reputation, and sanctioning effects (Coleman 1988: 107-108), solidarity benefits that facilitate cooperation and exchanges (Adler & Kwon 2002: 33), and eased bargaining (Sobel 2002: 150). Hence, "the amount of social capital available to an actor is thus a function of the closure of the network surrounding him" (Gargiulo & Benassi 2000: 184).

2. 6. 1. 3. Strategies, distributed agency, and time

Implicit in Burt's and Coleman's conceptualisations are three elements requiring explication in order to achieve a conceptual reconnection of the two conceptualisations for application within interorganisational networks: actor type and their intentions (i.e. strategy), actors' distributed agency, and the changes of these over time that are made manifest at network structural level.

As discussed above (Section 2. 3. 4. 2), interorganisational network actors have many different motivations for connecting to alters. These divergent interests may lead to quite different strategies being adopted by network partners, especially as a network grows. One implicit assumption of strategies in the conceptualisation of social capital as brokerage is that brokers seek to avoid network closure to remain in their exploitable, network-structurally-unique position. Hence Burt's (2001; 2005) extensions for closure as a by-product of brokerage argue that a broker essentially loses control over keeping the structural hole position (and its benefits) intact or that they require closure only to the extent that it gives them a suitable reputation to appear trustworthy as a broker.

Neglected in terms of the conceptualisation, however, is the situation in which a broker's (or several brokers') strategy is, in contrast, not to maintain and exploit their structural hole position but instead to use it to facilitate, encourage or drive the closure of a network (i.e. a dense group). Motivations for such a strategy could be to establish interorganisational conditions for the pursuance of a network's joint goals, such as R&D or learning, or seeking to 'insure' the network's joint efforts against free riders. Interorganisational networks often deal with such a situation by establishing a formal network administrative organisation (NAO) which is tasked with the centralised coordination of a network group, such as an alliance, consortium, or an alliance block (Grandori & Soda 1995; Provan, Fish & Sydow 2007: 504). In the absence of a formal construct, hub organisations can fulfil just such a role (Barringer & Harrison 2000: 391; Oliver 1990: 243-244). This difference in assumptions on an actor's motivations has several implications.

In the case of a formally created NAO, their initial position in the structural hole and function as a broker is transparent. Over time, however, the success (or lack thereof) of the NAO's strategy would actually be measurable in the 'loss' of the NAO's brokerage position, with the NAO probably becoming one of the most central (degree centrality) actors in the group.

Additionally, and in contrast to what has been argued in the "closure as strategy" extension (above), actors in the group may not necessarily be aligned in their pursuance of the benefits of social capital from closure, i.e. they might want to (try to) free ride despite otherwise stated intentions, e.g. in a situation of sharing a group membership with several competitors. Such an attempt would probably be located at a network *content* level (e.g. learning without contributing). On a *structural* level, however, these firms would still need to connect to others and thus become embedded in the network fabric just like the others, especially since social capital has three interacting dimensions (Nahapiet & Goshal 1998) which co-evolve and engage actors (Biedermann 2007: 44).

The case of (an) informal broker(s) with the intention to create a dense network around themselves, e.g. to facilitate their own survival/success in times of turbulent technological change (Oliver 1990: 243-246), is another case of brokerage potentially entailing closure. Other actors may notice and seek to leave the network or cut out the broker by connecting more closely with others. Or they may become attracted by the opportunities created through brokerage and be 'lured' into a developing network-structurally dense group of actors. Moreover, if more than one (initial) broker has such closure intentions and links many other organisations, all brokers would 'lose' their structural broker position, but instead 'gain' the structural situation of closure.

As a third example, a broker may seek to *maintain* their unique structural position, but others might recognise their relative structural misfortune and reactively seek to avoid being 'exploited' through brokerage or cut out from information advantages, for example. Consequently, they may either leave the developing network (if possible) or strategically bypass the informal broker and connect directly with the other network members, thereby creating dense ties. Such a concept of strategic, reactive closure has largely gone unnoticed in both Coleman's and Burt's conceptualisations, especially at the structural level.

In all cases, the 'loss' of social capital from brokerage would be exhibited in network structure but only in the last instance would this development be against the broker's will. When implicitly assuming that brokers seek to avoid closure or seek it only to the extent that it provides reputation (Burt 2005: 95-97), we neglect that closure may not only be a strategy for group members, but also for e.g. its founding member(s) or even all actors who broker in pursuit of closure as a goal. More broadly, it is even conceivable that the intentions of all involved actors align so that they pursue the same goal and strategy of brokering ties to achieve closure in a 'distributed brokerage' manner.

Dealing with organisations complicates matters further. Relations between organisations are not unlike social network relations in that they, too, may be multiplex, multi-directional and (unlike interpersonal links) even represent different intentions and relations from contrasting organisational units (as alluded to by e.g. Inkpen & Tsang 2005: 159; Tsai 2001: 935). Examples could include a learning cooperation between two technology departments with a simultaneous innovation-driven competition between the strategic departments. Structurally, such networks would appear dense because the connections between organisations exist, both despite and because of different network content flows. Network structure, then, appears cohesive, but the cohesion of intents and consistent action cannot automatically be inferred without further study of the internal dynamics. Of course, control over actors' own structural positions and their consequences necessarily remains imperfect, since due to distributed agency, no actor alone controls or creates network structure, and some may seek to exploit brokerage advantages while others seek closure in order to enforce group norms such as reciprocity (Baum, van Liere & Rowley 2006). This may also explain how empirical research on social capital finds both types at work simultaneously (e.g. Maurer & Ebers 2006: 288-289).

Nahapiet and Goshal's (1998) three dimensions of social capital have been argued to exhibit co-development, drawing attention to the important role time plays in social capital. Brokering a structural hole implies a time-step before the brokering when the hole was intact and afterwards when it is bridged, at least in respect to the two connected actors. To achieve network closure, however, many more time-steps are potentially required, since the three dimensions of social capital require movement along the various levels of analysis (i.e. personal -> organisational -> interorganisational -> organisational -> personal and so on) to co-develop (1998: 256; Biedermann 2007: 26-44; and see the section on social capital's positive feedback, further below).

However, not only does time, merely tick away, it has important productive effects: it is a definitional element for certain network measures, for instance, including tie strength (Carolis & Saparito 2006: 44) – one indicator of network structural embeddedness of actors, where repetitions of engagement over time are measured. Furthermore, time is a necessary factor enabling the three dimensions of social capital to develop and interact as described above, i.e. establish the feedback loops between network content flows, and the relational and overall structural consequences. The second effect in interorganisational relations is that the passage of time implies a stabilising force for relationships (pertaining to the overall network) since "once a relationship forms, it takes on a life of its own and sustains itself" (Dahlander & McFahrland 2013: 71), with the strength of the effect diminishing slightly, however, for closed triads (Greve et al. 2010: 315-318). Additionally, while the effects of brokerage are more initial, the potentially beneficial effects of closure necessarily need to develop over time (Baum, McEvily & Rowley 2012: 530-533).

Considering distributed agency over time with potentially diverging, yet reactive adaptations of strategy, adds to the complexity and the further embedding of relations within the network. For instance, the property of tie age is typically measured as the frequency of repetition over measurement periods, e.g. cooperation project duration, representing the endogeneity and reactivity of cooperative interorganisational relations that depend on a plethora of factors (see Section 2. 3. 4). Social capital, as a result, is not as fixed and appropriable as the capital stock analogy may lead us to believe, resulting from a "metaphorical confusion of a substantive quantity (capital) and a process that takes place through stages (embedded, goal-directed social relations)" (Bankston & Zhou 2002: 285). It is influenced and created by the distributed micro-actions and interactions of the participating actors who co-create network structure over time, partly as a by-product of pursuing their activities, and partly as a strategic response to the changing network (structural) conditions of their cooperation relations, insofar as they are conscious of them. Even if network content flows of the potentially multiplex ties are not necessarily cohesively aligned, as long as ties exist (or persist), network structure then exhibits some degree of closure in a (formerly otherwise disconnected) network.

Such a process of developing social capital involves an essential first step in which a broker or brokers with transparent or obscure intentions make(s) connections among otherwise unconnected actors, or even industries. Subsequently, relationships continue to be engaged in after the initial brokerage, many subsequent steps of network closure may develop, i.e. more and new relationships within the emerging group either in alignment with the broker's strategy or against their intention. Burt (2005: 164) describes how an "initial bridge relation begins to be embedded" and then "emerging closure is the proximate cause of advantage."

2. 6. 1. 4. First steps: brokerage

As indicated above, several motivations exist for firms to connect and broker mutual relationships. They often coincide or are difficult to distinguish (Oliver & Ebers 1998: 556-568; Gulati 1998: 298-299). They typically revolve around access or control over certain resources, e.g. information or the very relationships that are created in the bridging process themselves (Oliver 1990: 243-244). More general motivations for networking may stem from seeking economic efficiency, seeking stability through partners in unstable environments and seeking institutional legitimacy (Oliver 1990: 245-246; Oliver 1990: 246; Zaheer, Gözübüyük & Milanov 2010: 65). Apart from access or control over other agents' physical, financial, or other tangible assets, information and other intellectual resources provide strong incentives for joint learning in networking ties (Gulati 1998: 298-299; Zaheer, Gözübüyük

& Milanov 2010: 65).

In order to achieve such goals, brokering agents may choose the path of strategically establishing alliances that involve several other agents, often with a degree of organic growth that leads to the emergence of a group of firms. Particularly when joint learning or knowledge exchange is a broker's motivation for teaming up with others, such alliances can be purposive. They increase brokers' and connectees' ability to absorb information from others and/or strategically disseminate important information, knowledge or intellectual property within the network. This learning can be successful if it allows the broker and other network members to profit from the learning or knowledge exchange.

Moreover, these alliances can boost an individual firm's clout in the marketplace. They can, furthermore, establish (political) lobbying that aligns the interests of several stakeholders (Barringer & Harrison 2000: 376) and can even allow a certain group of companies to set and drive an industry's agenda. This is often the case when firms with similar characteristics establish partnerships, which has been shown to be the case (Brass et al. 2004: 904; Gulati 1998: 296-297). Strategic industry alliances can also reduce market uncertainty and enable the achievement of shared goals such as cost benefits, learning or economies of scale or scope (Brass et al. 2004: 804).

Alliances can additionally provide legitimacy that agents may seek, e.g. by providing legitimising ties or when isomorphistic mimicry is 'required' by the existence of other successful and competing groups in that industry (Barringer & Harrison 2000: 381). In such cases, building an actor group has been shown to increase survival rates (Brass et al. 2004: 806), even if this leads to some tension regarding a firm's ability to seek competitive advantage from differentiation – entering a group can reduce this ability but also further it (Gulati, Nohria & Zaheer 2000: 205). While differentiation may potentially be reduced, alliances can be useful in situations in which other powerful industry players or alliances are in opposition, and individual firms are not big, fast or knowledgeable enough to compete independently. When an alliance develops into a successful cooperation network, one important result (and thus also an indirect motivation) can be quasi-monopolistic, or at least oligopolistic, rents that are higher than if firms had pursued their activities alone. In the context of such intra-industry structures, strategic blocks may pose mobility barriers to members and new entrants by locking present members in or new entrants out of networks or even entire industries (Gulati, Nohria & Zaheer 2000: 206-207).

2. 6. 1. 5. Subsequent steps: closure

After initial brokerage has taken place and brokers have connected otherwise unconnected parties in an industry or even brought formerly unconnected industries together, alliances of actors emerge if the newly-connected actors see fit. Although it goes without saying that such a development does not occur automatically, research suggests that bridging also leads to improved outcomes for groups even if the broker stands to gain the most (Sobel 2002: 152). However, in high-tech and knowledge-driven industries in particular, the causes indicated in the last section have a strong potential to drive the development of such alliances and even entire industries, since they emerge with relative frequency (e.g. Gomes-Casseres 1996).

One of the characteristics of such alliances is that, over time, they develop an internal structure of increasing network density – which, as outlined above (2. 5. 3. 2), is indicative of/synonymous with network closure. Network closure can occur for several reasons. In its weakest form, closure can be the by-product of brokerage. As a broker makes the connections, one result can be linkages among now newly-connected actors who embark on joint projects merely because they now have knowledge of each other. Additionally, Burt claims that brokerage opportunities are best realised in a network that combines "brokerage reach with a closed, reputation-inducing structure" (Burt 2005: 27). Following this line of reason, brokers tolerate or even strive for a certain degree of closure in the network as far as it provides them with positive reputation. This is particularly likely if not just one, but several agents (competitively) engage in brokerage activities within the new alliance. As detailed above, strategy plays a role in the development of alliances and additional connections and increasing closure may develop as part of, or against the interests of the broker(s).

Besides these two rather incidental processes, closure may be pursued as an intentional activity. Closure allows firms to align their interests (Coleman 1990: 320), can limit access to the resources contained in the network such as information to the network members, reduce opportunities for free riders and encourage cooperative behaviour (Burt 2005: 97). Moreover, if and when new cooperation partners are sought, incentives arise to create connections with members of the same alliance. These stem from increased knowledge about other members and the generalised trust towards other group members, reputation information and sanctioning options (Coleman 1988: 107-108), because they ease cooperation (Adler & Kwon 2002: 33) and negotiations (Sobel 2002: 150). Additionally, because ties become more strongly embedded and are of longer duration, firms are encouraged to make non-recoverable investments, with the rationale for these being that particularly under highly uncertain conditions, such alliances perform better and terminate prematurely less often (Gulati 1998: 308).

Furthermore, closure can be driven by the emergence of norms such as reciprocity that facilitate cooperation and coordination through requiring repeated interaction (Oliver 1990: 244-245; Brass et al. 2004: 803). The resultant high network density can reduce transaction costs by eliminating the need for costly monitoring, replacing due diligence to some extent (Zaheer, Gözübüyük & Milanov 2010: 65; Gulati, Nohria & Zaheer 2000: 210ff.; Brass et al. 2004: 802) and thus facilitating (new) networking within the existing group. As a further result of a group's closure activity, outside agents may seek to connect to the group because membership becomes attractive when it gains an intrinsic value (Sobel 2002: 152). This can lead to an overall increase in contributing members who make the alliance even more densely connected and thus more cohesive and closed in so far as it ensures that the alignment of actors enables certain capabilities beyond an individual organisation's former options (Borgatti & Halgin 2011: 1174). This closure process is subject to positive feedback loops in terms of the three interacting dimensions of social capital as introduced by Nahapiet & Goshal (1998).

2. 6. 2 Social capital as a positive feedback mechanism

Part of the challenge of understanding the phenomenon of path dependence in interorganisational networks by lock-in to overly dense alliances lies in the conceptualisation of a positive feedback mechanism, identified here as the social capital process. Positive feedback is an essential ingredient of path dependence theory, since it is the driver of the phenomenon which can eventually lead to a lock-in situation. Positive feedback can be characterised as an initially virtuous cycle of continued or repeated actions that lead to the attainment of higher gains, which in turn make subsequent actions even easier, less costly, or more beneficial in short – a "dynamic eventually flips over into rigidity" (Sydow, Schreyögg & Koch 2009: 698) which can turn into a potentially devastating vicious spiral. Social capital is a dynamic process (as shown above) that can lead from brokerage to a closed, cohesive network structure. Several arguments exist in favour of why such a process exhibits the property of positive feedback, and these can be categorised into the three dimensions of cognitive, relational, and structural arguments following Nahapiet and Goshal's (1998) distinction of social capital dimensions.

2. 6. 2. 1. Cognitive dimension

As outlined in the literature overview above, the development of knowledge resources and intellectual capabilities lies at the heart of many strategic forms of cooperation and, after initial brokering ties, alliances often emerge on the grounds of mutual learning or the creation of new joint (knowledge) assets. Over time, learning grows easier thanks to increased experience and previous knowledge. Similar to an 'isolated' learning effect of individuals or individual firms (cf. Section 2. 4. 4. 5.B), networks, especially actor groups such as alliances, can also induce learning effects (Knight & Pye 2004 and 2005). The performance of certain actions with network partners becomes easier over time, just as working with particular resources and partners is less demanding. Thus, experience gained in the past results in decreasing efforts over time and enables strong incentives to continue with less effort rather than switching (Sydow, Schreyögg & Koch 2009: 700). These learning effects can lead to a focus on exploitative learning (Schreyögg & Sydow 2010: 7) that makes it easier to follow up on and provides incentives for reinvesting in current know-how.

Furthermore, apart from learning from others, an important motivation for networking lies in accessing other firms' resources. Just as with learning, this exhibits positive feedback because, as a firm gains positive experience with accessing and having a certain degree of control over the resources of another (one of the motivations for brokerage), the more it comes to rely on this positive experience and the more it commits to the relations(s), as they can become a strategically important asset. Moreover, firms learn from past relations with certain partners and groups and about partnering in general. A broker, for instance, learns how to connect others and benefit from these connections, while the connected parties learn how to rely on the broker and the relations with other parties. As this experience accumulates, it can lead to strategically valuable network and relationship management capabilities. It is likely that firms will exploit these skills in future and re-engage in partnering to refine these networking skills, in order to extract more value from them over time (Gulati, Nohria & Zaheer 2000: 208-209).

2. 6. 2. 2. Relational dimension

The relations that a firm entertains within its network have an effect on its propensity to further engage with the same. In this case, the positive feedback in this case stems from coordination effects which have several sources. One is the emergence of norms such as reciprocity or a norm of generalised trust in other members (Gulati, Nohria & Zaheer 2000: 211). The incentives for internal (re)connecting arise from the expectation of repayment of relational 'obligational debts.' Thus, a firm's attained reputation, the trust in others or the reliance on the emergent norms creates coordination effects that are based on rule-guided behaviour and reduce transaction costs when adopted by agents in the network (Sydow, Schreyögg & Koch 2009: 699).

Following the established rules or norms subsequently makes interactions and transactions easier, less risky, and cheaper. This in turn makes the adoption of the norms even more attractive for firms as an increasing number of other firms adopt them, and eases a future repetition of relations (Grandori & Soda 1995: 198; Parmigiani & Riviera-Santos 2011: 1116-1117). This networking then leads to the emergence of strongly binding norms through the firms' collective action (Ackermann 2001: 52-53).

Furthermore, membership within a (certain) alliance is perceived as a legitimate-inducing property within an industry. In such a case, ties with legitimate partners in well-connected networks or groups have also been found to increase firm survival rates (Brass et al. 2004: 806) and are thus prone to encourage an increasingly strong commitment to these relations over time as firms benefit from the legitimacy gains.

In interorganisational alliances, the existence of synergetic or complementary relations, like the creation of joint assets, can further lead to the emergence of supply-side economies of scale (David 1985: 334) when the production of a certain product and/or service becomes cheaper as the output amount of this product or service increases through cooperation relations (Ackermann 2001: 59-61). Hence the distribution of the fixed production costs over an increasing output through networked production can contribute to a strong self-reinforcing logic.

2. 6. 2. 3. Structural dimension

The structure of a network constitutes both the basis and the result of networking activities of firms. This endogenous nature of network structure thus makes it unique in its ability to display the results of agents' activities as well as being a property that agents seek to influence to their benefit.

Initial network structural holes within an industry allow brokers to bridge and close these gaps or even broker among formerly disconnected industries. When a broker engages in this activity, they become visible to others within the network and thus prominent – in network terms, their degree centrality (and likely also Betweenness) increases. Prominence can be perceived as a sign of attractiveness in terms of making connections, thus leading to more relations that further increase such an actor's centrality and likewise increase their attractiveness (Gulati 1998: 301). Such a centrality spiral can be emergent or may be actively managed by companies whose business model depends on high centrality in their network, as they have an incentive to continually increase their centrality (and thus implicitly network size) (Zaheer, Gözübüyük & Milanov 2010: 66) based upon the positive feedback they perceive from centrality.

If an interorganisational alliance emerges, network closure is a similarly likely property of the network that exhibits positive feedback. Closure, expressed as the density of relations in a network, is likely to increase over time because many of the other effects described above depend upon it. Thus, closure itself can also be perceived as an attractive network property since it enhances actors' ability to co-operate as adherence to norms is more likely in dense networks based on the easier detection of misbehaviour (Coleman, 1990: 269). Thus, a strategy of closure can be implemented by actors when they seek information access advantages and when trust, reputation and sanctioning effects are important for the functioning of cooperative activities and transactions (Coleman 1988: 107-108; Adler & Kwon 2002: 33; Sobel 2002: 150). Because the "amount of social capital available to an actor is [..] a function of the closure of the network surrounding him" (Gargiulo & Benassi 2000: 184), participant actors and even brokers (if that is their strategy) and NAOs may seek to increase closure through encouraging other firms around them to connect or engage them in joint projects in order to reap the increasing benefits of closure over time. This is typically achieved by connecting with partners within an already existing alliance, since density would not increase by connecting to others on the outside. However, the introduction of newcomers naturally increases the number of firms that can be connected with within a group, which may thus be a worthwhile pursuit if e.g. a broad membership coverage is advantageous in an industry.

Structurally, the network thus becomes denser over time. The culmination of activities in a fully connected network (`d=1`) is the theoretical maximum of achievable closure but is unlikely to be found in empirical settings, since it is not clear that the cooperation relations of actors with all others within a network would be fruitful when considering the relations individually and the resources required for such a situation. However, the resulting cohesion promotes structural closure as a result of the increasing incentives that arise to create closure.

2. 6. 2. 4. Summary: positive feedback through social capital

To summarise, social capital can exhibit strong positive feedback loops. These stem from learning in relations and exploiting the joint knowledge, learning about relations, and learning the skill of network management. They also lie in the continuation of relations where emergent norms and obligations require commitment or reciprocity and when they ease transactions or provide legitimacy. Lastly, they can be found in structural developments that may lead to both the increase in a brokering actor's centrality and the closure of a group such as an alliance where additional incentives exist to keep all the other mechanism in force. Strategic intent and distributed agency over time lead to the three dimensions of social capital to interact, e.g. structural cohesion enhances learning, which influences norm emergence, which leads to an incentive to strategically re-invest in closure activities. Structurally, the network becomes denser over time and this measure embeds the other levels of social capital as a result. Thus, it is at the structural level where social capital is best measured, since it is, endogenously speaking, the basis for and result of networking activities. The structural dimension and level of analysis thus forms the focus of this research's reasoning regarding the positive feedback mechanism of social capital (and in the construction of the computer simulation model) because the effects of the other two dimensions can also be captured by the structural level. The next section explores the way in which the three levels of social capital can prove problematic in terms of path dependence-like lock-in.

2. 6. 3 Lock-in through social capital

As discussed in the path dependence section on lock-in (2. 4. 4. 4), some feedback processes (2. 4. 4. 5) have the ability and tendency to drive a positive feedback process into a rigid situation which path dependence theory calls a lock-in, i.e. a lack of flexibility. These lock-ins are problematic, because they can lead to the disappearance of alternative options and be marked by a combination of managerial cognitive restrictions, resource-based, normative, political, and organisational restrictions that typically are inefficient, ineffective, or otherwise problematic (Sydow, Schreyögg & Koch 2009: 694). The analysis of a social capital-driven lock-in of interorganisational networks follows the above distinction of its feedback process into the three interacting dimensions of cognitive, relational, and structural arguments (Nahapiet & Goshal 1998).

2. 6. 3. 1. Lock-in: cognitive dimension

One of the important feedback loops of social capital at the cognitive level is learning. Learning with networking partner(s) or learning from exercising activities with them grows over time and makes learning easier. This can lead to a reinvestment into learning with the same partner(s) due to the strong incentives that arise from the easing of efforts (Sydow, Schreyögg & Koch 2009: 700). The first problematic issue with regard to learning is that it can lead to the development of groupthink. Groupthink is a group-based homogeneity of beliefs that, like dominant logic and shared practices, becomes reinforced through widespread adoption (Borgatti & Foster 2003: 998-999). Such shared language, experience and mental models can lock-in the cognitive abilities of group members to the thinking available with their group and restrict the influx of external influences (Sydow, Schreyögg & Koch 2009: 700).

A second problematic issue regarding learning is that it can lead to a cognitive focus on exploitative learning (Schreyögg & Sydow 2010: 7). Even if a strategic cooperation relation had the goal of jointly innovating, the increasing ease and quality of joint learning and its results coupled with decreasing overall effort can drive out exploration and cause a dedication of resources to exploitation alone (ibid.). Such social capital-based learning effects are even more likely to cause a lock-in when an interorganisational relationship exists mainly for the purpose of 'co-exploitation' e.g. through resource sharing (Parmigiani & Rivera-Santos: 2011: 1122). Quite clearly, exploitation learning may be intended by the networking partners but can turn into a dysfunctional mechanism when it drives out the necessary exploration beyond the closed network and becomes a narrow, simplistic behavioural pattern that turns from success into failure (Sydow, Schreyögg & Koch 2009: 700).

In addition, a firm's absorptive capacity, i.e. the ability to learn from cooperation partners, co-develops with learning. If it continually targets exploitation, this may lead to a lock-in of that firm to a network partner or group of which it is a member (Cohen & Levinthal 1990; Lane & Lubatkin 1998). A lack of investment into exploration that leads to an insufficiency of new external stimuli can be critical for firms, since the ability to continually innovate is the driver of much of firms' ability to survive and generate profits (Gulati, Nohria & Zaheer 2000: 211).

Apart from learning, the continued access to partner(s)' resources can cause a lock-in. This access exhibits positive feedback because, as firms gain positive experience of accessing and commanding a degree of control over others' resources, the less they are likely to engage in a search for or even perceive alternatives (if they exist), and the more they rely on those relations, the more they become a strategically critical asset. Such a situation has (confusingly) been described as a relational lock-in and portrayed as an instance of resource-based dependence on a certain networking partners or groups (e.g. Gulati, Nohria & Zaheer 2000: 203-204). This type of lock-in arises due to a dependence on a resource that partners bring into the relationship or that develops as part of the relation. The more specific this resource is, the more severe this lock-in will be from a strategic point of view for the participant firms.

Moreover, firms not only learn from and about certain cooperation partners, but also about partnering in general (Brass et al. 2004: 802). From this experience, firms can develop certain network management skills that they rely on increasingly and which come to constitute strategic resources (Gulati, Nohria & Zaheer 2000: 208-209), often with high specificity for certain (types of) relationships. Exploiting such skills may limit individual firms' performance, increase their risk aversion and lead to network overembeddedness, especially when they are bound to specific groups of firms.

2. 6. 3. 2. Lock-in: relational dimension

In interorganisational networks, coordination effects can emerge through the creation of norms, generalised trust, and firms' reputation. They make interactions and transactions easier, less risky, and cheaper. Adopting them becomes ever more attractive as other firms adopt them, too (Grandori & Soda 1995: 198; Parmigiani & Riviera-Santos 2011: 1116-1117). This positive feedback may generate a so-called 'dominant logic' of interaction (Provan, Fish & Sydow 2007: 503) which can lead to the norm-induced mimetic adoption of certain behaviour from network partners (Parmigiani & Riviera-Santos 2011: 1126), particularly when these are perceived as legitimate. Once the behaviour is no longer questioned or questionable, the situation can prove problematic as it strongly reduces a firm's ability to leave the pursuit of such a dominant logic and seek alternative exterior options. Particularly in dense networks (which are ironically created exactly for these benefits), this normative control can bear negative consequences, if a firm loses control over its resources and relations, for example, which has predominantly been the case for larger firms (Gargiulo, Ertug & Galunic 2009: 326-331).

Coordination through rules-based behaviour and respective expectations can further contribute to the reinforcement of the above-described phenomenon of groupthink (Borgatti & Foster 2003: 998-999). Firms' reputation and interfirm trust and group norms such as reciprocity (Gulati, Nohria & Zaheer 2000: 211) can lead to a strong binding effect, i.e. a lock-in (Ackermann 2001: 52-53). This binding force emanates not least from the potential loss of the trust, a firm's gained reputation or its legitimacy gained from cooperating with a certain alliance in the case that it left the group. The 'obligational debts' that an actor has earned (or owes) as part of reciprocal cooperation relations would be forfeited and previous investments in these relations would be lost. The latter constitutes a 'sunk costs' (or, in turn, a 'sunk owed debts') argument, and these have been shown to exert binding forces (e.g. Foray 1997: 742-744). These rule-based binding forces are often made manifest in the form of shared resources, assets, or structures (e.g. common staff, centralised coordination structures, aligned incentive systems etc.) which can even worsen the binding forces of coordination effects (Grandori & Soda 1995). This is particularly the case when these synergetic or complementary relations, e.g. networked production, or distribution, exhibit supply-side economies of scale, itself already a strong positive feedback dynamic (David 1985: 334; Ackermann 2001: 59-61).

2. 6. 3. 3. Lock-in: structural dimension

Since all the above social capital effects are expressed at the structural level, it is unsurprising that we can, at this level, also see that lock-ins occur as the result of social capital dynamics. Such types of network lock-in relate to a certain network position or a network's sub-structure, as indicated by the two conceptualisations of structural social capital discussed above.

With regard to social capital from brokerage, brokers who are exploiting their (initially) beneficial structural holes position of information or resource flow control can become immured in the same. As a result, they may be able to benefit from their brokerage position, but are subsequently excluded from other benefits of networking, e.g. other agents actively seeking to avoid going through the broker. Lost benefits could include closure and the ensuing close cooperation or the ability to benefit from mutual learning, as well as access to a resource such as generalised trust between network members. A detrimental lock-in occurs, then, if networking practices, norms or other structurally reinforcing mechanisms keep a broker in their place despite their wish to leave it, or their ignorance of better structural position options.

A further problematic dilemma as regards a lock-in into a brokerage position could arise from the situation that a broker attains an increase in their network property of centrality, which is typical. Centrality displays positive feedback and can affect the broker (or an otherwise comparatively central) agent by locking them in to their central, very connected, position. At first glance, this can be beneficial (Bae & Gargiulo 2004: 853). However, structural hole positions lose the benefits of financial gains over time and only allow their exploitation when the structural holes are relatively recent and not in the past (Soda, Usai & Zaheer 2004: 903). Thus a highly central broker forced to remain in their position could be limited in both the ability to exploit their central position of brokerage, and in their options as far as gaining some of the benefits of closure is concerned.

Furthermore, a high level of connectedness can prove detrimental when it leads to e.g. the exploitation of that central agent's knowledge or other resources if they are unable to restrict others' access to their realm. This situation is typically worsened by the resources and capabilities that a broker needs to commit in order to sustain a large and very connected (ego-)network around their structural hole position (Zaheer, Gözübüyük & Milanov 2010: 72). Lastly, Soh, Mahmood and Mitchell (2004: 914-915) show that a firm's high ego network centrality allows it to receive information, but in consequence, this can accelerate both firm success and failure. A similar situation is plausible the other way around: a firm in a dense network may not be able to exploit an existing information advantage when it cannot move into an open brokerage position, being locked-out through high embeddedness. This can also occur if there are no structural hole positions to fill, or if another firm already occupies this position and defends it. Overall, however, the effects of a broker's lock-in to their network position typically proves problematic for one actor in the structural hole position, not so much for the other organisations surrounding them (apart from potentially missing out on being brokered). While conceptually distinct (and empirically interesting), an individual firm becoming locked-in to a broker's fate is not so central to this research, since it does not necessarily exhibit the same micro-action -> meso-feedback process -> macro-consequence processual nature of network dynamics. Moreover, an individual firm's lock-in as a broker may be detrimental to that firm in the long run, but a focus on this situation would, in all probability, neglect the whole-network development which is of interest here to analyse the phenomenon of overly-stable, i.e. locked-in network structures at the macro level.

Additionally, the effects of brokerage are more initial and rely less on mechanisms developing over time than is the case with closure (Baum, McEvily & Rowley 2012: 530-533). This is because the brokerage position relies on the absence of surrounding ties, whereas closure relies on their development, implying that if new connections are forged within the network over time, closure is more likely than the continuing existence of structural holes (ibid.). This does not, however, mean that brokerage activities cease. They may well continue, but the structural hole position would reduce over time as the cognitive and relational dimensions of social capital's positive feedback become active in actor groups where they have the (structural) conditions to develop gradually. Finally, research has repeatedly pointed out and shown empirically that 'too much' closure is proving more problematic than 'too much' brokerage (e.g. Baum, Rowley & Van Liere 2006: 19; Gulati Nohria & Zaheer 2000: 203). In the following, I thus concentrate not on the fate of a structurally locked-in broker but on that of densely connected groups in interorganisational networks, even though such a pursuit may be worthwhile with a different research question.

Lock-ins through network closure constitute the second, and more process-like, network-structural type of social capital-driven lock-in. While high network closure (density) is rare at the level of an entire network, it more readily occurs at the level of groups within the overall network. In interorganisational networks, such groups are cooperative alliances creating consortia or industry blocks which develop around the establishment of common standards or platforms in technology industries. If a group offers such a resource, or market access and market power etc. upon which actors depend, this can cause a lock-in to membership of such a (sub-)group because of the resource access it provides. Group lock-ins occur at a higher level of social aggregation than the lock-in to a brokerage position, and together with potential lock-ins at the cognitive and relational level, the resulting social cohesion typically leads to structural cohesion, i.e. high network density.

Strategically-created groups such as alliances typically increase group-internal density based on the typical sharing of knowledge, information, mutual learning etc. This density can have drawbacks when it reduces firms' ability to protect their proprietary knowledge (Zaheer, Gözübüyük & Milanov 2010: 72), or can lead to the emergence of learning races (Gulati, Nohria & Zaheer 2000: 211). Increased density can paralyse firms in their networking activities when groups are so dense that members lose the ability to freely choose whether to cooperate or with whom (Duysters & Lemmens 2003: 52). In highly dense networks, additional inertial forces emerge from a focus on network-local search (Duysters & Lemmens 2003: 55-57) and the cognitive processes that create common mental models, groupthink, norms etc. as described above (Zaheer & Soda 2009: 6) which can lock actors into unproductive but stable network relationships within a group. Despite being potentially unproductive relations, partners see trust and norms of reciprocity emerge based on structural and social cohesion. These lead to further investment in existing relations, decrease technological and knowledge diversity, and result in homogenous information, behaviour, and beliefs (Burt 2005: 197-222).

These characteristics may in part be the reason for the strategic creation of alliances such as consortia. They can provide market barriers to entry for competitors, but members can become locked-in due to inertia and lack of alternatives (Nohria & Garcia-Pont 1991: 122). Furthermore, strategic inflexibility and dependence on the group arise not only for the locked-in member firms but also for newcomers in terms of a lock-out of certain knowledge (Duysters & Lemmens 2003: 65). Alliances may thus pose strategic mobility barriers for members and new entrants by locking-in present members or locking new entrants out of networks or entire industries (Gulati, Nohria & Zaheer 2000: 206-207). The existence of these strategic blocks can offer advantages such as increased performance or long-term survival for the members. They can, however, also constitute a disservice to the economy at large when membership of an industry network of high density entails high market power concentration with oligopolistic coordination and tacit collusion (Gulati, Nohria & Zaheer 2000: 205-206).

Moreover, when firms stay in dense relations without assessing external alternatives, this can prove problematic when successful relations breed failure in e.g. the performance of the firms involved in the long run. Hence overly close ties can be problematic with regard to performance. Competitive (dis)advantages can emanate from lock-ins that occur because firms have limited resources, and forming certain ties may preclude forming other ties. Expectations of loyalty among current members can impede or foster the formation of new ties and switching groups is difficult and costly (Gulati, Nohria & Zaheer 2000: 210ff.). When embeddedness become too strong, it can reduce the diversity of information that firms encounter and can thus make them more vulnerable to external shocks (Zaheer, Gözübüyük & Milanov 2010: 66).

Also, with the growth of group size, explorative learning and knowledge transfer become more difficult despite the density. This is mainly due to resource restrictions that prevent firms from cooperating with many more partners. These resource restrictions may exert further structural restrictions because firms' ability to benefit from their network relations depends on both the amount and frequency of past cooperation relations in the network (Barringer & Harrison 2000: 389). Striking new relations can only be achieved if resources allow for such activities. Similarly, in a firm's network relations, there may arise a point at which partnering demands more resources than it can produce in output, and this is problematic for firms if they are obliged to maintain these relations due to structural embeddedness and the resulting social obligations.

2. 6. 3. 4. *Summary and specification: lock-in through social capital*

Overall, the interacting dynamics in the positive feedback mechanism of social capital with its three dimensions can lead to a situation of lock-in. Lock-ins in interorganisational networks can be conceived of as being driven by (at least one of) the interacting cognitive, relational, and structural dimensions of social capital. The group and overall network level of analysis is where these lock-ins are represented by strong structural cohesion (density). As is typical with path dependence mechanisms (Sydow, Schreyögg & Koch 2009: 694), the initially beneficial and thus attractive properties of network closure 'turn sour' over time and result in unintended structural rigidity. A continued balancing of "the benefits of trust and embeddedness with the cost of lock-in and inflexibility" as suggested by Zaheer, Gözübüyük and Milanov (2010: 71) appears implausible, most certainly in the long run. The feedback mechanism's problematic side develops behind actors' backs, since the distributed agency of network actors allows only for at best imperfect and at worst near-total loss of control over the endogenous network structural conditions of their cooperation. A level of alignment necessary for a successful balancing appears unachievable, not least due to differing strategic intentions. Instead, the positive feedback of social capital 'entraps' the network members into a pared-down group of densely connected actors from which breaking out comes at considerable (perceived) and potentially detrimental costs for member firms. The positive feedback of social capital narrows down the available scope of cooperative action so much that member firms experience considerable strategic inflexibility.

All three dimensions of social capital can affect firms in contrasting ways. The multitude of different and co-developing dynamics produces a certain degree of ambiguity in the specification of the lock-in situation compared to the original conceptualisation of path dependence. However, a certain degree of ambiguity necessarily remains in (inter-)organisational settings, as their lock-ins are not as clear-cut compared to the situation in markets where they are typically (conceptualised as) fully deterministic. They are problematic with regard to important aspects of the situation and perceived as a fixed mode of action or choice pattern that reinforces the lock-in (potentially without intention) but allows for some minor variation (Schreyögg & Sydow 2010: 8). The lock-in thus exerts rigidity not in a total sense, but rather as a strongly narrowed-down degree of flexibility from which drastic deviation does not occur. When members of an alliance lose their strategic flexibility, this is rather problematic for firms, because only by being strategically flexible can they try to adapt to market developments, customer demand and supplier changes. Renouncing strategic flexibility in order to gain networking benefits is an impossible balance for a networking firm to strike, because the lock-in, as the situation in which that balance has shifted into the problematic zone, can only be corrected at a very high cost or may be perceived to be impossible without endangering firm survival or profitability.

A social capital-induced lock-in is thus a situation in which a firm has enjoyed the positive effects of social capital for some time. After the development of ties around an initial broker within an emerging group, the density within has made connections to outside partners (more or less) impossible, due to the cognitive and relational aspects of the social capital feedback dynamics. The members of the network are then structurally locked-in when they have only (or predominantly) cooperation partners from within their own group, while not perceiving or not being able to pursue connections to potentially more beneficial partners outside the known group. This situation can be measured in network terms when the property of density approaches very high levels and when the directions of network agents' connections point mainly towards the group inside. Furthermore, there is only low influx of members after an initial setup phase. When new members join, these connect quickly and heavily to existing network members and overall, few entries occur. Additionally, it is reasonable to expect that there would be hardly any outflow of members, beyond those that go under due to potentially network-induced problems with their survival or profitability. The following section outlines how social-capital driven network path dependence comes about in its entirety.

2. 6. 4 Overall path-dependent process in interorganisational networks

The overall framework is derived from the three (formerly only partially connected) literature streams on interorganisational networks, path dependence and social capital, merging both existing network-structural social capital conceptualisations. They are integrated with the processual three-phase path dependence theory (Sydow, Schreyögg & Koch 2009) with its temporal logic and cumulative inertial forces. This section summarises the framework and characterises its interacting elements. Figure 6 adapts the Berlin path dependence model, with the integrated mechanism of the social capital process shown as running in parallel. Here, the three dimensions of social capital interact on the basis of, and (re)establishing the links between firms.

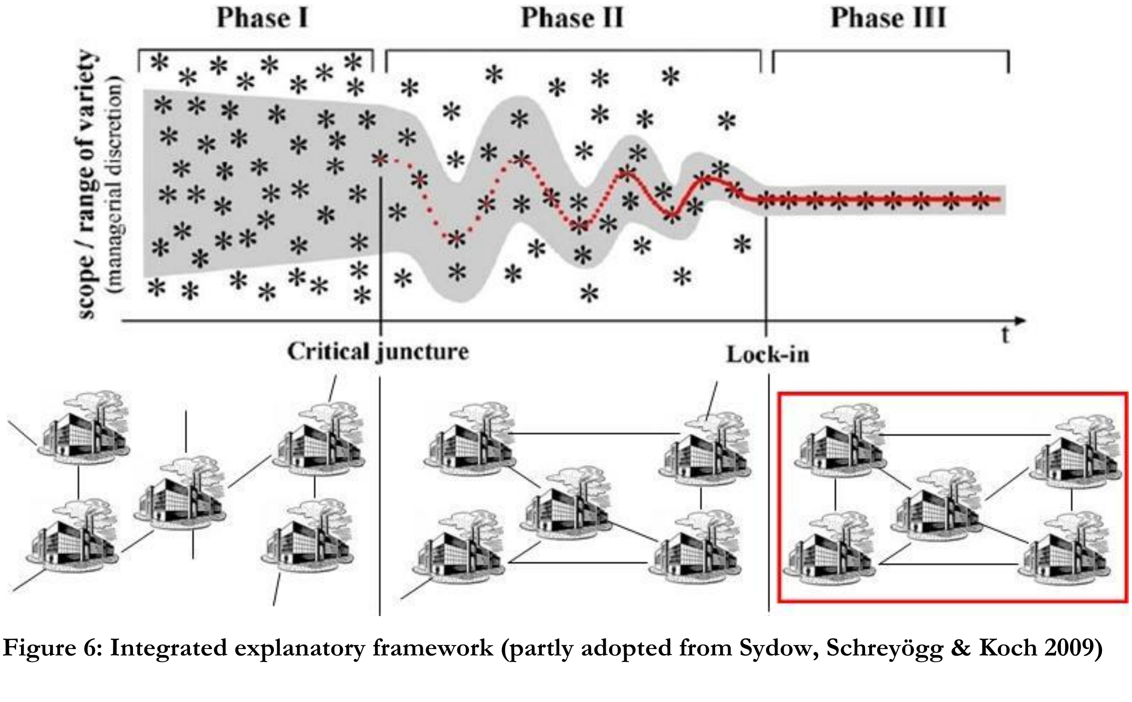

Figure 6: Integrated explanatory framework (partly adopted from Sydow, Schreyögg & Koch 2009)

2. 6. 4. 1. Initiation phase

As an industry develops, some actors become aware of others in a loose network of unidirectional or bidirectional consciousness. Of these potential linkages, certain ones become activated as actors engage with others through cooperation ties. These ties arise because firms seek to learn from or with one another, because some rely on others' resources or because forming a strategic collaboration has certain advantages in terms of market access, market dominance or for other strategic reasons such as joint research and development or asset sharing.

In this initiation phase of the path-dependent process, relations do not endure for eternity, but are purposive and not yet deterministic for future development of the network structure. The relations created in this process constitute the small events of path dependence theory, because at their point of establishment they do not point towards the lock-in as the outcome. Even if that effect were to be desired by some members because of distributed agency, this is not predictable. The relations are thus non-deterministic developments with regard to outcome at the beginning of the process (Sydow, Schreyögg & Koch 2009), since it is unclear if and which relations or positions may become persistent and lock-in actors. The relationships are, however, also meaningful enough for the actors to signify strategic interest. Hence the relationships hardly occur by chance in the way that small events in path dependence theory are sometimes claimed to occur but are based upon strategic decisions by firms' managers.

In the development of the emerging network, a critical juncture is typically a relationship that becomes more important than others or an actor who exhibits stronger importance for several other actors. This situation is often characterised by a strong, i.e. large, established or resource-potent actor who brokers between several others. Such a strong player can unite others from the same industry or even from different industries in order to mete out certain connections and projects. The broker closes the structural hole between other actors so that they connect and potentially also begin bridging structural holes between still more actors or industries by connecting with those from formerly unconnected realms of the same or different industries. The initiation phase ends with a critical juncture which is often marked by an official announcement by the connected agents that they are entering into a strategic group of cooperation and coordination, potentially with the broker becoming a hub firm or NAO. Alternatively, other players in the industry or even outside may develop an awareness of the importance of the connections that have been forged around the broker.

2. 6. 4. 2. Path formation phase with positive feedback

The second stage of the path dependence process is marked by the emergence of a social mechanism that exhibits positive feedback. Of the potential positive feedback mechanisms described above, one is social capital. From the initial brokerage situation, groups form around the central actor(s) and, after the critical juncture, this situation may further be marked by the announcement of an official alliance, alliance block, or consortium.

The agents in the emerging groups engage in concentrated interaction, cooperation relations and/or resource exchanges. Based upon positive experience and due to increasing dependence on other network members, inter-firm cooperation and resource exchanges increase among members. The increasingly dense network structure enables the building of reputations, mutual learning (Lubatkin, Florin & Lane 2001), the emergence of partner-specific absorptive capacity, and relation-specific investments. Furthermore, norms of cooperation arise that imply expectations such as reciprocity or loyalty. Moreover, the network relations may be or become coordinated by the lead firms (hubs/NAO) to some extent.

These activities increase the network's cohesion and the property of density which, according to Coleman, generates a great deal of social capital, which actors seek in order to facilitate future exchanges. These effects make investments into existing relationships ever more valuable and thus more likely for alliance members. Members hence replicate relations from the past (Zaheer & Soda 2009: 27) and simultaneously enact network closure which again provides the basis for the norms that bind actors to others and to the group. Over time, then, the positive feedback mechanism of social capital reduces actors' options for possible new relations outside their known network and restricts relation options to the existing network.

The networking activities and the positive feedback exerted by the same lead to a further increase in the network's property of density. Higher network density goes hand in hand with the social capital from closure. "Network closure is essential," (Burt 2005: 109) as a means of creating trust, but also for strategic reasons, because closure aids the pursuit of common goals. Closure does not imply the exclusion of potential new members (this may even be counterproductive if market power is a goal), but that it may impede external cooperation, foster internal cooperation, and prevent voluntary exits of firms from the network.

In contrast to Burt (2001; 2005), who views closure as part of the social capital generated by brokerage, this framework considers closure a distinct source of social capital in terms of Coleman's (1990) connectedness within the network. Burt (2005: 127) chiefly sees closure as a (potentially unwanted) by-product of brokerage and argues that brokerage and closure unfold simultaneously. In this framework, the processes may occur partly simultaneously, but after initial brokerage, the subsequent social capital from and incentives for closure are consecutive. Furthermore, Burt (2005: 197-223) neglects strategic interventions of network members to achieve closure, also on the part of the broker, and only considers rigidity in trust as potentially problematic. Here, incentives for closure arise after brokerage and stability emerge through structural network closure. Consequently, closure is a process that builds upon initial brokerage and has its roots in the strategy of the agents who seek to maximise the benefits of network closure. At the same time, these benefits exert strong restrictions on the strategic flexibility of firms to network outside their immediate network environment and can thus lead to them becoming trapped in a network of their own making (Gargiulo & Benassi 2000) if the network enters lock-in.

2. 6. 4. 3. Entering lock-in

The positive feedback forces of social capital from network closure are initially desired and sought after by network actors, but may turn into a vicious circle and lead to a lock-in in the final stage. There, the previously beneficial dynamics of the positive feedback mechanism of social capital turn into a restricting, stifling and strategically inadequate force of stability that binds actors to their previously chosen group and partners and can pose serious threats to a firm's performance and long-term survival.

Lock-in occurs when firms become overly dependent on other network members, potentially without perceiving and therefore not even pursuing any external alternative that may be better for them individually. This network lock-in itself may not necessarily be inefficient or ineffective for the respective actor. However, persistence in the reproduction of relations can prove strategically problematic, because structure is the basis for and carrier of the flow of resources, information etc. If potentially better interaction partners outside the network cannot be chosen due to the inert structural embeddedness of actors and access to these outside resources is rendered impossible by network constraints (Duysters & Lemmens 2003), such a lock-in becomes problematic because actors can no longer chose with whom to cooperate.

Furthermore, the lack of exposure to information and knowledge sources outside the known network leaves firms overly vulnerable to the impact of drastic change in the strategic environment. Firms' ability to perceive, acknowledge and adapt to external change is one of the most important sources of their survival. Firms that are too heavily invested in, and too heavily reliant on, their group are exposed to strategic perils. Among others, these include the reduction of firms' ability to access outside knowledge due to restricted information access beyond their network (sub-)group, the increased likeliness that they might not acknowledge external shocks due to trust in other actors, the potential for groupthink, an inability to adjust to change by altering cooperation partners quickly enough before external shocks harm the enterprise.

Moreover, as firms enter alliances blocks, it is reasonable to assume that competing alliances might seek to instigate precisely such drastic change, potentially by extracting one very important actor, e.g. a hub firm, from a competing group, if only because of its 'internal shock' effect on the networking partners of that hub firm. Relying too heavily on such a group leaves the engaged firms exposed to the risk of being unable to adjust to such drastic structural developments. This further increases the likelihood that group member firms, if they at least superficially monitor their strategic cooperation ties, will seek to increase structural closure around their networking partners and group. Although many of these developments may be benign when considered individually, their potential combined effect, i.e. the combination of the relational, cognitive, and particularly structural dimension of social capital, makes for a potentially toxic blend of network dynamics. It is conceivable that in the event of very heavy external shocks, the members of such a group may face problems of survival or at least much steeper adjustment costs than without the network lock-in to which they were exposed. It is, perhaps, this rationale that drives actors to continually invest in the relations in the expectation that the more closely they cooperate, the more likely the success of their (sub-)group and, subsequently, the avoidance of such steep adjustment costs.

Overly close networks that lock in their members can also leave them vulnerable to knowledge exploitation by others if the expectation of loyalty and reciprocity reduces actors' ability to protect their proprietary knowledge (Zaheer, Gözübüyük & Milanov 2010: 72). Similarly, a firm has to invest resources to remain in a favourable light within the network and to fulfil the social obligations it owes or maintain the value of the ones it is owed. Depending on the commitments made and intensity of cooperation links, a situation could arise in which the costs of partnering necessitate increased resource expenditure or higher investments than the output generated by individual relations or even the entire group. In such a case, it would be best to leave relations or the group. This may be restricted, however, in several ways. Firstly, a firm would have to recognise this situation and then be able to act on it. Both abilities, though, are reduced by the cognitive, relational, and structural lock-in of the firm to its group, as shown above. In this situation, membership of the group may become deleterious to a member firm, leaving it with no option but to continue the formerly successful ties due to being locked-in to their network and thereby excluded from other options.

A final structural argument with regard to social capital-induced network lock-ins is the form of a further strategic barrier in the network structure. As network density increases over time within a network (sub-)group around a hub firm which brokered the initial connections, that actor's ability to orchestrate the ties in order to maximise the degree of centralisation decreases. Density and centralisation, as indicated by the in-degree centrality measure, cannot both be strategically pursued at the same time. This can leave the former broker actor in a weaker position than would be the case if they had more control and less density around them, negating their advantages in the control of information or other resource flows and the implied learning benefit.

All in all, the positive feedback created by social capital can lead to a lock-in that exerts the forces of path dependence on the actors. Figure 6, above, summarises the integrated explanatory framework graphically, with the dynamics of emerging interorganisational network closure depicted alongside the development trajectory of path dependence as identified by the Berlin model of path dependence (Sydow, Schreyögg & Koch 2009).

3. Adding empirical context – an exemplary case

"We are going from a world where companies were independent systems, to a world where they became interconnected and interdependent systems" (Friedman 2005:90).

So far, unifying three streams of literature into an integrated explanatory framework has been a predominantly abstract endeavour. The ultimate purpose of the framework, however, is to explain *empirical* phenomena of path dependence in interorganisational networks identified as lock-ins driven by path-dependent positive feedback network dynamics. Since the discussion in the literature necessitates an abstraction from specific empirics, real-world examples have been limited thus far, although much empirical research was covered in the review sections. Newly-developed explanatory arguments, in particular, benefit from a confrontation with empirical reality for purposes of elaboration (Gilbert 2005: 743), substantiation and further development, by identifying how abstract mechanisms actually work in practice (Schreyögg & Kremser 2016: 699), especially if, like the present framework, explanations of an empirical phenomenon are being sought. This chapter deals with just that. As an important added benefit, the empirical case informs the computer simulation model presented in the next step of this research, because some of its elements profit from being empirically grounded (Edmonds 2012).

To begin, I explain the purpose and the approach taken. Afterwards, I outline the case selection and introduce the cases and their relevance for the research question. After detailing data collection and method of data analysis, I derive qualitative data categories for analysing the two embedded cases. A subsequent discussion of the findings in the light of the integrated explanatory framework is followed by a contextualisation for the cases– the mobile communications industry – in the form of a brief historical overview. The chapter concludes with the findings' implications for the framework and for the subsequent agent-based computer simulation as part of the multi-method research approach taken in this research. An early history of the mobile communications industry and an epilogue to the case study are contained in Appendices A and B.

3. 1 Purpose of case study and approach

The purpose of this case study is to substantiate the developed integrated explanatory framework's applicability to the empirical phenomenon of (potential) path dependence in interorganisational networks. As part of this effort, the case study serves to elaborate the framework (Gilbert 2005: 743), to illustrate the framework, and to further motivate both the research question and the framework developed to answer it (Siggelkow 2007: 21). The case study method also permits the identification of inductively arising elements that may need to be added to the framework for theory building and development (Sutton 1997: 99; Eisenhardt 1989).

'Testing' new theoretical arguments with empirical data is the typical means of assessing a theory's ability to explain real-world phenomena. In the literature, such a confrontation with empirical reality is often carried out through testing hypotheses derived from a theory. The according research design follows an archetypical structure of: (observation of phenomenon), inducing causality predictions from existing or new theory; deducing competing hypotheses from these predictions; testing these hypotheses – or often rather the null-hypothesis (Cohen 1994: 998-1003) – with quantitative data; feeding this data into multivariate regression models or other statistical data analysis methods in order to identify the stochastic relevance (i.e. statistical significance) of individual explanatory factors; testing, comparing and discussing multiple competing explanations based on these results; and lastly identifying one or several variables that explain a share of the variance in the data. This archetypical approach has its strengths particularly when competing explanations exist that can be measured in a quantitative way and when statistic generalisation is the primary goal (Smaling 2003: 52).

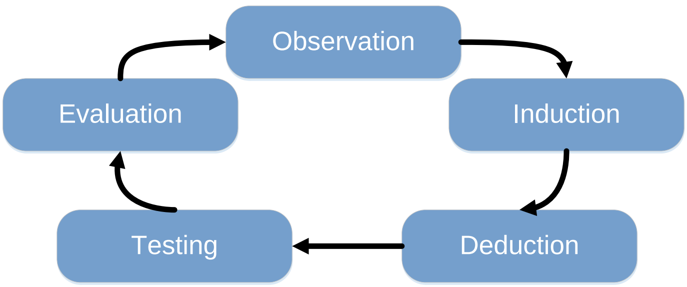

Figure 7: Scientific cycle (Wijermans 2011: 63)

The literature discussion in Chapter 0 developed an integrated *explanatory* framework rather than offering specific hypotheses whose testing could follow such a positivistic theory testing systematic using falsification (Popper 1935). For this chapter, the focus thus lies not on testing competing predictions and statistical generalisation, but rather on understanding and explaining an empirical phenomenon's internal logic (why- and how-questions), and on the framework's ability to explain this internal logic, i.e. to provide "conceptual insight" (Siggelkow 2007: 21). Deductive hypothesising cannot readily be applied, given the focus on why and how questions, and an interpretative approach appears more adequate for this task. Given this difference, an exploratory, qualitative case study (Yin 2009) appears adequate for substantiating the framework with a suitable empirical reality and for specifying and further developing the framework suggested above.

The case study approach is also appropriate because path dependence in interorganisational networks is a dynamic phenomenon that unfolds over time, i.e. it is longitudinal in nature and follows a non-linear logic with feedback processes. Thus, measures in terms of cross-sectional variables that are used in many quantitative approaches such as statistics are not readily applicable as this could result in a considerable distance between the phenomenon and the data (Siggelkow 2007: 22-23). Case studies, however, can be used more as a means of developing theory, rather than testing it (Gibbert, Ruigrok & Wicki 2008). Some scholars tackle this task in a grounded theory-like manner (Suddaby 2006), but this can lead to issues such as a case study just as complex or overdetermined as reality, thus yielding low insight into the phenomenon (Siggelkow 2007: 21). Striking this balance is important for achieving the goals of motivating the research, substantiating, and illustrating the explanatory framework, and inspiring new ideas for theory development. Hence, choosing suitable data and analytical methods are of high importance.

Taken together, the present case study serves four purposes: firstly, it provides a real-world example of cases that *motivates* the creation of the above explanatory framework, revealing the framework's relevance and its applicability beyond a purely abstract discourse. Secondly, since it was observed during the time of developing the framework, the case served and serves as an *inspiration* for the further development and specification of the framework. Thirdly, the case study is an *elaboration* (Gilbert 2005: 743) and an *illustration* (Siggelkow 2007: 21) of the developed framework, and thus both a contextualisation and plausibility check for the same. Altogether, these aspects enable the case study to *substantiate* the framework's arguments. Finally, a more practical aim of confronting the developed framework with an empirical reality is that learning from relevant empirical data allows for a further specification and operationalisation of the framework's elements, given that beyond broad categories, variables are not yet clearly definable. This aspect is particularly important regarding the creation of the simulation model (Chapter 4) which requires the precise specification of variables, processes, and their 'translation' into algorithms.

Eisenhardt suggests an 8-step model for theory development through qualitative research (Eisenhardt 1989: 533) which this chapter follows, with some indicated deviations. The definition of the research question and prior discussion of theoretical constructs (step 1) were extensively developed above. The subsequent two steps are the selection of cases and the development of suitable data collection methods.

3. 1. 1 Selection of cases

The selection of cases is performed through theoretical sampling (Eisenhardt 1989: 533) and followed by an introduction to the context, the cases, and their relevance for the present research.

3. 1. 1. 1. Theoretical sampling

The introduction, literature discussion and the explanatory framework above laid out several implicit criteria that a suitable case would need to satisfy. Overall, a presently developing high-tech industry that relies on collaborative ventures seems an ideal candidate, for the following theoretical sampling reasons. Firstly, the firms in the industry of choice need to practice networking to some extent for network path dependence to be generally conceivable. Secondly, the development of these networks must be observable over a period of time rather than as a cross-sectional view to be able to study the network dynamics and trace the phenomenon. Thirdly, such an industry needs to hold the potential to demonstrate how the mechanism of social capital develops from loose to denser ties, if the phenomenon is to be understood through the explanatory framework. To that end, a fully connected, densely networked industry would come too late to study the mechanisms at work, i.e. the process needs to be studied as it unfolds. Given the technological effect and standardisation tendencies of other networks in the path dependence literature (e.g. the cases of *QWERTY* or *VHS*), a technology industry appears adequate for an investigation into the framework's applicability and for illustrating and substantiating its mechanism.

A suitable context is the mobile communications industry, where the emerging smartphone operating system (platforms) market is treated as the overall case. It contains two networks that are studied here as two embedded cases (Yin 2009: 46): The *Open Handset Alliance* (hereinafter: *OHA*) founded by its hub firm *Google* is the (temporally) initial and thus critical case (founded 2007), while the *Symbian Foundation* (hereinafter: *SF*) founded by its hub firm *Nokia* shall be considered a literal or theoretical replication (founded 2008). The cases ideally fulfil the characteristics of a "most similar" yet contrasting research design (Yin 2009: 50-56.) since both developments occurred simultaneously and longitudinally at the time of study. The design thus follows a replication logic of an (expected) "literal replication" (Yin 2009: 54). Such an embedded case study design is particularly useful for achieving higher external validity through the cross-case comparison (Yin 2009: 41), although the embedded cases are sited in the same general context. The levels and units of analysis constitute the whole network level and the alliances (interorganisational networks) in which companies are members (of course, companies are typically represented by their staff), as well as their relations.

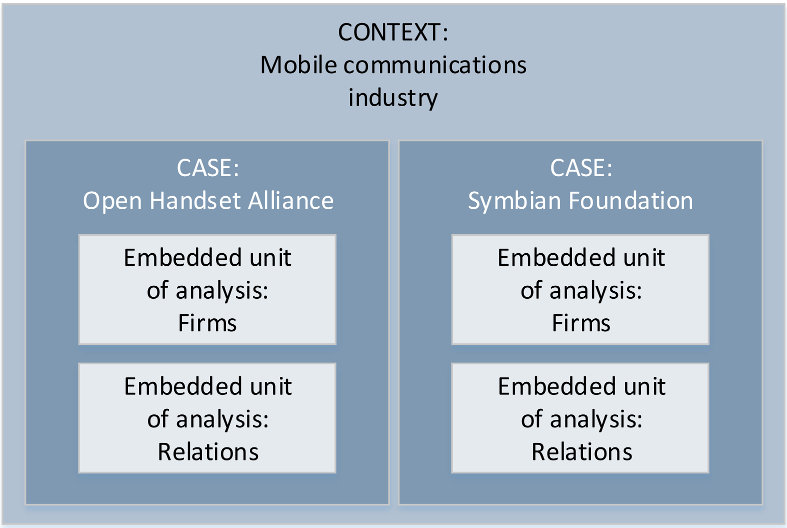

Figure 8: Case study design (adapted from: Yin 2009: 46)

3. 1. 1. 2. Introduction of the mobile communications industry

Mobile communications have rapidly become one of the world's most important industries. This fast-paced environment is characterised by globally operating firms, fierce competition, and technology-driven innovation. Recent industry developments include technological standards for mobile communication and mobile internet access such as 3G/UMTS (Ansari & Garud 2008) and more recently 4G/LTE. The internet has profoundly changed the way we use information, communicate, and organise our society (Bargh & McKenna 2004). The importance of mobile devices is growing steadily, mainly because they provide internet access anywhere and anytime (Lees 2010). We have become an "always-on" society (Manasian 2003) and smartphones[14] are becoming the main access device (Grech 2011). Analysts estimate that internet access from mobile phones exceeded that from computers in 2013 (Gartner 2010), even earlier in developing countries. In device numbers, mobile phone manufacturer *Nokia* estimated 4 billion handset users already for 2010 (Symbian Foundation 2009), while the frequently studied PC market (e.g. Shapiro & Varian 1999; Burgelman 2010; Dobusch 2008), pales in comparison: *Microsoft* CEO Steve Ballmer estimated 'only' 1 billion users for 2010 (Kanellos 2004), and sales have slumped since. Users are adopting smartphones at a rapid rate, as can be seen from the sales figures below. In 2014 alone, sales exceeded 1bn units and surpassed that of PCs and laptops as early as 2011 (Canalys 2012).

[14] Smartphones are mobile phones with an operating system that provides capabilities exceeding voice and SMS communication and including PDA or even PC functionality. Features include address books, calendars, email clients, internet browsers, cameras, audio and video players, satellite navigation, eBook readers, and touchscreen-operated user interfaces. Tablets employ essentially the same technology with larger touchscreens and are, in this study, always implied without particular mention when referring to 'smartphones.'

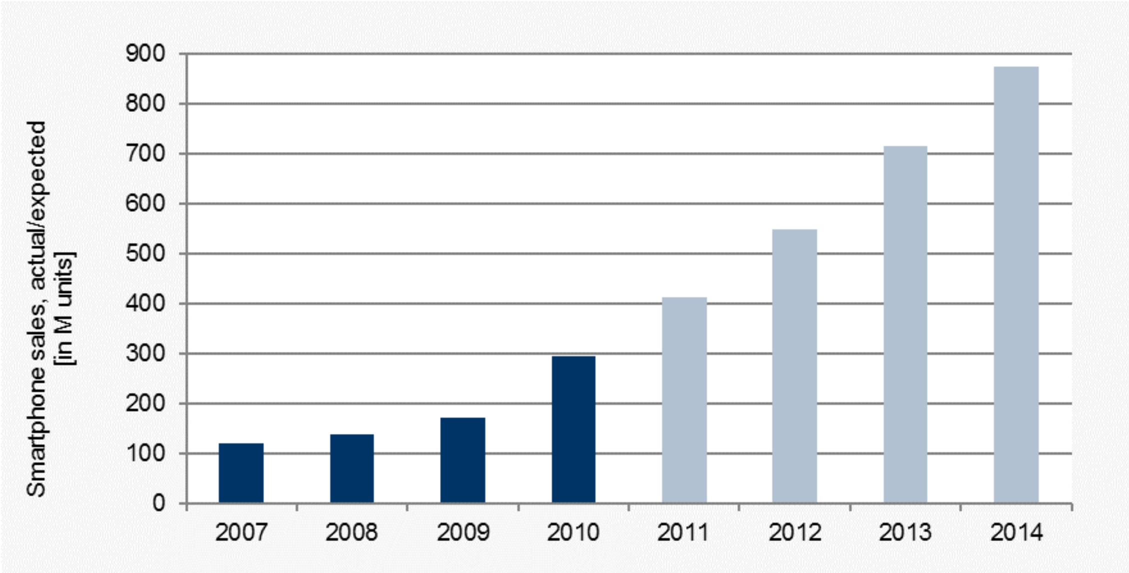

Figure 9: Smartphone sales 2007-2014 (aggregated sources)

One central technological development with major revenue potential is the capacity offered by smartphones for users to install own software, known as 'apps.' Running applications on mobile phones had been possible for several years on phones from e.g. *Nokia*, *SonyEricsson* (now: *Sony*) or *Microsoft Windows Mobile* operating system devices, but it was manufacturer *Apple* that 'inaugurated' this market with launch of the *iPhone* and a connected app platform. Albeit a relatively new phenomenon for customers, apps are already an attractive market, as indicated by the rapid growth of download numbers: 500 million in early 2009, one billion in late 2009 and three billion downloads in January 2010 from *Apple*'s proprietary *App Store* alone (Slivka 2009; Apple 2010a). This quick growth trend holds across platforms as was suggested by a reported 1 million downloads from only 30 apps available within 20 days after the *Palm Pre* smartphone launch, of which only 150,000 had been sold at the time (Ricker 2009). This averages approx. 7 app downloads per phone within this short time. The (now) famous phrase "There's an app for that!" symbolises the rapid proliferation of application solutions to address user needs. Apps do not work universally on all devices but respectively on a single software platform. These platforms are the operating systems (OS) that come pre-installed on devices and cannot be changed by users.[15] It is at this level that a real revolution is taking place: until recently, mobile phone makers had programmed proprietary operating systems for most of their handsets or purchased licenses for either *Microsoft Windows Mobile* or *Symbian OS*.

This changed significantly in 2007 (Google 2007) when *Google*, which had previously not been involved in the industry, announced the development of the OS called *Android*. Aiming at establishing the *Android* platform as a new market standard, *Google* founded the *Open Handset Alliance*, a strategic

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[15] This is becoming possible technically, but remains difficult and typically voids warranties or guarantees, thus remaining more or less a niche solution.

network first comprising 34, currently 87[16] firms, from several industries such as device manufacturers, semiconductor producers and software partners. The goal of this alliance is to develop and implement a free open-source OS for mobile devices. After the introduction of the *Android* operating system in late 2008, the market situation changed considerably. Driven by the powerful new entrant *Google*, this alliance is breaking the unwritten rules of the market – licensing an operating system – by building on the cooperation of several players to realise the platform. This marks a "rationality shift" (Koch 2008: 56) within the industry.

Then market leader *Nokia* reacted to this new situation by establishing a strategic alliance at the end of 2008: the *Symbian Foundation* with over 70 members initially, and over 180 members at its peak. The goals of this strategic network are congruent with those of its competitor: to provide a royalty-free open-source platform for mobile devices, albeit on the basis of the *Symbian OS*. This was originally a proprietary, license-based OS by the eponymous *Symbian Ltd.* which was an industry consortium dominated by *Nokia*. *Nokia*'s relinquishment of this licensing revenue source is indicative of the industry's disruption which has been described by *ZDnet* experts as the "battle royale" between the two alliances (Espiner 2008). While other platforms do or did exist (most importantly *Apple iOS,* and *Microsoft Windows Phone*, and the less important *HP (*previously *Palm) webOS, RIM Blackberry*, *MeeGo, Samsung bada, Tizen*), these alliances created two competing camps, each allying important players from several industries. Both camps' strategies involve gaining a large market share for tapping the app market which can help recover the loss of licensing income induced by the new open-source approach. In other cases (*VHS* vs. *Beta*, *Blu-Ray Disc* vs. *HDDVD*, etc.), similar developments have led to the establishment of a (single) new market standard or triggered a so-called 'format war.'

3. 1. 1. 3. Relevance to research question and explanatory framework

The mobile platform case lends itself to be studied from a path-theoretical perspective not least because it analyses what Arthur considers "agents choosing between technologies competing for adoption" (1989: 116) and potential standardisation. It is also of strong relevance to (inter-)organisational strategic networking research because it studies the competition of two alliances for technological market leadership (Reuer, Zollo & Singh 2002: 136). Creating alliances – and thereby changing the competitive environment (Gomes-Casseres 1996: 10) – is becoming increasingly important for firms, particularly in technology industries (Gulati, Nohria & Zaheer 2000: 204; Sydow, Windeler & Möllering 2004). The present case has been noted in research (e.g. Choi et al. 2007; Lin & Ye 2009) but neither from a network nor 'serious' path dependence informed approach (i.e. building on a processual model as used here). However, Nokia's shortcomings in interorganisational support have been named as reasons for Symbian's eventual decline (Laamanen, Lamberg & Vaara 2016: 14), and path

[16] The OHA website (http://www.openhandsetalliance.com/oha_members.html) claims 84 members but lists a total of 87 member firms at the time of writing.

dependence of Nokia as an organisation has been held responsible for the company's subsequent decline (Wang, Hedman & Tuunainen 2016).

The outlined developments are similar to the case of *JVC* positioning its *VHS* against *Sony*'s video system *Beta*. This prominent historical example of competing alliances and subsequent path dependence has been discussed even by path dependence critics (Liebowitz & Margolis 1995b: 218-222). It was reproduced almost exactly in the 'format war' between *Blu-Ray* and *HD-DVD*. In both cases, a single technology standard came to dominate the whole market. From a path dependence point of view both cases could be considered a lock-in to arguably technologically or economically inferior solutions.

Additionally, both cases were not a typical market decision as far as consumers choosing a standard through preferences revealed in aggregated demand was concerned, but rather clever collaboration with strategically important players on part of the technology firms. This networking aspect, however, was not addressed in research and creates a further motivation to study the interorganisational networks in the mobile OS alliances. The logic of interorganisational networks influencing a market standard differs from the conventional economic approach in that only the study of markets' supply side can reveal the reasons and mechanisms leading to potential lock-in. A further contrast to the video system case is that the mobile OS market has not yet become dominated by one standard. It thus allows not only for retrospective study, but for a contemporary perspective that treats it as a "phenomenon in the making" (Garud & Karnøe 2001: 3).

Furthermore, the case is relevant as regards the suggested mechanism of social capital introduced above, since both stages of the process interpretation of social capital are already superficially visible. Firstly, the activities of the two leading hub firms, *Google* and *Nokia*, suggest that they cross industry borders to create the alliances and thus bridge structural holes (Burt's argument) between the different industries involved. Secondly, once new connections are established, for each alliance and particularly their hub firms, it would seem logical to rely on strategies and activities that lead to strong ties and network closure (Coleman's argument). Such a strategy appears plausible in order to focus members on internal cooperation and disenable unfavourable external cooperation (Duysters & Lemmens 2003), and may ultimately lead to locking-in alliance members to the platform.

In sum, the case appears a suitable candidate for exploring the extent to which the integrated explanatory framework of path dependence in interorganisational networks can explain the phenomenon of interorganisational network structural rigidity. The theories of path dependence and social capital and the network approach will serve as 'sensitising devices' (Giddens 1984) in the process of analysing the data.

3. 1. 2 Processes of data collection and analysis

Collecting suitable data for the case study is an important step in the 8-step process of case study research outlined by Eisenhardt (1989: 533). Here she places importance on the selection of multiple data types and sources and, at best, several data gathering investigators. The notion of multiple data sources is seconded by Yin, who makes the tapping of several sources of information a requirement for the validity of the constructs used in qualitative research case studies (Yin 2009: 40)

3. 1. 2. 1. Data collection

This case study analyses the social capital dynamics and the potential path-dependent developments of two interorganisational networks. These aspects, the explanatory framework and the empirical field studied here are rather new, particularly when considered in combination. Hence this case study follows a general explorative approach. Moreover, the developments are relatively contemporary, and relevant information about the field should be obtainable, particularly because the focus of analysis is not so much on miniscule detail but rather on identifying the broad structural processes and activities in the strategic networks.

For the study of (whole) networks, Hollstein (2006: 11-35) suggests a relatively novel way of employing qualitative data collection and analysis rather than the standardised quantitative or statistical network analytical canon of methods. Qualitative methods can deploy their interpretative power when studying ‘networking work’, network developments and dynamics, and identifying central actors and network forms. Data sources suggested for this include interviews with network experts (Meuser & Nagel 1991), conducted either in a semi-structured or narrative way, the latter of which is useful when reconstructing temporally remote events (Manger 2006: 228-230). A further method is document analysis and particularly press analyses (Hollstein 2006: 23-24).

A press analysis was conducted in order to provide an outside perspective on the networks studied here. Furthermore, semi-structured and narrative interviews (see Appendix D for the interview guidelines) add to the press data gathered to provide an inside view, and because they permit a more theoretically informed approach rather than (merely) a fully-grounded theory oriented one (Flick 2007: 216) and allow for data triangulation (Flick 2007: 519). Interviews were noted down or recorded and transcribed.

Additionally, the field subjects and experts conduct a large share of their (net)working activities at industry conferences where developments and ideas are exchanged, discussed and to some extent aligned. Hence, participant observation, presentations and notes from these conferences added to the pool of data in the form of recordings and notes of verbal statements. Lastly, some unsystematically-collected industry documents, e.g. consultancy analyses, were made available during conference participation. These inform the general overview of the field but were not specifically analysed separately.

The press articles, conference observations, notes and interviews were undertaken in cooperation with a second investigator[17], satisfying the criterion established by Eisenhardt (1989: 538) for enhancing the creativity of the study. Especially for the first part of contextualising the case study with a rich description of the industry developments, both quantitative and qualitative data is used, thus enabling a deeper insight and an understanding of the field's rationale (ibid.).

All data collected from interviews, conference participation, notes, press articles and other field documents are treated as text document data as customary in OMS research (Short & Palmer 2007: 728). In the next section, I provide a catalogue of the data: the case database which serves to satisfy the quality criterion of transparency and, by extension, reliability (Yin 2009: 45).

3. 1. 2. 2. Overview of collected data

At the beginning of the research project, some decisions needed to be made regarding the collection of press data which constitutes a large part of the data basis for this case study. The collection of the empirical data and the writing of the first section was performed as a collaborative effort and focused on following and collecting relevant reports from relevant press services. These press services were chosen to include diverse publications from the business press, general newspapers attentive to technology, a weekly periodical and IT industry news channels.

The publications selected for the business section are the *Financial Times Deutschland* (now defunct German edition) and *The Economist* to cover major events and developments in business activities. Two general daily newspapers were selected, the *New York Times* and *The Guardian*, and the periodical *Newsweek*. Furthermore, detailed IT industry coverage was obtained from *InformationWeek* and additionally the respected and important German online news service *Heise.de*. Furthermore, the developments of the two major platforms *Symbian* and *Android* were followed with the aid of the *Google Alerts* service that reports any news activity involving the search terms by email. This offered the ability to integrate further sources that served data triangulation. A systematic *LexisNexis* analysis of the press covered with a research query using the terms 'smartphone' and 'smartphones' yielded the following results for the investigation time-frame with the starting date 16 February 2000 (the beginning of the database) until the end of systematic data collection on 31 March 2011 (the conclusion of the initial funding for the research project):

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[17] The case study material and data were gathered and Section 3. 2. 2 and Appendix A were developed and written in a collaborative dyadic effort with my colleague and friend Tobias Meyer. Parts of the case data used here also inform his PhD thesis (Meyer 2012), although there, the data was studied with a different focus of analysis.

Publication	Number of relevant articles
Financial Times Deutschland	436
The Economist	45
The New York Times	489
The Guardian	220
Newsweek	3
InformationWeek	67
Subtotal Print	1260
Heise.de Newsticker	1920
Total	3180

Table 8: Press material collected

As indicated above, further text data material collected includes statements and interviews from professional individuals representing the firms as units of analysis or industry experts insightfully describing the same. These were recorded or noted down when the individuals concerned were holding presentations or were interviewed informally in three cases. For accessing industry expert assessments of the developments conveyed during industry presentations, the author(s) also attended one academic conference and four suitable industry conferences featuring many presentations which, together with notes taken during or after attendance, are treated as documents for analytical purposes. With the exception of a phone interview, sampling subjects for interviews which were held in the context of the conferences, and the conference participation, followed a systematic of initial convenience sampling based on approachability and thereafter following recommendations from the field.

Conference / interview	Date, location	Data
Telephone interview	07 Jan 2009, phone	1 interview
DIW open meeting	18 Jun 2009, Berlin	3 presentations 1 interview
OSIM World	16-17 Sep 2009, Amsterdam	24 presentations 4 discussions
DroidCon 2009	04 Nov 2009, Berlin	6 presentations
DroicCon 2010	25 May 2010 Berlin	10 presentations 1 interview
WipJam@ITprofits, Linuxtag	09 Jun 2010, Berlin	8 presentations 4 discussions

Table 9: Field material collected

The overall case study database below gives an overview of all sources used for the case study as required to provide a level of transparency necessary for construct validity (Yin 2009: 45). The historical contextualisation on the early development of the mobile communications industry (see Appendix A) incorporates additional information on technological and societal developments from academic, technical, and professional publications and is quoted where applicable. Thus, it does not additionally appear in the overview in the case study database. Furthermore, the epilogue to the case study (Appendix B) elucidates its development after the period covered by the data.

Subject	Type of data	Number	Source(s)	Time-frame
Alliances, firms, relations	Press articles	3180	News reports	Feb 2000 - Mar 2011
Alliances, firms, relations	Conference participations	5 (55 sessions)	Observant participation	Jun 2009 - Jun 2010
Alliances, firms, relations	Interviews	3	Recordings, notes	Jan 2009 - Jun 2010

Table 10: Overall case study database

3. 1. 2. 3. Process of data analysis

For Eisenhardt's fifth step, "analyzing data" (1989: 539-545), she recommends following a replication logic and the tabulation of evidence. Here, I follow this recommendation with both the case study design as outlined above and by performing a cross-comparison of the evidence in the form of tables. Regarding the analysis of the data and arriving at the findings, the literature defines several ways of dealing with case data, especially material from different sources. These recommendations embrace similar ideas with regard to the structuring of the data and the findings – the building of categories, so-called 'codes', for grouping text units and then condensing these text snippets until theoretical saturation has been reached (Eisenhardt 1989: 533). Here, I follow the suggestions regarding qualitative content analysis (Flick 2007: 410) – selecting meaningful phrases and bundling similar phrases and paraphrases into categories that have been previously thought through (Bowman 1984: 61) – and theoretical coding (Flick 2007: 388-400; Böhm 2005: 477-485) – moving from 'open coding' and the refinement of initial categories through 'axial coding' to increasingly more 'selective coding' and conceptualising in the iterative process. The diversity of data serves the purpose of triangulation where possible (Flick 2005: 309-318).

I deviate from both 'pure' forms in that I fuse their techniques to some extent. This happens for two reasons: firstly, since the task of the case study is to assess the applicability of the explanatory framework to real-world cases, the case selection followed a theoretical sampling approach (Merkens 2005: 295-298). Thus, the categories for data analysis are necessarily derived chiefly from the framework in the sense that the analysis is guided by the theoretical constructs in the explanatory framework; path dependence, social network analysis, and social capital and they serve as 'sensitising devices' (Giddens 1984) for studying the material and building categories. The application of a purely grounded theory approach would not make much sense given the advanced stage of theoretical development. Secondly, especially when approaching a new field, it is important to remain open for categories which arise inductively, despite not following a fully grounded theory approach (Suddaby 2006). Accordingly, the process of building the empirical categories derives both from theory and reasons inductively from the data. The broad (deductive) categories from the framework were used when approaching the data and extended inductively during the process of analysis. The overall process of analysing the conference presentations and interview data essentially followed six steps:

- 1st Derive from the developed framework adequate categories according to which data excerpts could be grouped and represent the relevant constructs of the framework.
- 2nd Study the data and mark relevant findings in the data with the appropriate categories.
- 3rd In the data categorisation process, extend categories inductively where necessary and use these in the further analysis.
- 4th Gather data in category tables and allocate data excerpts (quotations and other examples as text strings) to categories.
- 5th Appropriately interpret the data examples and show their respective meaning and interpretation.
- 6th Discuss findings and interpretations per category while contrasting cases, finally extending this across all categories.

In presenting the findings, I deviate from reporting on the cases individually as suggested by Yin (2009: 57) and Eisenhardt (1989: 533), because I seek to condense the interpretation. Furthermore, some of the data reports simultaneously on both cases, a situation caused by having them both in the same context. Hence splitting up the findings into two different case narratives appears artificial. Furthermore, direct contrasting permits me to address the issue of internal validity as suggested by Yin (2009: 40), by testing rival explanations and pattern matching across cases, an effort aided greatly by direct contrasting, particularly so since the case design is a literal replication. I do, however, follow Eisenhardt's advice (1989: 540-543) on presenting the findings in a tabular form and adopt the conceptually ordered, content-analytic summary table format suggested by Miles and Huberman (1994: 183-184). In building the case analysis, I follow a "temporal bracketing" sense-making strategy (Langley 1999: 703-704), both because the subject matter of the case study is a process and because the phase-oriented theory of path dependence indicates a suitable fit.

The data analysis is thus constructed and ordered according to the processual order of the categories derived from the framework. Each category first receives a brief introduction focusing on the rationale for creating it and the reference to the framework. Then, excerpts or extracts of the data, its sources and interpretations are presented in tabular form. After the presentation of findings for each category, I discuss and analyse the individual categories respectively, to address Eisenhardt's sixth step, "shaping hypotheses" (1989: 533). Afterwards, I provide an adequate contextualisation for the case study (Yin 2009: 18) by reviewing relevant recent developments of the communications industry as a rich historical description which functions in a manner similar to the 'field notes' as part of Eisenhardt's fourth step 'entering the field' (Eisenhardt 1989: 539). For step seven, "enfolding literature", I reflect on the insightfulness of the overall findings for the categories and the historical context of the explanatory framework. Finally, I re-establish the connection with the framework and create a new connection with the computer simulation model in an effort to reach closure and theoretical saturation (ibid.).

3. 2 A tale of two networks: case data and findings

"No organization is an island" (Parmigiani & Rivera-Santos 2011: 1109).

Having discussed the reasons for the case study, selection of cases, and the data collection and analysis process, this section focuses on analysing and interpreting the data with regard to processes, relationships, social capital, and path dependence dynamics.

3. 2. 1 Field data analysis

Overall, I created five data categories, four of which are derived from the explanatory framework and one of which ('Fragmentation') arose inductively. These categories are presented, substantiated with empirical examples, and discussed individually in the following five sections. After subsequently outlining the historical context, I reflect on their connections, overall meaning and particularly their interpretation in terms of the explanatory framework. As above, I refer to the two alliances as (sub) case *OHA* (*Open Handset Alliance*) and case *SF* (*Symbian Foundation*) in the presentation and discussion of findings. Interviewees are designated as "expert" alphabetically to provide anonymity. Other material is named by source type. All quantitative information contained is deemed relevant and effective at the end of the data collection period, yet certain figures regarding sales, alliance memberships, devices, apps etc. have changed since.

3. 2. 1. 1. Brokerage and entry

The first qualitative category developed stems from the initial phase of the framework. At this stage, formerly unconnected firms initiate cooperative ties with other firms in a 'small events' manner, i.e. are far from establishing a lock-in. In the initial stage of the framework's process, firms enter a network and connect via or through some hubs. I therefore allocated the category 'brokerage and entry' the subcategory 'motivation for membership' in order to identify why they join the network, 'new relations' in order to capture what relations they enter, and 'membership entrance process' in order to detect how they become an official member of an interorganisational alliance.

Data category */ subcategory*	**Illustrative finding** *(Source)*	**Interpretation,** *meaning, relevance*
Brokerage and entry		
Motivation for membership	- *OHA*, *SF*: "We want to hear developments at an early stage and have influence" (expert A).	- The firm entered both alliances with the aim of gaining an information advantage and influence.
New relations / access to resources	- *OHA*, *SF*: "We have established many new relationships for cooperation" (expert A). - New cooperation agreements announced (press).	- After the firm's entry to the interorganisational network, it enters new relations which may bridge existing structural holes. - The alliance activities result in new cooperative relationships.
Membership entrance process	- *OHA*: "*Google* carefully selects alliance members and manages information flow within – all goes via Google" (expert B). - *OHA*: membership entrance procedure not transparent, fees unclear, application informal (web). - *SF*: membership application process transparent on website, fees indicated, voting rights explicit (web).	- Already at the beginning of a new relation, the hub firm is using its brokerage position in the network to control entrance and information. This position indicates a control/ information advantage. - The hub firm appears to decide upon admission alone, thus effectively exercising strong admission control. - This transparency suggests a less controlling approach compared to *OHA*.

Table 11: Findings for category 'brokerage and entry'

The analysis of the category 'brokerage and entry' category provides two central insights: membership and connections are largely based on the desire to access information, resources and influence within the network, as expert A reported. Expert A works for a network provider and the reason stated for cooperation points towards the power shift from the individual firm to the alliance. They seek to influence the industry through the alliance, rather than as an individual player. The firm for which expert A works was a member of both alliances at the time of the interview and thus seems to follow a portfolio strategy or to be "hedging its bets." The motivations for networking stated are consistent with the analysis of OMS research on the motivations for establishing cooperation ties with alters.

Additionally, the initial connections in *SF* are more transparent than in *OHA*. While the reasons for this difference remain unclear, the result is indicative of a dissimilarity in concepts of alliance management and leadership. While *SF* offers a clear membership application process on the internet where players can enter at will, pay a transparent membership fee, and gain one vote in the foundation's board, the process in *OHA* basically depends on the hub firm's acceptance and selection, as reported by expert B. This difference appears to indicate a more 'transparent & democratic' approach (*SF*) vs. a more 'steered & autocratic' (*OHA*) alliance management style. What can be deduced from this difference is that *Nokia*, the hub firm of *SF*, may have less or perhaps weaker connections than *Google* as the more steering-oriented hub. Based on this stronger steering, *Google* would be expected to exhibit more direct connections with other players, and more connections through them, indicating both higher network (degree) centrality and stronger social capital from brokerage than *Nokia* in *SF*.

At this stage, firms seem not to be immediately bound exclusively to the network they entered, since several bigger companies maintain multiple memberships. Hence the entry of players to the alliances only marks the beginning of a potential chain of events that may lead to increasing closure within the network. The events of entry and the connections established among firms do not exert lock-in forces over its members. Social capital effects from brokerage appear stronger in the case of the more brokerage-intense hub in *OHA* vs. *SF*'s more decentralised approach. The hub firm *Google* is spanning the boundaries within and beyond the industry and connects formerly unconnected firms, e.g. commercialisation consultants with developers, and integrates new industries such as game developers from the game console market, media publishers, and financial service providers. These new connections bridge structural holes that formerly left these firms and industries unconnected. Brokerage, the activity of closing structural holes, is additionally carried out by several of the alliance members in both subcases. A key difference lies in the intensity with which the hub firm *Google* initiates connections compared to the looser approach of hub firm *Nokia* which allows for more connections being forged directly by the members rather than going through the hub firm, i.e. it appears that *Google* is brokering more actively than *Nokia*.

3. 2. 1. 2. Alliance activities

After the initial stage of the developed framework, some firms can be expected to make use of their connections. It is interesting whether and to what extent the initial networking activities lead to something more over time, or if alliance membership becomes irrelevant after the initial connections. The latter would certainly indicate that a future problematic lock-in might be less likely, but an escalation of connections would provide indications for the workings of the social capital mechanism that leads from brokerage to closure. Neutrally-phrased, the category 'alliance activities' seeks to identify whether and to what extent the firms continue to interact (or not) and what kind of fruits their activities bear. These include applications produced as a result of working towards the common platform as well as devices launched. Furthermore, in network terms, collaborations such as joint R&D activities would be represented by alliance-internal network ties and, if the networks are attractive, more members. The duration of the relations in the field can provide advance indications of early stabilisation tendencies.

Data category / *subcategory*	Illustrative finding *(Source)*	Interpretation, *meaning, relevance*
Alliance activities		
Number of applications	- *OHA*: apps available in the Android Market app store: 50,000 and increasing (press). - *SF*: apps available are unclear; no centralised store exists, but: 6,500 apps and 1.6m downloads daily from Nokia's OVI app store (press, analyst reports).	- The activities in the alliances are increasing and producing app output. - The increasing output indicates fruitfulness in terms of the cooperative relations, but mainly for the hub firm, since others have no access to the OVI store.
Number of devices launched	- *OHA*: increase from 0 devices at foundation to some estimated 140 devices (including hardware other than smartphones e.g. Netbooks, Tablets, Blu-Ray players, SatNavs and cars.) 100,000 handset activations per day (press). - *SF*: unknown handset number, but still known to exceed that of *OHA*, with approx. 40%+ market share (press). - *OHA*, *SF*: new product announcements have been made by manufacturers of either platform (press).	- Marketable devices indicate that relations with other alliance members produce beneficial outcomes for the alliance members. - Members have announced new products, but to a lesser extent than *OHA* members. This might indicate decreased success of the *SF* alliance relations in producing marketable output. - The foundation of both alliances has spurred increases in activity. Further industries have been added by *OHA*'s hub firm Google, bridging further structural holes between industries.
Number of members in the networks	- *OHA*: starting with 5, now: 71 (press, web). - *SF*: starting with 8, now: 181 (press, web).	- The attraction of new members to both alliances and resulting growth indicates an increase in activities and, as a result, in relationships within the alliance.
Number of relations within the network	- *SF*: participation in an industry event doubled from 2009 to 2010 (press). - *OHA*: despite being monetarily not as lucrative as competi-	- An increasing number of developers is persuaded to cooperate in the development of apps, thus focusing their activities on relations around a particular platform.

	tors, the Android app store attracts an increasing number of developers (press, experts, conferences).	
Duration of relations	- *OHA*: "We are looking at this with a long-term planning perspective" (expert A). - *OHA*: "We have been closely cooperating with firm X for some time now and expect this to continue" (expert B).	- Alliance membership creates new relationships that are (expected to be) of a lasting nature. This increases incentives for continuing membership and further investment in existing relationships.

Table 12: Findings for category 'alliance activities'

The insights from the category 'alliance activities' reveal two main trends regarding the two subcases. Output in terms of applications and devices is on the rise in both subcases, pursuant to the announcement of the two industry bodies. These increases can, at least to some extent, serve as an indication of the outcomes of the network relations. While the connections' potential for beneficial cooperation remained unclear at the outset, after only a short duration of the relations, output is increasing. Given that these relations appear to bear fruit, it can be expected that firms will continue to participate, since success is often considered a prerequisite for the continuation of relationships. The output measure of market share is higher for *SF*'s subcase. However, this figure benefits from the devices marketed prior to the launch of the foundation, with the result that the higher market share should be interpreted with caution. The number of applications is difficult to measure across the two alliances, as Symbian apps are distributed across the manufacturer-operated app stores, of which *Nokia*'s *OVI* is but one while *OHA* has the *Google*-managed store as a common distribution channel. Overall, however, while both subcases suggest growth, *OHA*'s app store largely appears ahead of *SF*'s decentralised efforts.

The second alliance activity trend is the attraction of new members and the establishment of new relations within the alliance. Subcase *SF* shows a stronger growth in membership numbers than subcase *OHA*. However, this impression, can partly be explained by the fact that many more companies in *SF* had previously used the *Symbian* operating system around which the '*Symbian Foundation*' alliance is built. With the formation of the alliance, it was possible to build on already existing relationships and continue them as part of the new alliance. In subcase *OHA*, this history of previously existing relationships was not evident. While some firms had links before the announcement of *OHA*, there was no clear relation and connection to the operating system *Android*. Thus, the existence of historicity in the networks marks a key difference between the subcases *OHA* and *SF*; the former does not display it, while the latter draws heavily on it. In the context of path dependence theory, historical relations may contribute to a path-dependent development of the system. The increases in numbers of firms and relations within the alliances, especially combined with historicity, may lead to a further increase in cooperation in future and concentration of members' activities within the alliance. In network variable terms, density would be one central measure expected to increase.

Furthermore, actors from outside the immediate realm of the industry have been added to both alliances. Players from the fields of finance, video games, navigation and even automobile manufacturers were previously not connected to the IT/communications industry yet are now in the wake of bridging of structural holes. The existence of these relations can be considered indicative of bridging activities in which the founding firms, in particular, have engaged in order to create greater traction for their respective platforms. *Google*, *OHA*'s hub firm, seems to be more skilled than *Nokia* at attracting outside actors from a greater diversity of industries. By comparison, *SF*'s firms show more concentration on technologies connected to communications. *Google* thus appears to be more effective when it comes to drawing benefits from its brokerage position. Given that apps created for the *Android* platform are financially less attractive (smaller 'installed base' of user devices, fewer selling devices, and generally lower app prices, compared to *SF* or even *Apple*'s iOS platform), this effectiveness appears chiefly attributable to *Google*'s activities. In the light of this development, an increasing number of firms and industries are connected within the alliances in this subcase. This reveals a stronger pull potential for *OHA*, despite the smaller installed base and financial attractiveness. Given that many of these new players are from fields other than communications, much learning appears necessary and the willingness of new players to the field to enter more than one alliance may be comparatively low as a result.

Overall, the fact that many players in *OHA* are not based in mobile communications, and the stronger growth rates indicated by *OHA*'s activities, could lead actors to become more focused on *OHA*. The historicity within *SF*, though, could prove equally problematic in terms of persistent relations for *SF*'s actors. Despite the early stages of development, the statements of two experts reveal long-term orientation with regard to the membership and cooperation relations entered by their respective employers. Already then, there are tendencies for a continuation of relations, incentives for focusing firm activities within the alliance's network and, not least, fruitful output upon which strategy makers can base their decisions to continue or discontinue with their alliance membership and the relations within the same, the continuation of which appears more likely.

3. 2. 1. 3. Closure, steering and control

'Closure, steering and control' refers to the phase in the explanatory framework in which actors' options for choosing their partners, projects and/or alliance membership are becoming limited, i.e. the path formation phase. This category addresses the workings of the three levels of social capital. Structurally, the narrowing of networking options would become evident through a closure of the network relations. In relational terms, an increasing dependence on certain actors, i.e. network partners, would be indicative of partnering options becoming narrower. At the cognitive level, cognitive-normative mental models, decision-making practices, rules, and rituals that are adopted within the network (and/or artefacts thereof) would indicate adopted group standards. These can exert normative forces and consequently make alternative choices towards the outside of an alliance more difficult for network members. Furthermore, reliance on certain activities of some actors can imply a control and/or power difference within the network, where e.g. certain actors surrender the ability to make individual choices dependent on those of other actors.

Data category */ subcategory*	**Illustrative finding** *(Source)*	**Interpretation**, *meaning, relevance*
Closure, steering and control		
Steering of activities	- *SF*: *Symbian Foundation* is seeking an alliance manager (job advert, web).	- *Symbian Foundation* is seeking to actively manage relationships within the *SF* alliance.
	- *OHA*: *Google* has a strong reputation for professional and successful project management with strong steering through contracts and deadlines (expert B).	- This ability attracts new members, forms the initial basis for *Google*'s social capital from brokerage in the alliance through offering access to a set of resources (management, free operating systems, market clout)
Normative forces	- *OHA*: "At the end of the day, *Google* decides" (expert B). - Code contributions to the *OHA* platform can de facto only be authorised by Google (expert C).	- Strong dependence on the hub firm. *Google* maintains its strong influence in the alliance, revealing further brokerage potential (social capital). Members may perceive this as a problematic issue, but still make the decision to accept this leadership.
	- *SF*: code contributions will be decided on by voting in the Foundation board (expert A/press).	- *SF* integrates a "one member, one vote" policy which allows for a 'democratic' type of power distribution. Individual members have more influence in this alliance, which may lead to increased cohesion and commitment.
Regular activities and rituals	- *OHA*: "We meet at workshops, develop roadmaps, have annual plenary sessions and web conferences" (experts A, B).	- Regularity in meetings with other alliance members can create commitment to long-term relations and thus bind network members.

Table 13: Findings for category 'closure, steering and control'

Evidence in the category 'closure, steering and control' chiefly arises from talking to industry experts. The data indicates some differences between the two subcases. One important practice in the participation of industrial alliances such as the ones studied is the management of relationships within the network. *Symbian Foundation*'s search for an alliance manager indicates that the Foundation's central organisation committee has recognised the potential advantages of steering relations. The ability to create closer ties among developers/software vendors and device manufacturers and other technology developers is targeted at enhancing cooperation. This activity can lead to an increase in connections within the organised group and thus more closure, structurally speaking. As discussed in the framework, closure can have certain benefits, such as control over others and information diffusion advantages, but also holds the potential for a dangerous lock-in situation in which closure prevents firms from discontinuing established relations or at least appears near-impossible to members.

A further difference between the two subcases lies in the fact that *SF* has a central steering unit (NAO), whereas the evidence from the interviews indicates that *OHA* is essentially managed by the hub firm *Google*. It is *Google*'s reputation and execution of project management activities that drives the alliance activities forward, and it appears that members are 'hooked' onto this driver. This is an indicator of relational dependence, although it is an even clearer indication of *Google* using its social capital from brokerage to advance cooperation within the network.

A connected contrast in alliance management is the way in which the alliances undertake their alignment. *SF*'s members have a voting board in which one company holds one voice, and their votes decide on code contributions to the platform's software. In *OHA*, however, "at the end of the day, *Google* decides" indicates a stronger role of the central network actor in managing the other members in a more "autocratic" approach vs. the more "democratic" voting mechanism established by *SF*. It is not clear at this stage which of the two steering philosophies might hold more merit or more danger in terms of path-dependent developments. In purely speculative terms, *Google* with more direct influence could steer *OHA* more quickly towards certain developments, implying less(ening) influence of individual member firms. If the hub firm follows an approach that leads the alliance into problems, the more direct steering approach may make it difficult for other actors' voices to be heard. Conversely, *SF* hears all members' voices during their board voting meetings since every member participates in these. As a result, steering is more of an aggregate of members' intentions than in *OHA*. However, this influence can theoretically both avoid and lead to path dependence problems. *SF* may address individual members' issues more willingly, but in cases of groupthink may also more readily accept detrimental courses of action if enough members support them. An exploration of the effects of the 'autocratic' vs. the 'democratic' orientation lies beyond the scope of this study, but the question holds much potential for interesting future research.

OHA's more directive approach of alliance management may point towards an increase of alliance-internal ties, given that closure offers certain advantages and steering an alliance towards closure is easier based on existing hub firm influence. Similarly, a lack of exits would be expected from a managed alliance with many internal connections and few with firms outside. For *SF*, the less directive management approach may contain opposite developments. However, empirical network structural data to answer these questions beyond theoretical extrapolation was not available, since (with few exceptions) many of the cooperative relations are not made public on the grounds of secrecy and competition, as was reported by experts and industry observers. In this sense, it is difficult to access and assess what goes on behind the scenes of the alliances.

What is revealed by the different alliance management approaches is the influence of individual firms on the processes of decision-making. One of the factors in social capital's three dimensions is the creation of cohesion. Cohesion may be easier to achieve in *SF* since individual member firms in this more 'democratic' atmosphere may be more able to freely engage, discuss, contribute, and build partnerships with alters than in the comparatively more steered *OHA*. The cognitive dimension of belonging, recognition, commitment, and mutual support (mediated, of course, by the people representing their firms in the board, for example) is more easily gained in the egalitarian board model.

Increased cohesion, however, also holds the potential for a stronger and potentially problematic reliance on other network members. *Google* in *OHA*, in contrast, maintains its position as a broker, apparently seeking to reap the structural and relational dimensions of social capital more than the members of *SF*. The dominant position of the hub firm in *OHA* points towards large brokerage potential in the face of increasing connections within the network. It does appear from the data, however, that *Google* seeks to circumvent the potentially lesser cohesion-inducing management style by a high frequency of meetings. Experts reported to have engaged more often with alters within *OHA* than with those within *SF*. However, the data on this matter could not be triangulated and it remains important not to over-interpret this report from the experts. It does, however, appear plausible that more meetings between *OHA* members take place since contrary to *Symbian*, *Android* is an entirely new software where more need for discussion may arise for purely technological reasons. *SF*, in contrast, can build on a more established code base and might require less meetings, albeit with a voting system when these do take place.

3. 2. 1. 4. Fragmentation

Fragmentation is an inductive data category that arose from field input and from data exposure. The issue of platform fragmentation was mentioned repeatedly by experts and industry observers. Fragmentation was raised as a concern because it holds many technological problems for an industry group seeking to advance a joint software platform. Fragmentation can exist for two main reasons: the first is the creation of a so-called 'fork': following a tree analogy, a fork is version of the main software that has been split off from the main stem into a new branch while drawing on some input from the initial stem. The importance lies in the fact that if forking is an aim, then these new developments are intentionally no longer fed back to the main stem but are strategically positioned to become their own stem. Such a situation can arise if a certain powerful software developer or hardware manufacturer which uses the software for devices creates a new manner of implementation, develops this into many subsequent versions that are no longer connected with the main stem and, over time, become fully detached, potentially even implying incompatibility.

The second major way in which fragmentation can occur is that device manufacturers and developers continue to use the main software stem. Rather than keeping up-to-date on developments and updating code, however, some, or even many devices stop updating or even working at a certain stage of development. Such a simultaneous existence of many different software versions on devices can be problematic with regard to device comparability, compatibility, functionality, and finally platform attractiveness from both user and alliance member perspectives. While 'forking' happens intentionally, version fragmentation occurs either due to slow or ineffective product maintenance, or for strategic reasons, e.g. intending a stronger selling proposition for devices with newer versions of the platform software – a practice similar (but not equal to) "planned obsolescence" (Bulow 1986).

These technological concerns also have a strong organisational component. Both ways in which fragmentation can occur have the effect that they weaken the platform individually, but particularly with regard to competing platforms. A forking or version fragmentation of any platform can be a problem for users and developers and can lead to a decreasing attractiveness of this platform, potentially limiting its commercial success. Fragmentation is thus problematic for all members of an alliance, even if they do not engage in activities that lead towards fragmentation individually. The category deals with ways in which field reports indicate that firms recognise the issue of platform fragmentation and how they seek to avoid it.

While studying the data and conversing with individuals from the field, fragmentation was expressed as a worry by several experts. However, only those in the *OHA* subcase expressed such concerns, not those involved in *SF*. This difference is surprising given that similar issues must be expected for *SF*, but experts and the press focused solely on *OHA* regarding fragmentation. However, history might be a reasonable explanation here, given that *SF* uses the *Symbian* operating system that had existed for several years before SF was established. Hence, fragmentation might have already been solved or, because of decentralised app stores, be generally less of an issue for *SF* members.

In *OHA*'s case, the issue of fragmentation is widely recognised and discussed. Representatives of hub firm *Google* commented that they perceive fragmentation essentially as a threat that needs to be avoided. Not surprisingly, the company has been engaging with network member firms to address the topic. Additionally, software developer companies have raised awareness of the issue in terms of creating websites (e.g. www.android-fragmentation.com[18]) to inform others of the dangerous possibility that the platform may lose traction through fragmentation.

[18] Now defunct. But similar new efforts exist, e.g. https://opensignal.com/reports/2015/08/android-fragmentation/

Data category */ subcategory*	**Illustrative finding** *(Source)*	**Interpretation**, *meaning, relevance*
Fragmentation		
Awareness of the issue	- *OHA*: "It would be a problem if projects dissociated. This is one of the biggest risks with open-source projects" (expert C).	- The hub firm and alliance members have recognised the importance of creating cohesion in the platform.
	- *OHA*, *SF*: "There is a lot of fragmentation here…" (app developer, Droidcon 2009)	- Both platforms are experiencing version fragmentation which is problematic for (app) developers.
	- *OHA*: developers are experiencing fragmentation-related problems in adapting code. Website projects have been dedicated solely to this issue (press, conferences).	- Developers (some of which are alliance members) are seeking cohesion through transparency to avoid extra coding efforts on their part.
Avoiding fragmentation	- *OHA*: new platform versions will be released to tackle fragmentation (press).	- A common technical solution will be implemented to tackle fragmentation.
	- *OHA*: developers are jointly discussing and developing means to overcome fragmentations issues (experts, conferences, press).	- Cooperative relationships have been established to overcome fragmentation.
	- *OHA*: *Google* is actively working to prevent forks away from their alliance's platform (press).	- This attempt at avoiding forks could be interpreted as an attempt to lock-in members to the alliance and the platform.
General platform development	- *OHA*, *SF*: improved versions of both operating systems have been released (press).	- Both alliances received (code) contributions from members to improve and extend the technological capabilities of their platform.

Table 14: Findings for category 'fragmentation"

In terms of avoidance measures, *Google* has been utilising its brokerage position and resulting control power to achieve cooperation and closure around the platform project. Their project management is engaging with developers and manufacturers to stop the issue from escalating. This discussion and a prospective solution regarding the non-forking or non-versioning of the platform code would represent a cooperative norm within the network that purposively restricts actors' individual liberty. Such a norm can have the effect that actors find themselves bound to such a rule and limit themselves in their freedom of strategic choice. To a certain extent, that is exactly what the norm requires, but commitment may spill over into other areas and enforce behaviour escalating to a lock-in within the cognitive dimension, subsequently resulting in a relational/structural lock-in.

The issue of fragmentation thus holds the potential to serve as a type of unification mechanism that would connect the alliance members more closely, increase internal cooperation, impede external cooperation, and ultimately lead to a lack of other options. It follows that software code serves as a formal way of enforcing this cohesion. In this context, the announcement of new software platform versions that embed changes made by the diverse contributors to the platform could be a way to overcome fragmenting diversity and ensure that "code is law" (Lessig 2006: 6). This law-like character of software platform code may have the ability to enforce common adherence, uniformity, and cohesive behaviour of network members, and also ensure that future cooperation is a goal. Additionally, it acts as a reference point for external alters who may find this orientation attractive and decide to join, creating further network growth.

3. 2. 1. 5. Lock-in / exit

The last analytical category is derived from the final stage of the explanatory framework – namely the phase of lock-in. Lock-in is a defining characteristic of path dependence because it is here that the process of narrowing down alternative/outside options culminates in a firm's inability to choose or even be able to recognise such alternatives. A lock-in is problematic in alliances when member actors are bound to certain relations and/or the overall network by forces of social capital. The three subcategories represent the cognitive, the relational and the structural network dimensions of social capital. Several indications exist for lock-in *tendencies* at the different dimensions of social capital.

An important development is that one firm – *Motorola* – has committed to using the technology of *OHA* exclusively, and has also confirmed that it will restrict itself to active membership of this alliance alone, despite having formerly been a founding member of *SF* and having used *Symbian* software for many devices, too. This new exclusivity represents a lock-in at the cognitive and network-structural dimensions (hence it appears twice in the above Table 15). The cognitive level consists of a newly restricted code-base. The skills of developers and engineers had been allocated to create devices with both operating systems simultaneously for some time, which indicated something of a portfolio approach to the software basis for their devices. Having learned much about both systems and having invested accordingly over time, *Motorola*'s decision to divest itself of its *Symbian* capabilities thus marks a strong strategic departure for this network member. At the network-structural level, *Motorola* gave up its influential position as an *SF* founding member (and a partner to the predecessor organisation *Symbian Ltd.*) and retreated to exclusive membership of *OHA*. Since metrics on relations and connectedness are unavailable, it is difficult to establish the effect of this decision on relations with other firms with which *Motorola* had previously maintained relations within SF. Similar arguments hold for the subsequent exits of *SonyEricsson* and *Samsung*, although of course all three firms had been members of OHA prior to the exit decision and were thus able to transfer their cooperative ties to the other alliance.

Data category */ subcategory*	**Finding** *(Source)*	**Interpretation**, *meaning, relevance*
Lock-in / exit		
Cognitive level	- *OHA*: *Motorola* commits to only using *Android* OS in future; *Samsung* announces use of *Android* for at least a third of its devices (press). -*OHA*: *SonyEricsson* and *Samsung* later follow *Motorola*'s lead (press) - *OHA*, *SF*: adapting software applications is difficult and resource intensive (experts).	- A first organisational and subsequent technological lock-in of an alliance member seems to have occurred. A further firm indicates strong commitment. - The same firms later leave *SF* and another important player cuts ties with *SF* to remain only active within *OHA*. - Learning investments into technology may bind members to a particular alliance.
Alliance – network-structural level	- *OHA*, *SF*: *Motorola*, *SonyEricsson* and *Samsung* signal their commitment to working with *OHA* (press). - *OHA*, *SF*: industry conference participants play the famous US TV show “The Dating Game”[19] with the software platforms as candidates to be ‘wedded’ by developers (some of which are already alliance members) (conference: OSiMworld). - *OHA*: no alliance members leave the alliance; all apparent exits have been M&A activities (press). - *SF*: three major alliance members leave the group to join OHA (press). - *SF*: *Nokia* remains the only big contributor and closes SF to the public, i.e. abolishes the open-source approach (press)	- The lock-in of *Motorola* to *OHA* and *Samsung*'s and *SonyEricsson* increasing focus indicate a concentration on intra-alliance activities and reduction of extra-alliance efforts. The alliance-internal focus suggests positive feedback loops with interdependent multi-level lock-in potential. - The game represents industry participants' recognition of the lock-in potential of their decision to join a platform. The wedding analogy resembles a strong bonding relationship that developers enter with platforms. Presenters and participants state that such decisions should be made with care and reflection. - The lack of exits indicates that members perceive involvement as beneficial and thus stay. Alternatively, they may already (perceive) to be locked-in and not be able to leave as a result. - The discontinuation of the firms' membership and related cooperative tie signals a decline of *SF* and reduces the alliance's ‘pull’ by leaving only one major member: its hub and founding firm *Nokia*. - Closed-sourcing *Symbian* and reducing *SF* to a licensing body allows *Nokia* to continue some

[19] International versions of “The Dating Game” are called “Blind Date” (UK/Ireland), “Herzblatt” (Germany).

		links with hardware partners (e.g. *Fujitsu*) while keeping control of the codebase as the main benefactor. For smaller member firms, this means loss of control and frustration with the (former) partners leading to exits.
Relational level	-*OHA*: "Our Role? We are clearly a follower." (expert B).	- This alliance member is set on strategically following a hub firm. This may become problematic if that organisation fails itself or takes advantage of its position.
	-*OHA*:"If we no longer benefit, we will leave" (expert A).	- A lock-in seems avoidable from the expert's perspective who does not perceive breaking-out as problematic. This perception may be explained by the financial capacity of the firm and/or its standing in the industry.

Table 15: Findings for category 'lock-in / exit'

With regard to network structure, however, *Motorola* (and later *SonyEricsson* and *Samsung*) clearly cut itself off from the information flows and influence on SF and concentrated on relations within *OHA*. Having been in a position of potentially brokering between the two alliances, *Motorola* gave up substantial brokerage social capital in order to pursue *OHA* prospects. Structurally speaking, *Motorola*'s exit from *SF* entails severed connections to former collaboration partners – at least the relations with firms that did not move together with *Motorola* or were also already in *OHA* like *Samsung* and *SonyEricsson* –, losing voting rights on the *SF* board, and accepting the comparatively stronger dominance of *Google* in *OHA*. This new restriction may become problematic if relations within *OHA* do not prove beneficial, and since access to the old network is no longer possible, this would leave *Motorola* with cooperative and technological difficulties. In this sense, the restriction could develop into a strategic problem; however, at the time of analysis, no indications of such problems exist.

Nevertheless, the lock-in to both network and technology is evident and represents a certain element of vulnerability for the company. This is not least because of the considerable investments in adapting the software code base to devices, as developers frequently indicated. At the same time, *Motorola*'s, *SonyEricsson*'s and *Samsung*'s ability to switch from the much longer-used *Symbian* to *Android* indicates that at least large, established companies (as which *Motorola, SonyEricsson* and *Samsung* can certainly be defined) could have fewer problems with technological dependence (and a related cognitive-level lock-in) than the many smaller developer firms. Further support for this argument emanates from the statements of a representative from a smaller developer firm who clearly indicates a lack of resources for supporting several platforms simultaneously since adapting the code base is difficult. It can be inferred that, to a certain extent, this would also be similar with regard to network relations and alliance memberships.

Further evidence for the lock-in character of the decision to join a platform is the metaphoric "*Dating Game*" as played by the participants at the industry conference *OSiMworld 2009*. The participant players were mostly representatives of smaller software developing, consulting and commercialisation firms. The "wedding partner" candidates rotated in rounds of three to represent the six platforms on offer: *Android*, *Symbian*, *Windows Mobile*, *Apple* and *Java*, the latter of which was then still in use for the majority of apps running on so-called 'feature phones', and *Linux Mobile*, a very young project (at the time), represented at the conference by the *Linux Foundation*.[20]

The participants would then ask their questions to the respective candidate platforms, compare several of their features, and finally choose one of the platforms as a 'partner.' During this last decision stage of the game, audience observers would cheer or boo depending on the respectively voiced features in the summary and thus cheer-steer participants towards "wedding" a certain platform. Arguments in this game included many technical arguments (e.g. "*MIDP-Java*, I'm a little old and outdated.") but also alliance-oriented arguments (e.g. *OHA*: "I think *Google* will make it happen."), and even other platform differentiation aspects (e.g. "My name is *Apple*, I think luxurious."), often presented in slightly mocking fashion. The atmosphere of cheering or booing indicated the differing perceived levels of attractiveness of the different platforms.

This game was designed to showcase the different platforms' comparative features to developers in a light-hearted, enjoyable manner. It is remarkable that the symbolism of partnership and wedding is invoked by the industry players, since an older alternative word for 'marriage' is the common word 'wedlock'. This latter almost spells out the word 'lock-in' and the playful presentation of the decision was clearly relationship-oriented. It remains unclear whether the participants consider their lock-in problematic. However, they certainly appear to be aware of the restrictions regarding other alternatives, once having chosen a platform.

At the relational level, it appears that some firms are prepared and strategically aware of the fact that they are becoming dependent on the hub firms, as indicated by expert B's statement on their small developer firm being "clearly a follower." However, the evidence regarding the relational lock-in is not unambiguous: a representative from a bigger firm (expert A) indicated a clear continual monitoring of the benefits of alliance membership and explicitly included an exit option for the case that these benefits might decline.

It is perhaps the interdependent combination of several types of lock-in, at two or three dimensions and analytical levels that makes the lock-in problematic for the network member firms. Depending on the size and resources of a member firm, even one lock-in level may already prove problematic for a small firm, while a large firm with a better resource situation may be more skilled at handling

[20] This project has seen several subsequent iterations (and names), and is now defunct.

multiple alliance memberships and coping with the effects of a potential exit. Furthermore, big firms are also more likely to be better able to keep track of multiple code bases and to maintain more relationships overall. The last stage of the framework thus finds support, but with the qualification that it seems to apply at varying levels and not always to all participants, particularly because larger, more established firms seem to cope with the potential for lock-in more easily than smaller firms.

Finally, the closed-sourcing and taking control of the maintenance and development of the *Symbian* codebase effectively closed off *Symbian Foundation* to the public, signifying an effective sull-reversal of the 2008 open-source strategy. This signifies a contrast to *OHA*, where hub firm *Google* always had more control, and it appears that, to some extent, *Nokia* was trying to copy that situation by taking control of *SF*. However, despite keeping tighter control of *OHA*, *Google* kept the codebase open-source, allowing lesser-involved members and even network outsiders to work with versions of the software, even if without the support and monetisation opportunities brought about by *OHA* and *Google*'s leadership. The detrimental effects and transition for *SF* members meant a loss of control over both network relations and influence on the codebase and ultimately lead to members' exit from *SF* and also business exits, as evidenced by developments subsequent to the period of data collection (outlined the epilogue to the case study in Appendix B).

3. 2. 2 Contextualisation: the communications industry

A historical review of the relevant recent development of the mobile communications industry provides a contextualisation (Yin 2009) through a rich description similar to Eisenhardt's 4th step 'entering the field' (Eisenhardt 1989: 539). Besides contextualising the cases, it also provides background information on interconnected events above and beyond the units of analysis, permitting an analysis of the phenomenon with processual mechanisms unfolding over time (Pettigrew 1990: 269), because context necessarily shapes and is being shaped by the actions of the units of analysis (ibid.: 270). In short, if 'history matters' in terms of (potentially) path-dependent developments, it appears instructive to familiarise oneself not only with present events, but also with the historical events that continue to influence the present. Appendix A provides additional historical grounding for communications industry-related studies, since such an account has so far not been provided in the literature, despite the field increasingly attracting scholarly attention in OMS. The historical section also describes important cooperative relations and thus the overall resulting cooperative 'modus operandi' of the mobile communications industry.

3. 2. 2. 1. The emergence of smartphones

Based on several collaborative technological achievements such as telegraphy, mobile radio technology, digitisation, the internet, and increasing connection speeds and network coverage,[21] smartphones are becoming the main internet access devices. They can be characterised as the culmination of a process convergence in which technology, software and content media are becoming increasingly integrated. Smartphones thus combine elements of a plethora of technology products and services such as telephones, film and photo cameras, PCs, PDAs, TVs, radios, music players, mobile messengers, email, eBook readers, (mobile) game consoles etc. They are de facto successors to several technologies that previously required dedicated devices (e.g. mobile messengers, PDAs, mobile audio players etc.) and complement other coexisting products and services (e.g. TVs, radio, PCs, email, cameras etc.) that continue to be used on other devices. Tablet computers, using essentially the same technology and ecosystems as smartphones, can themselves be considered complementary devices to smartphones, adding a larger screen to the user experience. The diagram below summarises the developments of smartphone technologies and ecosystems. The following section deal more in detail with the period under study.

[21] More details on the early history of the communications sector can be found in Appendix A.

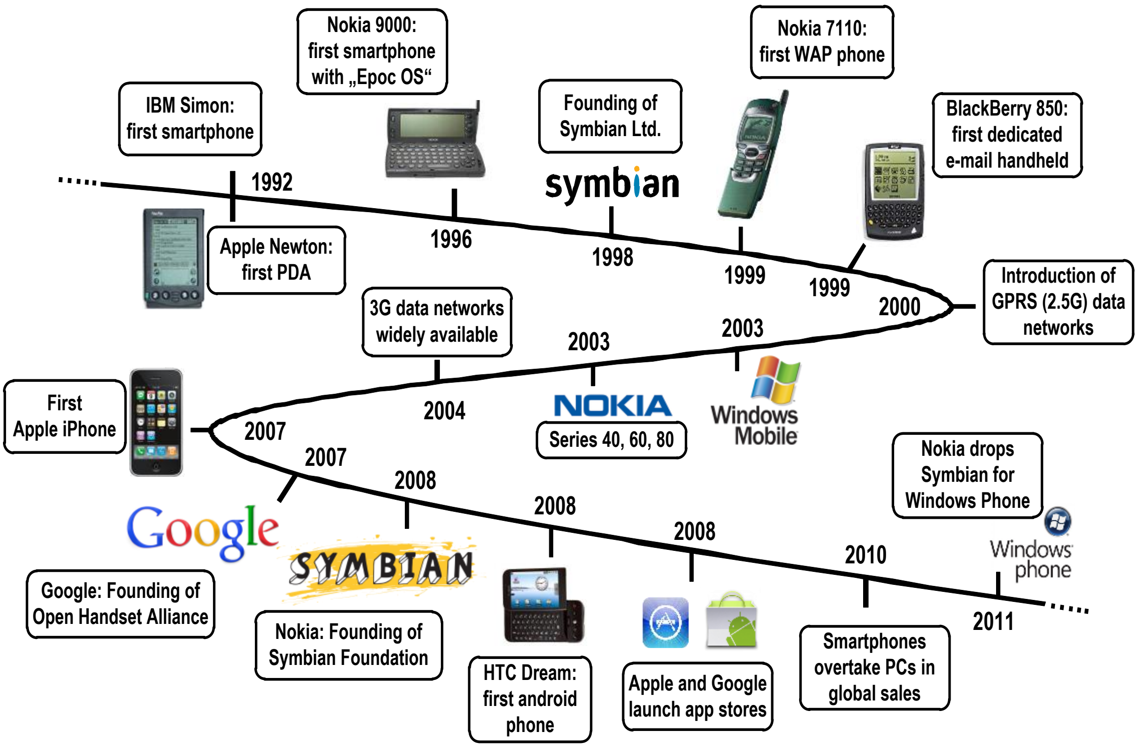

Figure 10: Graphical summary of smartphone history

3. 2. 2. 2. The iPhone changes everything

Apple's announcement of the long-expected *iPhone* in January 2007 (Apple 2007a) and the product launch in June (Apple 2007b) marked a major change in the mobile communications industry. The industry found itself in a big *iPhone* hype and thus also in a smartphone hype (Laube 2007: 4). *Apple* integrated the *iPhone* into its already existing *iTunes* ecosystem of audio and video content. Users could now buy and synchronise multimedia files from computers to their *iPhone* and use it as a multimedia player and communication device. The proprietary operating system *iPhone OS* (branded *iOS* as of June 2010) provided the basis for this functionality. The majority of the *iPhone*'s features were not new and had been in the market e.g. on *RIM*'s *Blackberry* devices. The most important attributes, however, were its new user-friendly, fully finger-operated touchscreen user interface, consistent integration of a better internet experience and embedding the device into the existing multimedia ecosystem. *Apple* partnered with mobile operators as exclusive sales partners (e.g. *AT&T* in the USA, *T-Mobile* in Germany, *o2* in the UK) and tied the sale of the device to expensive data tariffs, thus targeting a high-income market segment.

The market responded strongly to the *iPhone* and it became a market success (Apple 2007c) so that competitors were put under pressure to catch up. The internet firm *Google* competed by launching the *Android* smartphone platform (Google 2007a) at the end of 2007. The platform is accompanied by an industry consortium, the "Open Handset Alliance, a multinational alliance of technology and mobile industry leaders" (Google 2007). The *Open Handset Alliance* (*OHA*) comprises operators, manufacturers, software companies and others who cooperate to provide and use a royalty-free, open-source smartphone platform. Google's intentions with this for-free approach were twofold. Andy Rubin, founder of *Android* – the company of the same name developing *Android* before it was bought and open-sourced by *Google* – and then head of *Android* development at *Google* – describes the situation thus: "Unless there is a vendor-independent software solution, the consumer isn't going to be well served. […] What Android is doing is trying to avoid what happened in the PC business, which was to create a monopoly" (quoted in: Auletta 2009: 208). The other reason lies in data collection and advertising: "Smartphones will yield more data for *Google*. And they will allow *Google* to explore ads and services to generate revenues" (Auletta 2009: 266). So, in order "to protect its business interests, *Google* had to be in the smartphone business" (Auletta 2009: 356). Network operators like *Verizon* saw this development rather critical, as noted by its CEO Ivan Seidenberg: "Google's vision of Android is Microsoft's vision of owning the operating system in every PC" (quoted in: Auletta 2009: 266). Nevertheless, many network operators, device manufacturers and software firms joined *OHA* to support the *Android* platform.

Stock markets responded favourably to this announcement (Ohler, Maier & Kölling 2007: 4), since it strengthened the alliance members' market positions. *Nokia*, *Symbian*'s biggest contributor and benefactor, however, did not perceive *OHA* as a threat and *Symbian* CEO Nigel Clifford was convinced that: "We are market leader and will continue to be market leader" (quoted in: Ohler, Maier & Kölling 2007: 4, translation by the author). *Palm* was already struggling and experienced an existential threat since it had no membership of any platform and found itself faced with now increasingly strong competition (Laube & Müller: 2007:4). To gain market foothold in new segments, *SonyEricsson* announced its first ever *Windows Mobile*-based device. This was interpreted by industry observers as a weakening of the *Symbian* platform, but also as a further indication of the importance of platforms (Müller & Lambrecht 2008: 4). *Microsoft* even purchased a smartphone manufacturer, *Danger*, which had invented the app store concept, to strengthen its platform's position (Markoff 2008: 9). Even *RIM*, while strong in its traditional corporate market, struggled to keep up on a bigger scale (Stone 2008: 1).

The emergence of the *iPhone* caused "software [to grow ..] in importance" (Shannon 2008: 7), leading *Microsoft* to drive its marketing efforts to sell more *Windows Mobile* licenses (Laube 2008: 6). Before any *Android* platform devices were available, *Google* announced the *Android Developer Challenge* at the end of 2007 (Google 2007). $10 million were spent to gain developers' attention and were awarded in May 2008 to the fifty best submissions to the *Android Market*[22]. *Apple* had, conversely, initially not allowed any third-party software to be installed on *iPhones*, responding strategically by introducing the *App Store,* together with the *iPhone*'s next generation shortly thereafter (Apple 2008b). This central

[22] Now called Google Play (Store).

third-party software application store is embedded into the *iTunes* environment and launched with 500 apps in mid-2008, thereby emphasising the significance so rapidly acquired by smartphone 'apps.'

Recognising the increasing importance of platforms and under competitive pressure from two strong platforms, market leader *Nokia* made a strategic decision. It announced the full acquisition of the company *Symbian* with its synonymous proprietary platform and turned the operating system into an open-source platform (Müller 2008: 4). Very much mimicking *Android*, the platform was supported by several companies that partnered up in the newly created *Symbian Foundation* (*SF*), a strategic alliance with goals congruent to its competitor, *OHA*. "Nokia reacts to Android without even knowing its market success" (Müller 2008: 4) concluded industry analyst *Gartner*. Attempting to prevent *Android* and *Apple* from reducing *Nokia*'s then 60% market share, *Nokia* invested substantial financial (€264 million) and human (more than 1,600 staff) resources into *SF*. The company also abandoned the substantial revenues from licensing fees it had formerly earned and made the system freely available to all alliance members.

The alliance surrounding the platform lowered the barriers for firms to use *Symbian*, and *Nokia*'s Vice President for *Symbian* development, Kai Oistamo, commented "I am convinced that this will lead us to sell more phones" (Wray 2008: 24). Market analyst *Global Insight* characterised the situation as follows: "By tying up the top five mobile handset makers, key chipmakers and the likes of AT&T and Vodafone, Nokia wants to starve Android, and similar initiatives, of influential industry players, leaving them to toy around with smaller players with lesser chance of changing the status quo" (quoted in: Wray 2008). Behind the scenes, a fierce platform competition ensued and also engulfed technology firms such as semiconductor firms and chipmakers *Intel*, *Qualcomm*, and *ARM* (Markoff 2008: 1).

Apple's strategy with the *App Store* paid off, and the firm announced 10 million app sales on the launch weekend alone, exceeding all expectations (Apple 2008c). With web browsing from *iPhones* accounting for then 75% of all mobile internet access and app usage increasing exponentially, industry observers concluded that the *iPhone*'s introduction in 2007 "changed the smartphone market for ever" (Fry 2008: 108), not least by popularising the *App Store* market model. As shown above, the ability to run applications on mobile phones was itself no innovation and had been possible for several years on phones with *Symbian* or *Microsoft Windows Mobile* operating systems. The *iPhone*, however, brought this market to the industry's attention (Holson & Helft 2008: 1). When *Google* launched the first *Android* device *HTC Dream* together with partners *T-Mobile* and *HTC*, *OHA*'s own app store – the *Android Market* – immediately became a standard feature of the platform (Laube & Maatz 2008: 4).

Apple's market success continued and made it the second biggest manufacturer in terms of device sales in 2008 while other manufacturers, most importantly *Palm*, *RIM*, former US market leader *Motorola* and even global market leader *Nokia* struggled with the new competition, particularly in terms of technical abilities and design (Wendel 2008: 4). Apps as a concept, however, were becoming universally successful across platforms. To illustrate, when *Palm* launched its *Palm Pre* handset in 2009 with an own proprietary operating system *webOS* (Ritchel 2009: 4), it only took 20 days until the users of the 150,000 phones sold thus far reached one million app downloads of the only 30 available apps (Wortham 2009: 5), thus averaging approx. 7 app downloads per phone and user.

The attractiveness of this new market for apps was further underlined by the rapid growth of download numbers from e.g. *Apple*'s *App Store* to one billion in early 2009 and 1.5 billion in its first year of existence (Apple 2009a; 2009b). App usage led to strong data traffic increases and thus yielded returns for network operators and platforms. Operators needed this revenue source to recover the large investments they had made in new network technology in the early years of the decade (Maatz, Wendel & Laube 2009a: 8). Simultaneously, however, network operators found it difficult to keep up with the demands of smartphone traffic. They reported network failures and outages and thus had to extend their networks into new frequency spectrums, such as 4G/LTE, to cope with rising demand (Rysavy 2009: 23).

The app and platform revolution, driven by the powerful new entrant *Google*, broke the unwritten rules of the market, because it drew on the cooperation of several industry players for the platform, marking what Koch (2008: 56) called a "rationality shift" within the industry. Consequently, competition for the most innovative developers ensued between the platforms (Maatz, Wendel & Laube 2009b: 8) and the industry's disruption has been characterised as the "battle royale" (Espiner 2008) between the two alliances of the biggest phone maker *Nokia* and the biggest internet company *Google*.

3. 2. 2. 3. The app store year 2009

At trade fairs such as the Mobile World Congress 2009 in Barcelona, this 'battle royale' gained new speed as many new devices were announced (O'Brien 2009: 5) and the platform alliances attracted new members, even including PC firms *Dell*, *Acer*, and *Asus*, which made their débuts on the smartphone market (Vance 2009: 1). Virtually every platform now had its own central app store, following *Google*'s and *Apple*'s example (Information Week 2009a) with mobile games at $5.4 billion global sales as an important driver (Information Week 2009b). Despite more firms supporting *SF*, established player *Nokia* struggled severely with technological difficulties and declining sales (Maatz 2009: 8) and forged new partnerships with e.g. *Microsoft* for *MS Office* integration and *Intel* for software services to maintain its position.

Apple, the initiator of the new smartphone market, saw the *iPhone*'s technological leadership slowly decline, mainly through competition from *Android*. The platform market in 2009 was essentially split into the two competing camps *OHA* and *SF*, because the *iPhone*'s *iOS*, *RIM Blackberry* and *Palm*'s *webOS* are only available on these firms' own devices. The latter two platforms were also mainly relevant in the USA, and *Windows Mobile* only held a small overall market share (see Figure 11, below). Both camps' strategies involved gaining a large market share to tap the promising apps market and to recover the loss of license fees induced by the open-source approach.

This split-market development had the potential to lead to the establishment of a (single) new market standard or at least trigger a so-called 'format war,' or rather 'platform war', as fierce competition ensued between industry camps, like that experienced during other prominent technology cases (*VHS* vs. *Beta*, *Blu-Ray* vs. *HDDVD*, etc.). At the end of 2009, the market looked favourable for the *Android* platform (Nuttal 2009: 7) which had positive effects for *OHA* alliance members such as *Motorola*, the first major player to take sides and limit itself exclusively to the *Android* platform (Hansell 2009: 8). *OHA* and *Android* thus helped *Motorola* achieve the turnaround from its corporate crisis and avert bankruptcy. Despite these developments and their strong involvement with the *Android* platform (e.g. negotiating the design and manufacture of the popular *Nexus S* phone for *Google* during that time), *Samsung* launched an additional proprietary mobile operating system called *Bada* in late 2009 (Samsung 2009). *Bada* is similar to the existing platforms in many respects but is limited to Samsung devices. It hence remained at low market shares with comparatively limited user numbers.

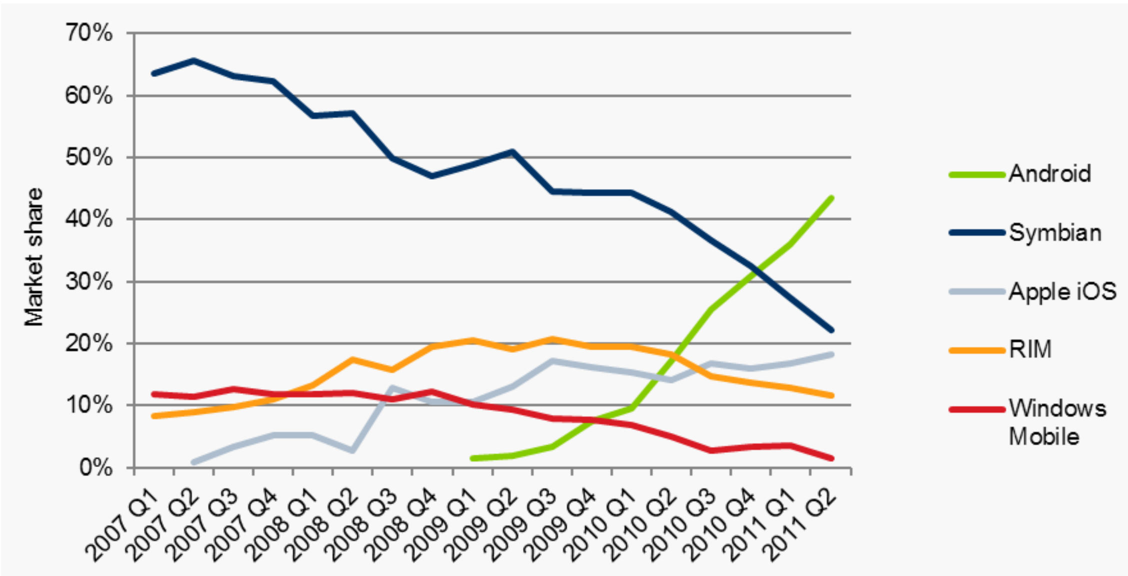

Figure 11: Mobile platform market shares 2007-2011

3. 2. 2. 4. Consolidation efforts in 2010

2010 began with several industry announcements. Downloads from *Apple*'s app store exceeded 3 billion (Apple 2010a) and the tablet computer *iPad* beat competitors to the market and extended *Apple*'s *iOS* platform beyond the *iPhone* and *iPod touch* (Apple 2010b). *Google* launched the popular *Nexus One* – the first device sold under *Google*'s own name – and the *Android* platform found widespread use in new smartphones and tablet computers. For *Google*, the mobile business had increased in importance so much that its CEO Eric Schmidt announced the company's "mobile first" (Schmidt

2010) overall strategy at *Mobile World Congress* where all players focused on platforms and apps (Glahn 2010). *Nokia*'s mobile phone director Rick Simonson remained convinced that "there is definitely no room for more than four or five smartphone operating systems" (quoted in: Wendel 2010: 1, translation by the author), but more were competing in the marketplace. *Nokia*'s assessment was accompanied by its own product announcements and slightly improving financial results (Ward 2010: 7). Yet it reduced its relative support for *Symbian* platform by closing *SF* to the public and making other investments such as in *MeeGo*, a joint mobile operating system project with *Intel* (Arthur 2010). *Microsoft* launched its new *Windows Phone 7* operating system, the successor to the older *Windows Mobile* and several companies partnered with Microsoft to announce devices (McDougall 2010: 17).

All firms were facing a decline in mobile phones sales and dropping revenues caused by the continuing financial crisis. The struggling industry players began suing each other for patenting breaches and outdid one other with new product announcements. As the last remaining PC manufacturer without smartphone plans, *Hewlett-Packard* purchased *Palm* including the *webOS* platform in mid-2010 to enter the smartphone market (Vance & Wortham 2010: 1). Shortly afterwards, it became clear that *Android* would be the major benefactor of the almost 50% smartphone market growth and would attain sales majority in 2010 (Wray 2010: 27). *Nokia*'s responded to this trend and its 40% sales decline with heavy corporate restructuring and a new division dedicated entirely to smartphones, changes in top executives and general personnel cuts (Ward & Parker 2010: 2; Wendel 2010: 2). In late 2010, *SonyEricsson* and *Samsung* announced that they would follow *Motorola*'s example and discontinue supporting *SF* and its platform but switch to *Android* for new products (Ohler 2010: 1). This crucial announcement heralded a drastically new situation for *SF*, since *Nokia* remained the only major device manufacturer with an interest in the operating system. Its decision to discontinue the open *SF* and close the codebase off to the public hit many smaller companies that had continued to rely on this strategic consortium and led to lay-offs and business unit closures, especially in the case of smaller, developing companies.

With eBooks, mobile music, and video streaming, new types of content entered the smartphone realm and immediately gained strong sales (Arthur 2010: 5). *Google*'s announcement of its newest smartphone *Nexus S* in late 2010 demonstrated its technical ability as well as *Android*'s market momentum. It was now outselling all competitor platforms, not only with smartphones but also increasingly with tablet computers. *Android*'s continued market success caused a decline in market share of *Symbian OS*, which was subsequently forced to rely chiefly on its large installed base.

3. 2. 2. 5. Drastic changes for Symbian in 2011

The *Mobile World Congress* in Barcelona was once again the event at which major changes were announced. Many new devices launched – mainly for *Android* – but the most relevant announcement came from *Nokia*. Due to further losses in its smartphone market share, *Nokia* executives became alarmed. *Nokia*'s new CEO Stephen Elop – a former *Microsoft* manager – prepared his staff for change in an email likening *Nokia's Symbian* focus to a burning oil platform: "We too, are standing on a 'burning platform', and we must decide how we are going to change our behaviour" (Elop 2011). He referred to technical problems with *Symbian* which were held responsible for the marked share decline. The industry was convinced that "Nokia [was] at the crossroads" (Economist 2011). The new direction taken was announced only days later: *Nokia* would adopt *Microsoft*'s *Windows Phone 7* platform for all new smartphones to "compete in the war of ecosystems" (quoted in: Arthur 2010a: 42). Industry analysts like John Delaney of *IDC* summarised the move: "It's Nokia going for the best option that was available to it. It remains to be seen whether it will work or not" (quoted in: Arthur 2010a: 42). *Nokia*'s employee base was not convinced of this new direction as it implied significant layoffs and corporate restructuring at *Nokia*, and many of *SF*'s former member firms were struggling due to their focus on this declining platform.

After these drastic developments, *Nokia*'s CEO Stephen Elop expected the future of this highly dynamic market to be a "three-horse race" (quoted in: Wearden 2011), referring to the three major platforms *Android*, *Microsoft*, and *Apple*. Past and present market shares of the five major platforms are depicted above up until Q2/2011, the end of systematic data collection. With *Nokia* largely dropping its support, *Symbian* would go on to lose further market clout. *Android* already exceeded 40% of market share in 2011 while the *Windows Phone 7* platform was expected to stagnate until 2012 when *Nokia* launched initial products based on that platform. Some industry experts predicted further market consolidation, possibly an integration of *RIM*'s *Blackberry* or *HP*'s *webOS*. Since smartphones already outsold PCs in 2010 (Arthur 2010a), smartphones continued to grow and increase their impact on the global mobile communications industry.

An epilogue detailing relevant developments of mobile communications since the end of systematic data collection in March 2011 is provided in Appendix B ('Epilogue to the case study: 2011-2018'). In brief: apart from *Apple*'s *iOS* and *OHA*'s *Android* under the auspices of *Google*, none of the major platforms survived. New entrant *Jolla*'s *Sailfish OS* and *Samsung*'s *Tizen* remain very minor competitors despite attempts at establishing interorganisational alliances to copy the *OHA* model. After joining the *Windows Phone* platform, *Nokia*'s smartphone business was eventually purchased by *Microsoft* and then closed down gradually over several years due to declining sales and little success as far as efforts at reviving the platform were concerned. *Nokia* resurfaced as a brand after *Microsoft* sold the hardware manufacturing along with the brand name. The new owner – *HMD Global* – created by former *Nokia* employees, joined the Android platform just like *HP* after abolishing *webOS* and *Blackberry* having discontinued *Blackberry OS* incl. successors and sold its hardware business. With approx. 85% market share, *Android* is now (2018) clear market leader with *iOS* at stable approx. 15%, with other remaining platforms around just below the measurability threshold of 1%. Both platforms have been fully extended to tablet devices and also power devices from other industries such as automotive, smart home and hardware control, wearables etc. While sales of both devices and apps remain high and have been increasing until a recent peak, profitability remains an issue for all players except *Apple*, with its premium-priced device strategy. The next section reviews and summarises the historical events before discussing and reflecting on the overall findings from the case study.

3. 2. 2. 6. Recapitulating telecommunications industry developments

Cooperation among firms has historically been one of the key drivers of the communications industry's technological advances, from the very beginnings of building copper wire networks to the standard-setting industry bodies created in the late 20th century. Digital technology convergence has enabled the emergence of smartphones. Previous communication device innovations were mainly hardware-driven (quality, speed, coverage). After *Apple*'s *iPhone* launch in 2007, however, smartphones focused the industry on touch-operated software ecosystems which created two-sided markets (Meyer 2012) with several new players entering the industry.

These emerging platforms turned the former competition between individual firms or joint ventures into a competition between two main alliances: *OHA* and *SF*. This development has disrupted incumbent firms, their business models, and the competitive and organisational environment of the market. The already existing 'co-opetition' environment between firms (Madhavan, Gnywali & He 2004) has changed in both nature and scale, with more firms joining the alliance over time. *Nokia*'s decision to abandon its license fee sales from *Symbian* in favour of building an interorganisational alliance, only to reverse the decision later when (larger) cooperation partners had left, is an indication of the shifting market logic and disruption. These developments have technological, market, and organisational implications:

A) Market power: platforms matter greatly

Smartphone platforms are the new gatekeepers to the mobile digital world: they define how people connect, which apps they use, and they strongly control the distribution of digital content to smartphones. In this sense, the competition between smartphone operating systems is thus also a competition between *smartphone ecosystems*. Moreover, it is a competition between *open vs. closed* environments with profound social and economic implications (Bradshaw & Gelles 2011).

Apple is the prime example of a closed, tightly-controlled ecosystem. *Apple*'s operating system is a proprietary, closed-source system, available exclusively on *Apple* devices. Apps are distributed *only* through *Apple*'s own *App Store* with *Apple* earning a 30% share of every app sold. Developers must even have their apps approved by *Apple* who claim this ensures a better user experience. However, *Apple* has been accused of misusing its power through banning apps that could impair *Apple*'s own business objectives (Johnson & Schatz 2009) – an indication of the level of control exercised by the platform company.

Compared to the PC industry, this is a revolutionary shift in power. A PC market analogy would be *Microsoft* exclusively controlling the software distribution for *Windows* PCs, 'censoring' all software not explicitly authorised and commanding a 30% share from developers. In early 2010, *Apple* additionally seeks to lock-in developers to *iOS* by contractually excluding other programming languages and even cross-compilers. *Apple* thus intentionally restricted apps' portability to other platforms, effectively making 'multi-homing' – the ability of app producers to cater to more than one platform – much more difficult (McAllister 2010). Due to fierce opposition and developer complaints, *Apple* later relaxed some of these restrictions (Apple 2010c).

Apart from its app strategy, *Apple* also earns a 30% share of any digital media sales such as e-books, newspaper subscriptions, music or videos files offered by third-party publishers (Economist 2011c). Publishers are "not permitted to offer cheaper deals outside Apple's walled garden" (Halliday 2011). Moreover, *Apple* limits the types of content that can be offered, prohibiting, for example, "explicit and offensive material" (Apple 2011b; Gebauer 2010). This also led to strong opposition by publishers, who refuse to relinquish too much control and money to *Apple* (Economist 2011c) but see little other choice but to comply since *Apple* has (temporarily) banned sales of reputable material they consider in violation of their terms.

Google follows a more open, accessible, and 'democratic' approach. The *Android* platform itself is open-source and developed in cooperation with other industry partners. It is available on a wide range of devices from different handset makers. *Google*'s *Google Play* app store (formerly: *Android Market*) is similar to *Apple*'s distribution platform, also charging a 30% commission for sold apps. However, *Google* allows alternative distribution channels for *Android* devices and engages much less in 'censorship' (Kendrick 2011). In February 2011, *Google* announced *One Pass*, a distribution platform for digital content across websites and mobile apps. Unlike *Apple*, *Google* takes only a 10% sales commission from publishers, as well as giving them broad freedom on pricing decision and providing access to customer data (Bradshaw & Gelles 2011).

The platform competition has profound consequences in terms of advertising revenues generated, the power balance between consumers, developers, network operators, handset manufacturers, media publishers and platform providers, ownership of valuable customer data etc. (Auletta 2009: 210).

B) Technical and market challenges for network operators

Network operators are under added pressure from mobile platforms. Fierce price competition had long characterised the market, but the declining network operators' measure of profitability – the

Average Rate per User (ARPU) – (ABI Research 2010).[23] has led many operators to cut cross-subsidies for devices. This decline is now in remission, based on new revenues from mobile data usage on smartphones (EITO 2009). Increased data usage, however, also poses a challenge for operators, since their networks have been breaking down under the increased data traffic caused by the smartphone platforms (Rysavy 2009: 23). Their reaction of restricting data throughput for certain applications – mostly music and video streaming, and Voice-over-IP telephony services such as *Skype* (Cohn 2010) – resulted in heavy criticism of operators because it reduced usability. This sparked the continuing 'net neutrality' debate, which also extends to landline networks' internet access (European Commission 2011).

Furthermore, smartphones are responsible for a shift in market power from network operators to platform providers. By signing exclusive distribution deals for early *iPhone* generations, *Apple* was able to negotiate substantial revenue shares with network operators. In 2007, British network operator *O2* was rumoured to "return to Apple as much as 40% of any revenues it makes from customers' use of the device" (Wray 2007). Similar deals had never been done before in the industry. Formerly, network operators were considered the gatekeepers to users' device usage, user experience and network usage. They are continuing efforts to brand the devices they sell with contracts, including operator-specific apps and functionality to recover some of the lost market power incurred by the emergence of platforms, but to little or no avail. Even the formerly highly-profitable *SMS* business is declining since over-the-top messenger apps such as *Whatsapp*, *Threema* or *Signal* using data traffic have begun to replace the *SMS* and its successors *MMS* and *AllJoyn* and *RCS* that gained only little usage.

C) Organisational consequences

At the network level, the emergence of these competing platforms led to the advent of the respective interorganisational networks – *OHA* and *SF*. This new market logic implies that technological leadership no longer defines market success, but rather that alliance membership strongly influences the opportunities of firms. Those struggling already, such as *Blackberry* or *webOS*, have even more difficulties in sustaining comparatively insular systems against the interorganisational network structures. New, proprietary attempts at launching mobile platforms have largely failed, e.g. *Samsung*'s *Bada*. With its uniquely strong hardware-integrated *iOS* platform, *Apple* remains the exception to the rule. Their platform, however, still relies on the extensive support of developers contributing software to the platform, albeit without any formal interorganisational alliance and, at best, loose informal relations

[23] In the European Union, the effect of strong price competition among standardised and comparable call and text message services has been strengthened by regulation from the European Commission. It repeatedly limited the EU internal roaming fees and national call and SMS rates that operators may charge customers. The steps were taken to reduce price levels set by the many former national monopolists and to enable customers to profit from the efficiency gains of increasingly global companies (European Commission 2008, 2009, 2010).

between developers, emerging through *Apple*'s annual *Worldwide Developers Conference* (WWDC)[24] event. Positive feedback from strong sales has contributed to platform growth for *iOS* and *Android* in terms of content and network members, while *Symbian* has declined despite having initially been a clear market leader.

At the relational level, for firms joining a platform are required to subscribe to the networking mode driven by the hub / lead organisation to varying degrees. While *Apple* retains absolute control of contributors to the platform as described above, hub organisations *Google* and *Nokia* adopt a more open approach. The hub organisations are important pull factors for organising the advancement of their platforms and push their technology developments to other members, albeit in different models: *Apple* decides unilaterally on changes, while *Google* reserves control over *Android* versions but welcomes contributions and extensions from *OHA* members, and *Nokia*, as leader of *SF*, establishes a voting model for code contributions. The co-opetition between the firms develops in interesting ways. While network building can generate technological momentum among members, including or excluding certain members affects the entire competitive environment. As an attempt to influence platform competition, *Nokia* attempted to gain support of two important players for *SF*: US market leader *Motorola* and *Samsung*. While both were *SF* members initially, both companies, in contrast, committed to *OHA* and thus the *Android* platform shortly after.

At the resulting, and intertwined technological (and cognitive) level, membership of an ecosystem alliance entails adherence to its software standards, programming languages and other guidelines. These require know-how investments for dealing with application-device integration, attending meetings and events with other alliance members and cooperation partners, and a degree of subscription to the hub organisation's mode of driving the platform. Such investments are bound to the platforms and usage of the platforms requires memberships, which binds additional resources.

Given the open-source licensing model, *Google* cannot restrict *OHA*-outsiders from using *Android,* but it can and has implemented other restrictions to enforce platform alliance cohesion and protect the ecosystem (Rubin 2012). When online store market leader *Amazon* decided to heavily adapt *Android* as an operating system fork (named *Fire OS*[25]) for its *Kindle Fire* (now *Fire*) tablet devices in 2011 (Halliday 2011), it decided not to join *OHA* or cooperate with *Google* or other *OHA* members. Instead, it opened its own device-integrated application store. *Google* – as a new default contractual treatment of non-*OHA* members – prevented *Amazon* from using *Google*'s *Google Play* app store and *Google*'s own popular *Android* apps on *Amazon* devices. *Google* even prohibited other *OHA* members like *Acer* from cooperating with Chinese *Amazon* competitor *Alibaba* which created a similar platform fork called *Aliyun OS* (Rodkin 2012). *OHA* member *HTC* later decided not to cooperate with *Amazon*

[24] https://developer.apple.com/wwdc/

[25] https://developer.amazon.com/docs/fire-tv/fire-os-overview.html

under threat of having to leave the valuable *OHA* alliance (Amadeo 2013a), a policy characterised as "Google's iron grip on Android" (Amadeo 2013b: 3), but also as "standard for alliances of this type" (Kendrick 2012). While this policy was later relaxed for new platform entrants *Blackberry* and *Nokia*, perhaps due to impending regulation, implications of the (potential) exclusion from alliance membership would include an inability to use the hub organisation's influential app store and to contribute to *Android* code development, and the loss of goodwill of the hub firm and other members for cooperative relations. Notably, *Google* does not own *Android* and its source code as this is governed by *OHA*. As a hub firm, however, *Google* rules with considerable legitimacy and polices adherence to the commonly established rules of cooperation and standardisation and even members' cooperative relationships.

3. 3 Discussion of case study findings

As we learned from the historical account, major network developments are occurring in the telecommunications industry. While the first commercially successful smartphones were *Nokia*'s 1996 "Communicator" phone (Evans, Hagiu & Schmalensee 2006) and later Blackberry devices, only *Apple*'s 2007 launch of the touch-operated *iPhone* pushed smartphone technology onto the mass market. Global smartphone sales subsequently exceeded PC sales and have since even replaced PCs as the default internet access device, especially in developing countries (Heise 2012). The smartphone market is seeing signs of a slow-down in growth due to a maturing of technology, and formerly very profitable companies such as *Motorola* and *Sony* are struggling with declining revenues. The forces of decelerating growth and market saturation increase competitive pressures on market players. Several big industry players, including new entrants like *Google* and incumbents like *Nokia*, have changed the competitive landscape in several ways at a fast pace.

Membership of and cooperation in the interorganisational networks around the emerging smartphone platforms are becoming ever more important for all industry players, as the traditional structure of competition has shifted towards the new interorganisational alliances surrounding the platforms. The platforms themselves have profound consequences for new and incumbent players. For instance, the formerly licence-oriented market-leading system *Symbian*, which produced licence income, has become free and open-source due to market pressure from peer systems. The linking of several industry players and the integration of those from other industries is partly responsible for that development but is also perceived to amend the loss of revenue sources and produce market clout through platform-based sales growth. The emergence of smartphone platforms after the year 2007 thus pushed cooperation among competitors and other actors even higher up the industry's agenda. The emerging platforms turned the former rivalry between individual firms or joint ventures into a competition between strategic interorganisational networks and their platforms, transforming the industry into an even more marked 'co-opetition' network environment (Madhavan, Gnywali & He 2004) from an individual firm's perspective.

Standard-setting occurs in a technological sense, as every platform works only with a certain code, but also in an organisational sense: the interorganisational networks have formal constructs, are based on membership agreements, rules, and monetary and source code contributions. Furthermore, membership holds promise for individual firms when they are willing to strongly engage in cooperative relations since better-connected actors would be likely to gain influence within an alliance. It follows that standard-setting practices and the struggle for market domination have shifted from the former 'firm against firm' (as in *JVC*'s *VHS* against *Sony*'s *beta*) to 'network against network' (as also in the case of *Blu-Ray* vs. *HD-DVD*).

Network operators have seen their gatekeeper role diminish markedly while at the same time, increasing demand for fast data access to the internet requires a constant drive towards expanding data capacities at ever lower prices and decreasing earnings. Society is still adjusting to the consequences of the constant availability of internet connectivity, and users' behaviour and capabilities are changing in interaction with or through their devices, or because of the additional surveillance implications of this technology.

Considering the broad debate on path dependence in the PC industry and its social and economic implications, smartphone platform competition continues to be a highly interesting and relevant case with similar repercussions: "The stakes are huge, as the mobile computing market [has already proven; the author] to be larger than the PC market ever was" (Helft 2010). The data collected on these actors' networking behaviour over time and the categories derived from the explanatory framework revealed several important insights.

The first category, 'brokerage and entry' relates to the first stage of the explanatory framework and thus the brokerage argument of social capital theory (Burt 2005) and finds relatively strong support, especially through the *OHA* case in which the hub firm *Google* is reportedly rather active as a broker in creating connections between new members. The evidence for brokerage in *SF* is less strong in this category, not least because of the more transparent and egalitarian voting approach for alliance management. In both cases, the motivations for membership were reported as access to shared resources and information and several new members joined, especially in *OHA*. The data shows that several firms establish new cooperative ties upon entry into the alliances, thus bridging the previous structural holes in the newly created interorganisational networks. Furthermore, the steering in the early stages of the alliances was, in *OHA*'s case, performed exclusively by *Google*. Hence the firm retains a strong brokerage position in that alliance, whereas *Nokia*, the other main network hub, has a lesser structural influence in *SF*.

The brokerage argument of the framework thus finds support insofar as the brokerage relations constitute small events in terms of path-dependence theory. The support from the two cases is, however, not identical. While *Google* actively steers *OHA* in a manner close to idealised strategic network leadership, *Nokia* (and other founding members of *SF*) appears to follow a different, more decentralised approach, or one that the data could not capture. The latter could be due to access issues or depend on the information level of the industry observers and representatives. It is clear, however, that new connections between firms are established in both cases. Both *OHA* and *SF* have seen the announcement of new cooperative relationships, and related outputs from the work of these cooperative connections are entering the market. The brokerage argument can thus form part of the explanatory framework since the relations, whether more intentionally brokered (*OHA*) or emerging as part of commercial activities (*SF*), constitute small events in the sense of a path-dependent process.

'Alliance activities' refers to developments during the second stage of the network path dependence framework. Increases in activity are to be expected if a positive feedback mechanism is at work and if it holds the potential to develop in such a way as to limit actors' scope of options in the long run (Sydow, Schreyögg & Koch 2009). The activities in the alliances have increased on various levels. Firstly, their output in terms of products and apps has grown strongly. Secondly, the number of members in both alliances has risen, as has the number of announced cooperative relations.

These increases indicate a positive feedback mechanism, but this requires some interpretation in order to identify it. Here, it lies in the following logic: the experience of (so far) beneficial cooperation relationships on the part of the alliance members leads to an increase in output. This output increases the positive incentives to invest further in cooperation with other alliance members and this results in more alliance activities. In turn, these activities again lead to more cooperation relations – the markings of a positive feedback spiral. In the long run, the result of this spiral is stronger closure, enabling more internal cooperation with partners known to be trustworthy, i.e. having a reputation to lose should they renege (or, in game theoretic terms: defect) on an agreement. As such, cooperation may increase in a kind of virtuous cycle.

Furthermore, path dependence theory contains an element of stability in terms of activities and/or mechanisms that occur despite external turbulence (Koch 2008). While the market environment continues to be turbulent – as revealed, for example, by the unexpected acquisition of *Palm* by *HP* (Laube 2010) – a certain element of stability can be found with regard to the alliances: the relations within are oriented towards a longer-term duration, the continued existence of the alliances (during systematic data collection), the regular meetings and workshops and the steady, uninterrupted growth of output. The interviewees, however, indicate a clear orientation towards establishing long-term relations which is a required element for the temporal linking of a path-dependent process.

While the stability has, arguably, not been problematic for *OHA*, the decline of *SF* (after systematic data collection, see epilogue), however, is symbolic for the problematic nature of said stability. With an initial market share of over 40% and powerful industry players, *SF* members did not anticipate the sharp decline they experienced after the main hub firm *Nokia* pulled out of the alliance. The platform's success hinged on the maintenance and contribution efforts of this important player. While larger, financially strong members such as *Sony*, *Samsung* and *Motorola* had already joined *OHA* as part of a platform portfolio approach and could alleviate some of the damage from *Nokia*'s withdrawal, many smaller firms such as app developers, user interface designers and developers, technology integrators etc. saw their investments nullified and were forced to close, some not only parts of their business, but entirely when *Nokia* essentially closed *SF*. Even *Nokia* itself ultimately lost its business and its entire smartphone workforce pursuant to the acquisition by *Microsoft*. The steady success of *SF* turned to failure, as it transpired that the potential external threat actually emanated from inside the alliance.

While strong similarities initially exist between the two cases, there are differences too. The category 'closure, steering and control' reveals contrasts in the way in which alliance activities and member entrance are governed. The alliances differ strongly with regard to their application procedure. *SF* allows the application of any individual or company for membership, has pre-determined annual fees and voting rights for participating in decision-making procedures (one vote per member). By contrast, *OHA* invites the application of members by email but does not offer transparency regarding the admission process or decision-making procedures.

The data also revealed that *OHA*'s lead firm is selective about who may join. The same appears to apply to the management of contributions to the code. While *SF* decides 'democratically' through votes in a board, *OHA* has the lead firm make the decisions in a more 'autocratic' way. It appears, though, that *SF* seeks to expand its alliance membership methods since they are looking for staff to support this development professionally and, contrary to *OHA*, actually established an explicit network administrative organisation (NAO). Together, this data category on the alliances' steering and control appears to support the framework's suppositions, albeit in different ways. Most importantly, the data reveals that the dimensions of social capital are at work and play out their effects on the alliance members over time.

Network steering and closure also find support regarding the inductive category 'fragmentation'. Interviewees perceive problems caused by differing platform code versions in different handsets and the resulting extra coding efforts that bind many extra resources, and sources frequently state the same with regard to the entire market. When talking to experts, they attribute this to a lack of cohesion. Alliance cohesion, resulting in everyone working with the same version and thus increasing compatibility, is regarded as a solution to overcome the widely perceived problem of fragmentation. Industry observers chiefly discussed this aspect at the cognitive level of social capital. This cognitive dimension should, however, be reflected in a high resulting structural cohesion through the interplay with the other two dimensions of social capital (Maurer & Ebers 2006), because a strong sense of belonging can lead to further cooperation and vice versa. In network terms, this increasing cohesion would be measurable as higher network density, leading to increasing levels of network closure.

Pursuing such a strategy thus results in social capital from closure with the associated benefits and problems caused by the same. In this sense, overcoming fragmentation can serve as a symbolic means of inducing cooperation through the normative forces of software code in a "code is law" (Lessig 2006: 6) manner. The binding forces of efforts to overcome fragmentation may lead to actors' further integration into the alliance in *OHA*. This was evidenced rather strongly (after data collection) when *Google* – at the threat of exclusion – discouraged *OHA* members from pursuing outside cooperation that would lead to *Android* forks. As for *SF*, the efforts in overcoming fragmentation issues are less obvious, which is somewhat surprising given a similar, or to some extent even worse, fragmentation situation with the additional issues of decentralised app stores and heavy UI layers. This lack of alliance cohesion through app store centralisation, common user experience, and the much looser alliance steering are arguably, however, important factors that contributed to *SF*'s ultimate decline in the marketplace (Wang, Hedman & Tuunainen 2014).

The explanatory framework does not originally account for the issue of fragmentation. It resembles the "format war" situation of competing market standards but differs insofar as the incongruences of technology occur within the same 'standard', i.e. software platform. The issue of fragmentation and particularly the way in which the actors seek to overcome it certainly appears compatible with the cognitive dimension of social capital. Support for the relational dimension appears weaker, yet stronger again for the structural dimension because normatively enforced uniformity affects group level conformity. Thus, the data category on overcoming fragmentation displays at least two out of three dimensions of social capital at work and can arguably be considered part of the social capital mechanism developed above.

The findings so far indicate that both the bridging and closure types of social capital are active in the alliances. They also appear to occur in a temporal order one after another, although not strictly, since bridging efforts continue while closure is already at work. This is consistent with the explanatory framework's view on the mechanism, since for reinforcement through positive feedback over time to exist, an increase of closure should lead to more relations created within an alliance. The findings are also indicative of a broker's strategy as increasing closure, certainly for *OHA*, where hub firm *Google* is actively managing, steering, and brokering relations within the alliance, while curtailing those to the outside where possible. Moreover, this behaviour exhibits precisely the activities to be expected of a broker agent with the strategic goal of creating closure (see Section 2. 6. 1), to both limit access to the public good of social capital by locking others out and reducing opportunities for free riders within.

The data from the time of systematic collection does not, however, unambiguously support the concept of a lock-in which is the final stage of the network path dependence framework. Three firms have exclusively limited themselves to one platform (*OHA*) and that restriction could prove problematic e.g. if the platform ceased to exist (as in *SF*'s case), if technological or (inter-)organisational change might require a costly switch away from *OHA*, or more generally if better cooperation partners were available outside but the firms find themselves bound to fulfil alliance obligations and honour internal agreements (e.g. among each other) rather than leave – a strategic lock-in.

However, classifying this lock-in as an inefficient network lock-in of firms at this stage would exceed the data's power. *OHA* is flourishing and, while the positive feedback mechanism of social capital is at work, there is no clear support for a downside to this focus. Still, in terms of strategically building cooperative relationships, *Motorola*, *Samsung* and *SonyEricsson* have limited themselves to the members of *OHA*, thus ridding themselves of the potential to follow a portfolio approach and of 'hedging their bets' in this manner. As it transpired in the years following systematic data collection, *SF*'s decline indicates how problematic the dependency on *SF* would become for the many firms not making the switch as a result of lock-in.

The lack of strong support for the lock-in – the final stage of the network path dependence framework – may be partly due to the fact that some of the firms covered in the interview data are financially able to cope with losing (some of) the resources they invested in alliance activities. One interviewee declared that their firm would simply quit an alliance if it considers membership no longer beneficial, hence indicating no perceived lock-in for the individual firm, and, by extension, at the whole network level.

However, this situation is different for smaller companies whose financial and other resources are not as robust, and a network lock-in together with the resulting switching costs may inhibit network exit even if desired. If the market rejected the platform supported by them, this would then render their lock-in inefficient and not just strategically problematic, thereby nullifying their investments and knowledge accumulated in the relationships, and potentially implying corporate failure for small ventures, as evidenced in *SF*'s case.

While neither technical platform capabilities nor market success forms the focus of this study, a lock-in can be at least strategically inefficient or problematic (Sydow, Schreyögg & Koch 2009). It limits actors' options for other alliance memberships and binds them to a single one of a few platforms, certainly in the case of smaller firms. However, when they are perceived to be breaking the rules of the alliance, larger firms can also be discouraged from cooperating with alliance-outsiders (see epilogue). For *OHA* member *Acer*, remaining in *OHA* entailed the 'cost' of losing an important, potentially very lucrative cooperation option with an alliance-outsider.

With learning and investments made in the corresponding technology, a decline of that platform would be likely to strongly affect member firms, at least the smaller or more specialised companies, potentially causing financial difficulties. As a result, members will be eager to spur the market success of their platform through supportive cooperation even in the case of technological inferiority compared to other or new alternative platforms or forks. This may also result in a lock-in at cognitive/strategic level and at network level, both of which are clearly perceived by industry members as evidenced by the playing of the "Dating Game" with platforms as 'wedlock' candidates.

It follows that the case study findings on both embedded subcases generally substantiate the explanatory framework as developed above, albeit not unambiguously and not without variance. Studying how abstract mechanisms work in practice (Kremser & Schreyögg 2016: 699) was thus fruitful in revealing some important differences which raise new questions (see below). Some of the five data categories receive stronger support than others and these differ across the cases. The results of the cross-case comparison (based on the data from the period of systematic collection) are summarised in the following Figure 12:

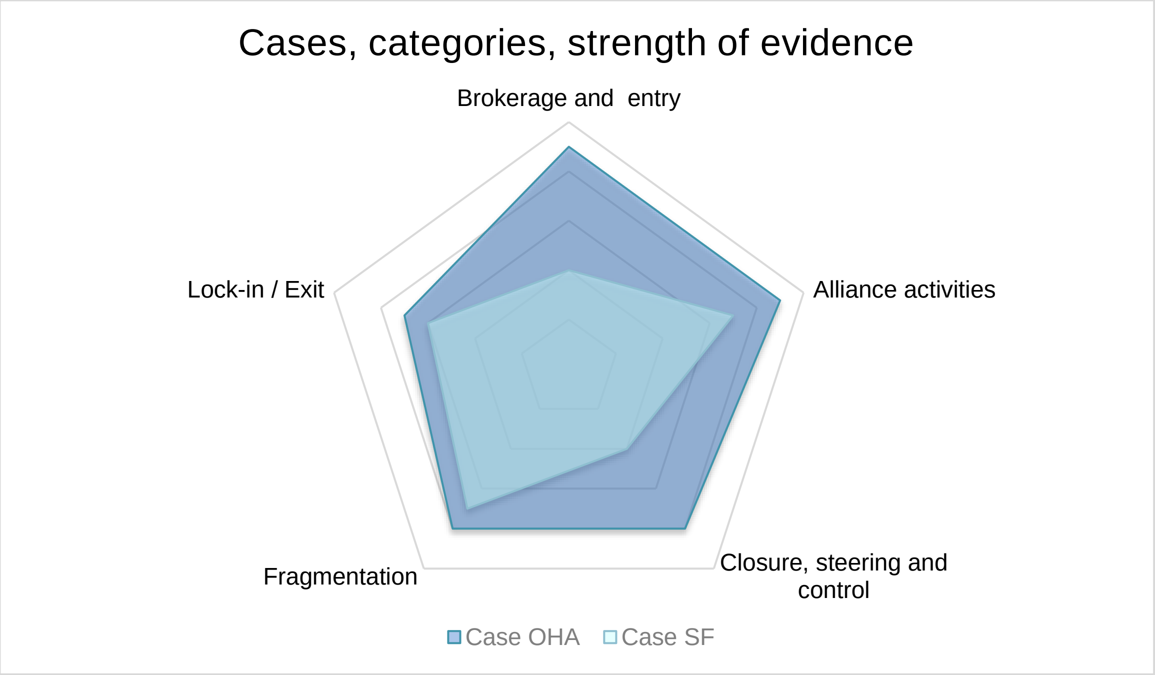

Figure 12: Comparing cases, categories, strength of evidence

3. 4 Reflection: making the connections

The purpose of the case study was to study instructive evidence from an adequately suitable case for substantiating the integrated explanatory framework of path dependence in interorganisational networks through to a real-world, illustrative example, and thus also to further motivate the framework's creation. This was useful because the framework was previously at a conceptual stage of development and because path dependence is a dynamic theoretical concept (Siggelkow 2007: 22).

The rich historical context of the communications industry developments (incl. epilogue and early history, see appendices) reveals the strong overall economic and societal importance of the communications industry. It shows how this sector transitioned from voice-centric services to data-centric services (Khosrow-Pour 2005: 1987) through – not least – high levels of cooperation. The recent changes were organisationally, technologically and socially disruptive because they connect players from several formerly separate industries, because they have made the internet experience truly mobile, and because they replaced competition of firms with a competition of platforms supported by cooperative interorganisational alliances, pushing for global domination amidst continuous technological change from voice to data and from 2G and 3G to 4G, and increasingly 5G mobile technology.

Adding to the rich historical context for the cases, the case study – designed as an embedded two-case study (Yin 2009: 46) – focuses on two contrasted empirical cases of interorganisational networks in this high-tech industry with technological standardisation tendencies. Hence, a good fit of case study design and framework could be achieved through contrasting the results from one case with its literal replication. Case study data was measured in terms of four data categories derived from the framework and one inductive category. Regarding results, some differences between the two cases exist, as well as many similarities. The strength of support for the categories derived from the explanatory framework also varied, with a tendency of the *OHA* case to exhibit the mechanisms and stages of the framework more clearly and more strongly than SF.

'Brokerage and entry' found support from both cases, but more so in the *OHA* case. The hub firms' (Jarillo 1988: 32) (*Google* and *Nokia)* activities suggest that they cross industry borders by establishing the alliances and bridge structural holes (Burt's argument) between the different industries involved and, of course, between firms invited to participate in the alliances. This structural phenomenon would probably not have occurred to this extent without the initiative of the two hub firms *Google* and *Nokia*. In *OHA*, however, *Google* retains this active role of brokerage more than *Nokia* in *SF*. Many network ties emerge within the alliance and make members more densely connected. Output increases through these activities and leads to continuous investment in the relations within the alliance. This leads to more local search (Duysters & Lemmens 2003) and more closure in the network (Coleman's argument), while the increasing alliance activities show an intensity of collaboration and this attracts many new members.

The steering activities pursued by *Google* also indicate a strategy of enhancing internal cooperation and disenabling external cooperation for the alliance and its software platform to gain momentum in the marketplace. The industry players' strategies for tackling the perceived threat of software fragmentation rely on integrating the activities of member firms into *OHA* more intensively. These activities are aimed at creating cohesion in terms of the cognitive and relations dimensions of social capital, with the structural dimension being the resulting outcome measurement.

Social capital as a potential driver of path dependence was found active as a process from brokerage to closure and in its three dimensions, although a purely temporal succession was difficult to diagnose. The case study reveals that brokerage and closure occur simultaneously and not only in a strict temporally consecutive fashion. This finding provides support for the newly conceptualised mechanism of social capital (see Section 2. 5) as part of the explanatory framework. It is the very nature of path-dependent processes that dynamic effects occur close to simultaneously and reinforce each other, with their temporality often not easy to disentangle. The concurrence of brokerage and closure is also not surprising in terms of networking activities. In developing the framework, I postulated a process character leading from brokerage to closure and the strategic intentions of actors seeking to influence their networks.

While the case study indicates that both occur simultaneously, the consecutive logical sequence remains, also in the stricter sense that without closing structural gaps there cannot be closure and that, if closure is a strategic goal e.g. of the hub firms, brokering new connections is the relevant means of strategically enacting such closure. The case study findings add to this consideration regarding the logical causal sequence of events (rather than a purely temporal one) and support the framework's conceptualisation regarding a process nature of social capital overall. Furthermore, the case study shows how the dynamics of the networks may ultimately lead to locking-in alliance members to the network, and simultaneously to the software platform. In that sense, the technological (cognitive dimension of social capital) and the network path dependence (structural dimension of social capital) go hand in hand, and even become manifested as software code. A platform gaining momentum attracts new members and makes the alliance grow further, while simultaneously increasing closure – the virtuous, and potentially vicious, circle of a path-dependent dynamic.

One important finding (and limitation) of the case study is that the problematic nature of the final lock-in stage of the network path-dependent process could not be shown empirically with sufficient confidence, at least not with the data from the period of systematic collection. While lock-ins can clearly be diagnosed for three firms in *OHA*, an *inefficient, ineffective* or otherwise problematic lock-in has not yet occurred. From the subsequent epilogue, we learn that lock-ins to *SF* clearly became problematic when the withdrawal of major supporter *Nokia* led to the closure of *SF*, resulting in negative consequences particularly for smaller firms with less financial clout. It remains to be seen whether similar developments will occur in the future development of *OHA*. With a current market share of 85%, such a decline would be somewhat surprising, however, and would be unlikely to occur swiftly.

The case study also shows how the industry players, and particularly smaller ones, are quite aware of the potential for lock-in, as the 'wedlock' analogy indicates a situation similarly described in the literature (Gulati 1998: 299). Yet the extent to which this 'wedlock' is perceived as threatening remains unclear, since subjects did not readily state (potentially) problematic issues with their alliance memberships. This may be an effect of social desirability, however, since other alliance members were present during the game. Clearly, though, many industry players are aware of the looming lock-in and even of the terminology, albeit mostly in reference to technology. While smaller actors are not actively reducing their lock-in potential or are unable to do so, some larger ones – especially the hub firms – are more active in surrounding themselves with lock-in-like closure. More weighty actors appear less concerned with lock-ins in both technology and network, and they exhibit skills of switching, as evidenced e.g. by *Nokia* (*Symbian* to *Windows*, subsequently to *Android*) but not without considerable switching costs, such as giving up an entire corporate division.

Questions thus remain regarding the extent to which and what kind of influence firm size and available resources exhibit in the path dependence tendencies of interorganisational networks. A related question is how actor heterogeneity in such contexts affects path dependence tendencies, and also industry-structural criteria such as density. A systematic analysis of contrasted scenarios appears necessary to answer these questions. The computer simulation model in the subsequent Chapter 4 avails itself of experimental scenarios to uncover such effects and to systematically explore the circumstances leading to lock-ins and the resulting conditions.

The case certainly indicates beyond doubt that agents are not (all) blindly sleepwalking into path dependence, which is what some path dependence critics have claimed to be an explanatory weakness of the theory. On the contrary, the case study shows that even with the events and dynamics unfolding in front of agents, rather than behind their collective backs, they may not be able to adequately address, halt, reverse or even reduce the dynamics unfolding before them. In that sense, the criticism of path dependence critics such as Liebowitz and Margolis (1990) appears unwarranted with regard to agency aspects in path dependence, because, in a nutshell, being aware of a (potentially) problematic situation does not necessarily entail being able (or willing) to do anything to prevent it from happening.

Overall, the framework provides meaningful categories for analysing the collected data and the contrasting of the two subcases provided extra insights into the workings of the social capital mechanism and path dependence in interorganisational networks. The iteration between literature and case data offered an understanding of a high-tech industry building on competing interorganisational networks.

The findings point towards certain problematic developments, especially for smaller network members and their reduced strategic flexibility. Finally, firms' networking behaviour indicates the existence of the path dependence mechanism of social capital (bridging->closure) developed as part of the explanatory framework above, and a narrowing-down of options towards a lock-in to their alliance over time, albeit with bridging and closure activities being more *logically* consecutive than *temporally*, i.e. they occur at the same time. In conclusion, the case study indicates that the developed explanatory framework has merit.

There are two limitations arising from the case study that warrant further study. Firstly, the findings from the case study did not provide much detail on the specific conditions of the final lock-in stage of the process. While lock-ins in the case are conceivable, probable, and developing, not enough clarity from the data on their problematic nature for member firms was available. This may in part be due to social desirability issues, since subjects and observers of the alliances were somewhat reluctant to express certain potentially problematic issues in the alliance developments at the observed industry conferences. It is, however, rather interesting to understand more about the lock-in stage, e.g. what the overall network structure among competing alliances may look like before and after lock-in occurs, how membership to such locked-in alliances is distributed at the whole-network level, and how new entrants and firm exits from an alliance affect the network dynamics. High network density is an important characteristic of a closed interorganisational network, but the lack of comprehensive network data relating to the cases means that such aspects will benefit strongly from study in the simulation model, where a high degree of formalisation allows for the measurement of desirable variables much more easily.

Secondly, while the precise manner of the social capital process was studied in greater detail, it proved impossible to obtain some information regarding path dependence, particularly the instances of lock-in unfolding in these interorganisational alliances. These include how fast the process is developing, how problematic and severe the lock-in really is for the members, and how the more quantitative properties of the alliance groups are developing. Regarding the more quantitative properties of alliances, issues as regards empirical data access and resource and time restrictions exist, which inhibit the acquisition of the fine-grained data points required for an adequate processual interpretation. It is doubtful that these restrictions could be overcome by gathering more data, e.g. on new cases from the field, further triangulation (Flick 2005) or that measures such as consensual coding (Schmidt 2007: 453) or inter-coder reliability (Mayring 2007: 471) would improve the quality of the findings. Additionally, theoretical saturation has already been reached by the case study and it has thus fulfilled its purpose.

Similarly, the case study data did not provide for studying the effect of relations and networks existing before the creation of the alliances on the formation and potential path dependence of the same. Moreover, the firms in the case study exhibited great diversity in their individual characteristics such as their resources (financial strength, project management skills, number of staff etc.), their size (from industrial giants to single developer members, at least in *SF*), their age (from incumbents to start-ups), etc. These characteristics carry meaning for other alliance members and new entrants as they assess which other firms they may seek to cooperate with. Firm age has also been considered a proxy for the experience, reliability, importance and overall prominence of a firm (Stuart 2000: 795, 805) and relative organisation size differences have been found to pose considerable management challenges for members and lead organisations (Fortwengel & Sydow 2018). Resources have been stated in the literature as one of the main motivations for networking, and indeed the creation and maintenance of a joint asset – the software platform code and related digital services – constitute the main motivation for creating and entering the alliances. However, the case fails to reveal the extent to which individual firms' resources such as dynamics capabilities (Zott 2003) or the project management skills of *Google* influence networking behaviour among firms. Furthermore, it remained open in how far the dense networks' normative control (which are ironically created exactly for this reason) leads to particularly big players losing control over their resources and relations (Gargiulo, Ertug & Galunic 2009: 326-331).

Additionally, the case data reveals that the strategies with which firms approach their alliance memberships also differ greatly. Some firms indicated that they wanted to shape the developments, while others clearly referred to themselves as "followers." Likewise, firms' perceptions and evaluations of the constantly changing network parameters and network-related firm characteristics remained in the dark. They are important, however, for assessing potential cooperation partners, especially when these are brokered by central actors. Perceived potential benefits from a cooperation relation and from participating in the overall network are naturally strategic considerations of actors. They remain inaccessible and abstract, however, and require a degree of formalisation for study that cannot be achieved in case studies.

The remaining questions lie in the realm of study that is best addressed by a high degree of formalisation such as that offered by a simulation study. More mathematical, network-analytical properties of the alliances and actors in their path dependence process, including properties such as density, can be modelled with the required precision. Simulation models are also formalised implementations of theory and require making all conceptual model elements and their relations *explicit*, which helps uncover answers to at least some of the questions raised by the case study. Together with the ability to experiment with contrasting virtual scenarios, simulation models permit the systematic exploration of frameworks like the one developed here to explain the path dependence developing in interorganisational networks. As an initial formal implementation of the developed framework, a computer simulation model of this nature will be created and used for experimentation in the next chapter.

4. Building a model

"To understand collective dynamics, we must study the collectivity as a whole, but we must not study it as a collective entity"
(Hedström & Ylikoski 2010: 63).

In the previous chapter, I used an empirical case study to substantiate and illustrate the developed explanatory framework and provide empirical insights into its applicability and suitability. However, certain questions remain open due to lack of observability in the empirical data, and several others were newly raised by case study findings. This necessitates a further investigation of path dependence in interorganisational networks and its social capital mechanism as developed in the framework in order to gain a deeper understanding of the still partially abstract concepts and for further theory development. To this end, I employ an agent-based model of path dependence in interorganisational networks as an initial formalisation of the framework. The formalisation of conditions, processes and causal mechanisms permits the systematic exploration of scenarios and different initial conditions that will help reflect on and further develop the explanatory framework.

In this chapter, I first address the need for using an agent-based model (Section 4. 1), the method itself (4. 2), and the developed computational model (4. 3) by following the ODD+D documentation format (Müller et al. 2013). Subsequently, I detail the design of experiments (4. 4) and the questions to be answered through the experiments. Following that, I present the results of the experiments, analyse, and interpret the data (4. 5) and finally discuss overall findings (4. 7).

4. 1 Why create a computer simulation model?

In short, I use a computer simulation model to enforce precision and logical consistency, transparency, and instructive documentation in theory development (Adner et al. 2009: 202-203). This type of modelling of the causal relationships is necessary to gain an adequate understanding of why and how path dependence arises in interorganisational networks. Computer simulation allows for such an explanation that specifies the micro-level mechanisms underlying the aggregate, macro-level phenomenon.

4. 1. 1 Generally advantageous characteristics of computer simulation

In general terms, computer simulation is a powerful scientific method or approach. It has been characterised as "the 'sweet spot' between theory-creating methods [..], and theory-testing methods" (Davis et al. 2007: 480) with regard to its abilities. This dual purposiveness of computer simulation stems not least from the method's precondition for conceptual clarity and precision. The advanced level of formalisation is due to the fact that computer simulation is just one specific way of modelling, itself a well-established scientific method (Gilbert & Troitzsch 2005: 2). Models are by definition simplifications of real-world processes, dynamics, and phenomena, but offer the advantage that – since all causal relationships must be specified – they must (and can) be understood beyond the level of 'statistical significance' of traditional quantitative models that often fail to capture the complexity of the interdependent processes in which they arise (Harrison et al. 2007: 1229).

Furthermore, simulation models are an appropriate means to explore both theory and phenomenon, because compared to other methods they can more adequately account for emergent and interdependent processes (Gilbert & Troitzsch 2005: 11-12). Where the interaction of individuals can lead to emergent processes, forms of organising, (social) mechanisms, institutions, norms/rules or (social) structures beyond any individual's grasp or control, simulation is the method that can best address theoretical concepts such as the autopoiesis of complex social systems (Maturana & Valera 1992: 188-201). Matters of emergence cannot easily be addressed with other quantitative empirical methods and only with difficulty in inductive, qualitative empirical research (Carley 2001: 77). Some argue that based on this "emergentism thinking" (Sawyer 2004b: 265), social simulations "may ultimately be just as central as theories in providing social explanations" (Sawyer 2004a: 228).

It has even been argued that computer simulation signifies a third symbol system next to language and mathematics – the symbol systems of qualitative and quantitative approaches (Ostrom 1988: 381). This third symbol system is able to transcend the boundaries of both the others where they limit our understanding of causal interdependencies over time and structural processes, i.e. the subject of this research. A simulation is thus "a theoretical experiment that mediates between observations of the phenomenon and natural language descriptions" (Edmonds & Hales 2005: 209).

As a result, computer simulation in general, and agent-based modelling in particular, are uniquely suited to fully address all levels of Coleman's prominent concept of the sociological 'bathtub' (Coleman 1990: 10). Simulation does not need to (bridge-) hypothesise regarding the stages of the 'bathtub' model, it can actually (re)produce each individual step and the interdependency of levels: from collective actor types and states through their (heterogeneous) individual characteristics to their individual behaviour and finally to the aggregate emergent state that they create by their actions (Gilbert & Terna 2000: 60). Computer simulation is hence capable of creating an understanding of both the behavioural micro-foundations and the relationship to the macro-level outcomes that the micro-level produces, and their causal linkages (Hedström & Ylikoski 2010: 62-64).

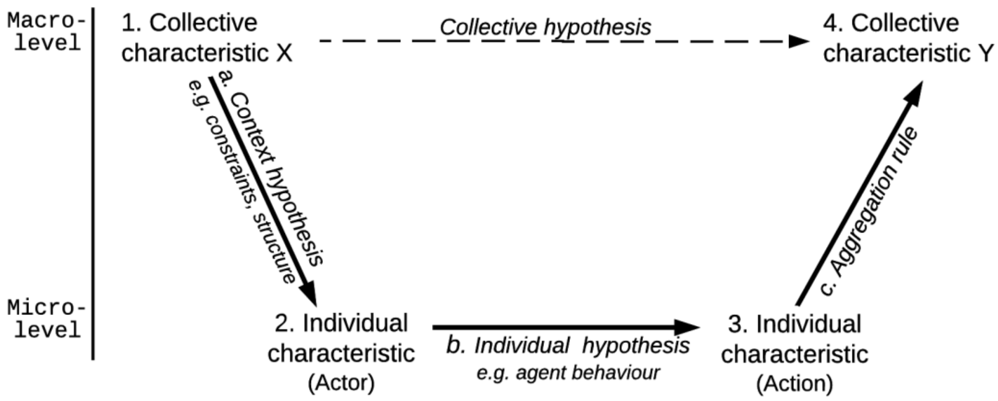

Figure 13: Coleman's bathtub (adapted from: Coleman 1990: 10)

Additionally, simulation can (re)produce the necessary causalities without the need for inferential statistics that test for significant variable relations. Instead, when evaluating the results of computer simulation, researchers employ frequency statistics based on the actually built-in – not hypothesised – causal mechanism. This is possible because both causation and population are included in the model, thus rendering irrelevant the often-problematic axioms regarding statistical distributions, data scales, samples sizes, unobserved heterogeneity etc.

Given these general strengths, it appears warranted that Vergne and Durand (2010: 749-751) use their critical review of path dependence research to call for more application of computer simulation to the study of path dependence phenomena. Apart from the aforementioned general characteristics of systematisation, formalisation, embedding of emergence of social structural outcomes and data richness, Vergne and Durand specify further criteria explaining why social simulation is ideally suited to path dependence studies.

4. 1. 2 Advantages of simulation pertaining to the present research

Vergne and Durand (2010: 750) consider simulation approaches purposive because they enable researchers to specify the initial conditions, contingencies, i.e. small events and non-ergodicity, and self-reinforcing mechanisms (hereinafter referred to as *positive feedback mechanisms*). These are important definitional elements of path dependence theory (see Section 2. 4). Satisfying the need to address these constitutive concepts of path dependence theory is one of the strengths of the simulation method, because more than other methods, it ensures that all elements exist and function: they can be consciously created in software code that enables the study of the system's core dynamics (Epstein 2008: 1.9). Additionally, simulation ideally meets the methodological demands of this study, since its focus is to develop a longitudinal, nonlinear, and processual framework for the explanation of how path dependence arises within interorganisational networks, and because empirical data specifically on the lock-in stage of the framework proved difficult to access (Davis, Eisenhardt & Bingham 2007: 481). I separate the further consideration of the advantages of computer simulation over other approaches into the common deductive – inductive distinction.

4. 1. 2. 1. Computer simulation vis-à-vis deductive, quantitative methods

Deductive quantitative approaches typically deduce causal hypotheses from theoretical concepts and translate these into formal models that are analysed by computer software. Most such approaches exclude or aggregate the role of time and rely on a linear logic. Computer simulation models are both similar to and dissimilar from these quantitative analysis methods in that they also rely on assumptions, but inherently involve time, allow for a higher level of control than even lab experiments, and permit non-linear behaviour, i.e. address the complexity and interdependencies of social science topics much more effectively (Harrison et al. 2007: 1230).

In the case of (analytical) mathematical models, conclusions are drawn based on numerical solutions (calculus of derivations or mathematical proofs). Alternatively, conclusions can be *inferred* from the statistical analysis of empirical data in the case of stochastic analytical models (Harrison et al. 2007: 1230). There, the goal is null hypothesis significance testing (Cohen 1994: 99) to examine the viability of a theoretical claim regarding the relation of variables. Common inferential statistic-analytical methods used in OMS are correlation and (multivariate) regression analysis models, and (laboratory) experiments.

As described in Section 2. 4, path dependence is a processual concept and needs to be studied in its unfolding over time, with path-dependent dynamics following a non-linear logic. For many quantitative methods such as correlation and regression analysis even in their multivariate and more sophisticated variants, these remain unresolvable issues. They often exclude or compress time in cross-sectional data and assume and rely on (approximations of) linear relationships between variables, whereas more dynamic developments are captured only in terms of the (actually static) mediator or moderator effects (Baron & Kenny 1986). Hence, these inferential methods as well as mathematical models do not allow for an analytical understanding of non-linear effects or dynamics (Gilbert & Troitzsch 2005:10). Simulations can be run for varying durations of time while simultaneously facilitating re-runs of historical events. This enables a level of in-depth pattern tracing that no other quantitative method can offer for identifying the causation of lock-ins (Vergne & Durand 2010: 750).

Vergne and Durand (2010: 750) further point out that, similarly to laboratory experiments, simulation allows for altering the initial conditions and contingencies while controlling for each individual effect by systematically altering the variable combinations. When using other quantitative methods, contingency at the beginning of a path-dependent process can essentially only be assumed or argued to exist, since there is no definitive way of verifying it post-hoc (Vergne & Durand 2010: 746). In this vein, path dependence theory argues that small events are essentially random, not in absolute terms – neither firms nor individuals act fully at random – but as far as their effect on the lock-in as an outcome is concerned. Similarly, the 'smallness' of a small events cannot be captured by analytical statistics but can only be assumed. Simulation is a way of ensuring that small events are consistently triggered at random and that development trajectories emerge from this randomness, rather than being assumed. This would be the case in most other quantitative (deductive) approaches, where randomness is hard-wired in terms of assuming normal distribution of variables, exclusion of latent variables, linearity of effects etc.

Another difference, compared to laboratory experiments, is that simulation allows for an even more controlled level of heterogeneity of subjects (agents) than experiments can. While the controlled nature of experiments can avoid the danger of confusing correlation with causation based on the high internal validity of laboratory conditions, they still contain a potentially high level of unobserved heterogeneity among subjects, and its effects cannot be identified clearly. The argument for laboratory experiments with human subjects is that generalisation can be applied to a sample in order to make statements about a population of subjects. This generalisation, however, bears the risk of being over-general or does not hold across situational and subject contexts. Simulation's high internal causal validity – rather than statistical validity – and its ability to scale up the performance of the simulation much more easily than laboratory or natural experiments, makes it an apt choice when studying the path dependence of a social system (Vergne & Durand 2010: 750).

Adding to the arguments by Vergne and Durand, laboratory (or natural) experiments can be deemed a close relative computer simulation which has also been termed "virtual experiments" (Carley 2001: 70) or "theoretical experiments" (Edmonds & Hales 2005: 209). Laboratory experiments have been used successfully in path dependence studies but focus on path dependence of individuals and not that of systems (e.g. Langer 2011). However, it is not suitable or possible to use actual experiments in the current investigation of the increasing rigidity of network structure. Since the phenomenon under scrutiny concerns the interorganisational and not the individual level, it would be impractical and highly resource-intensive to experiment with firms in a laboratory situation, let alone doubts concerning external validity. Regarding natural (but controlled) experiments, since the present research is about understanding a problematic phenomenon, experiments would have to use triggers and treatments to reproduce several comparative instances of situations that are highly problematic or even detrimental to firms. Such treatments of actual firms would be ethically questionable as regards testing firms' propensity to become locked-in. Although actual experiments are consequently not possible, but virtual, i.e. simulated experiments are, and the latter additionally come without issues of ethical concern.

4. 1. 2. 2 Computer simulation vis-à-vis inductive, qualitative methods

Inductive qualitative methods such as case studies (Yin 2009) have frequently been used to study path dependence phenomena but have restrictions that computer simulation can complement. The interpretative and heuristic approaches used in case studies to analyse empirical material can account for positive feedback mechanisms and non-linear dynamics similar to computer simulation and essential to path dependency research. In case studies' very nature of collecting in-depth field data, however, lies the fact that they typically only cover short time-frames and/or a small number of cases. This limitation was already in place for the original studies of path dependence (e.g. David 1985) and persists more recently.

In contrast to these inductive path dependence studies, and to address some of the criticism path dependence research has received, Vergne and Durand argue that case studies, in particular historical ones, fail to adequately address certain elements of path dependence theory. These include initial contingency which can only be assumed to exist, randomness that is difficult to reconstruct post-hoc, and the smallness of events that remains solely argumentative (Vergne & Durand 2010: 751). Additionally, to overcome small case number restrictions for meaningful inductive or analogical generalisation (Smaling 2003), cases must be similar, yet different enough to permit contrasting so that similarities and differences among cases lead to findings that exceed idiosyncrasies but display systematic patterns (Eisenhardt & Graebner 2007: 27). Overall, as Eisenhardt argues (1989; Eisenhardt & Graebner 2007), case studies are suitable for building theory where there is no understanding of a phenomenon and as such have been used to uncover mechanisms of path dependence in cases where the theory needed to be expanded, for example (e.g. Berthod 2011; Dobusch 2008). Others, like Siggelkow (2007), argue that cases best serve the purposes targeted in the previous chapter, namely exemplification, motivation, and illustration. Moreover, the phenomenon of path dependence in interorganisational networks has been explained above by means of the positive feedback mechanism of the social capital process. Hence, at this stage, a systematic exploration of the created framework's elements and their interaction which may give rise to the phenomenon of network path dependence appears necessary in order to gain insights into the conditions of the final, lock-in stage of path dependence. This can be achieved by studying the emergent effects of actors' interactions.

Furthermore, as already noted with regard to the case study above, access difficulty already persisted in the present case study, where industry players were secretive about their activities in order to maintain a level of control over information in the public realm, not least due to competition, regulatory, and political issues. Even if more data access were possible, an additional challenge in a larger-scale empirical investigation would be the observation of a large quantity of firms, their connections and activities and the motivations for these simultaneously over a long period of time. Such observations would be a considerable exercise in logistics, and can often only be achieved ex-post (Kenis & Knoke 2002: 290) and with limited data points (Walker, Kogut & Shan 1997).

Computer simulations can generate numerous 'virtual cases' as scenarios that are, of course, not real-world data but synthetic data from the virtual simulation world. However, simulation overcomes the issue of short time periods covered by delivering data over long timescales and with fine-grained longitudinal data and continuous time points without data gaps. Unlike classical empirical data, simulation can also repeat variable combinations several times to show the statistical distribution around potentially available empirical cases. This allows for a thorough understanding of dynamic effects in terms of the internal validity of the constituent elements of path dependence, provided that the internal structure of simulations is built on valid internal micro-foundations.

4. 1. 2. 3. Computer simulation and network research

With regard to network research, simulation has the advantage of being one (if not the presently only) method allowing for a (re)production of the endogenous and emergent nature of network structure, where the interdependent interaction of network actors creates a system structure, and said actors' actions are influenced by that very structure in a structurally-complex longitudinal process. Contrary to empirical network-analytical studies, assessing simulation data actually facilitates a properly dynamic representation of the phenomenon, rather than the comparative static approach used in most temporally-oriented network studies with e.g. 2-3 time-points (see, for example, Walker, Kogut & Shan 1997).

Simulation has virtually no data collection restrictions other than computer memory capacity and the elements included in the model. It is through these advantages and abilities that simulation "can help assess the probability of path dependence [...] thereby providing scholars with estimates of the probable frequency of path dependence" (Vergne & Durand 2010: 750) – an endeavour which we will approach by assessing the frequency statistics of the simulation output data in the analysis stage below. Together with its ability to produce the necessary highly-detailed data points, simulation also appears an ideal choice from a network approach perspective.

4. 2 Computer simulation- a modern scientific method

Given that computer simulation has been characterised as a "third way of doing science" (Harrison et al. 2007: 1230), its development and its usage in OMS deserve a brief summary at this point. This scientific method has further spawned its own sub-types that require delineation from the agent-based model that I use here.

4. 2. 1 Development of computer simulation

Simulation as a scientific method was first used during World War Two to analyse the potential impact of nuclear weapons, but could not advance due to a lack of digital programmable computers, and had to rely on punch-cards (Harrison et al. 2007: 1230). In other sciences, simulation modelling existed as early as the 1960s (Macy & Willer 2002: 145), but the method really took hold in the 1990s when computers became widely available and powerful enough for scientific endeavours (Gilbert & Troitzsch 2005: 1). In many scientific fields, computer simulation has become a prominent method, particularly when prediction is a goal of the scientific exercise. These fields include meteorology, climate science, biology, (astronomical) physics, engineering, and many questions in the natural sciences, economics and those that cut across scientific disciplines and embrace complexity theory, such as social-ecological systems research (Wijermans & Schlüter 2014). Computer science is probably the discipline that has the strongest connection with computer simulation, but this involvement lies less in the actual use of the method than in its advancement through the development of simulation toolkits and libraries, programming languages, analytical software, versioning systems etc.

The benefits of computer simulation for OMS research were demonstrated early on by scholars such as Cyert and March (1963) or Cohen, March and Olsen (1972) with their famous garbage can model that used simulation to study emergent organisational choice. Despite such early signals, computer simulation has been used surprisingly seldom in business-oriented social science research. Harrison et al. (2007) find that management and sociology (essentially Organisation and Management studies – OMS) considerably lag behind other social sciences such as psychology, economics (especially game theory, such as Cohen & Axelrod 1984; Axelrod 1997), and political science in terms of publications using computer simulation (Harrison et al. 2007: 1232). This lack of application is surprising, given that simulation offers so many benefits, especially for the social sciences and management, and even for management practice (Sterman 2000: 84; Deckert & Klein 2010). Harrison et al. (2007) attribute this trailing behind, as well as the lack of studies, at least in part to simulation not being taught in postgraduate curricula and widespread scholarly aversion to the level of abstraction required for simulation modelling (Harrison et al. 2007: 1231).

Social science has been picking up in terms of simulation usage, and more studies use the method today than the 0-7% of papers in the 1990s (Berends & Romme 1999: 577). However, both the trailing behind and the lack of studies continue to exist, perhaps due to insufficient clarity as regards what a simulation model is and can do, a dearth of knowledge concerning which simulation types are useful for social science endeavours, and the previous absence of a common framework for documenting model design (Lorscheid, Heine & Meyer 2011: 23; Grimm et al. 2010: 2760; Grimm et. al 2006: 116). These aspects are addressed in the following sections by first detailing the characteristics of social simulation, subsequently distinguishing the agent-based modelling approach chosen here from other simulation approaches and, lastly, by using the increasingly established ODD+D protocol (Müller et al. 2013) to describe the simulation model designed below.

4. 2. 2 Characteristics of social simulation

Social simulation is synonymous with the application of computer simulation methods to social science research questions. Social simulation is a tool for systematically exploring and experimenting with the relationships between variables derived from social theory or from empirical investigations. It is typically used to advance social theory through "theory-based exploration" (Bortz & Döring: 363) and is "particularly useful when the theoretical focus is longitudinal, nonlinear, or processual, or when empirical data are challenging to obtain" (Davis, Eisenhardt & Bingham 2007: 481). Advancing social science using simulation requires a representation of relevant social system elements in an abstract – for generalisation and reduction of complexity – yet meaningfully complex way that enables an understanding of the interrelations between mechanism and variables. Having identified key actors, variables, relations, processes and events, a simulation model is *both* derived from theory and also constitutes theory itself in the sense that it embodies a computerised version of the same (Harrison et al. 2007: 1233). Social simulation can also be defined as the act of understanding, extrapolating, or predicting empirical data.

In that broader sense, the logic of social simulation is not unlike that of statistical models in which a mathematical system of equations seeks to capture the relationship of variables representing a scientific phenomenon (Gilbert & Terna 2000: 58). As depicted in Figure 14, simulations are one specific way of building (and experimenting with) a model of real-world systems in a structured form (Law 2007:4). Here, systems are understood as a combination of variables, their states, interrelations, their development, and rules for the behaviour of the relations based on variable states (Law 2007: 3). As such, computer simulation is, in general, an "imitation of a system" (Robinson 2004: 2).

The crucial difference between statistical or mathematical models and computer simulation is that the formulae can neither be solved mathematically, e.g. with proofs, nor would it suffice to feed it with empirical data as is the case for statistical formulae (Gilbert & Troitzsch 2005: 15-17). Rather, a simulation model consists of mathematical rules translated into *computational* rules such as a stereotypical `IF X=0 THEN do Y, OTHERWISE do Z` (Harrisson et al. 2007: 1233). Such a formal model, then, is not solved analytically, but rather through systematically varying variable states and their relationships. This is necessary, because a mathematical solution is not possible due to the complexity of the equations and their built-in causal interconnectedness (Law 2007: 1).

A further crucial point is that the exercise of building a simulation model is useful for theoretical and formalised precision, since programming the model code requires the transformation of theory and often implicit assumptions and theory elements into variables, relationships, and functions – a process that enforces scholarly reflection and decision-making on what a theoretical argument really means in terms of causal relations, coherence, and completeness (Sawyer 2004a: 220; 225-227). The main interest, however, lies in the experimentation with the model to understand the behaviour of the system it represents (Gilbert & Terna 2000: 58). Simulation is useful in a social science context, not least because the causal direction in statistical models has to be assumed but can be modelled and tested cohesively in social simulation (Robinson 2004: 4-7).

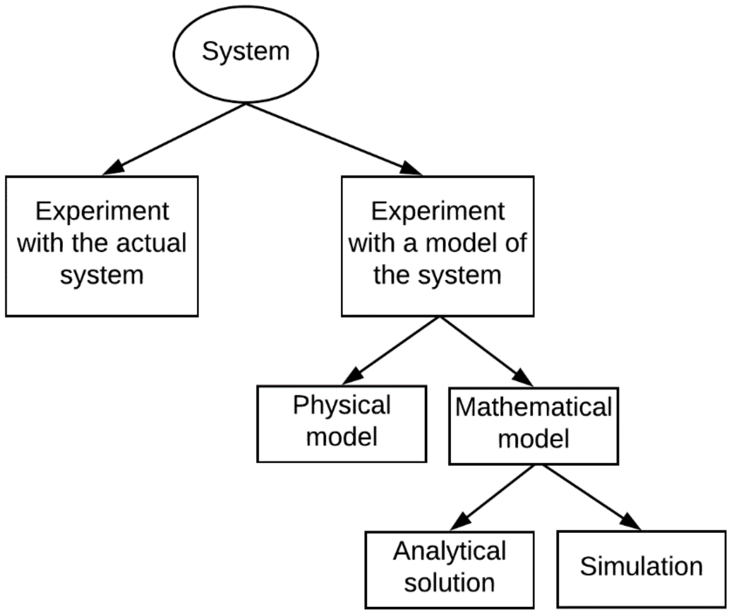

Figure 14: System science methods adapted from (source: Law 2007: 4)

Interpreted thus, social simulation is a type of formal modelling of social systems where computational rules connect mathematical variables, define their relationships, and allow them to change over time (Harrison et al. 2007: 1232). Change over time is a particularly important aspect, since this abstraction from the empirical world not only facilitates a specification of causal relationships, but also allows for the use of 'virtual time' as ticks (tick – the progression steps of virtual time) to trace the behaviour of variable and relations developments over time-frames typically not observable with empirical methods, at least not to the same level of detail (Robinson 2004: 8). This is based on simulation's ability to accommodate the integration of several different ways of dealing with time. Not only can any simulation run (run – the performance of a system behaviour experiment) and be re-run, but also many different historical trajectories can be virtually created from the same initial settings that way (Zott 2003: 109), which caters well to the present study of longitudinal mechanisms unfolding their effects over time. There are several options for implementing the progression of time into the simulation process. These include the use of time-slicing (Robinson 2004: 14) discrete-event simulations, static, dynamic, event-oriented etc. (Law 2007: 6-76). This advantage of simulation in terms of facilitating over-time studies naturally plays into the hands of scholarly endeavours of studying dynamic mechanisms such as the positive feedback mechanism explanations used in path dependence research, and emergent structures and processes of networks and their dynamics.

Furthermore, social simulation differs from the set of analytical models such as statistics in its logic. Statistical models estimate the effects of variables and the effect size based upon data collected from a real-world empirical sample. It predicts the relationship and the effect sizes based on this real-world data, while typically averaging-out heterogeneity, and then compares the predicted average effect sizes with those of the real world. The sample's data results can then be compared with other real-world data to test whether the prediction holds, and the findings can be generalised.

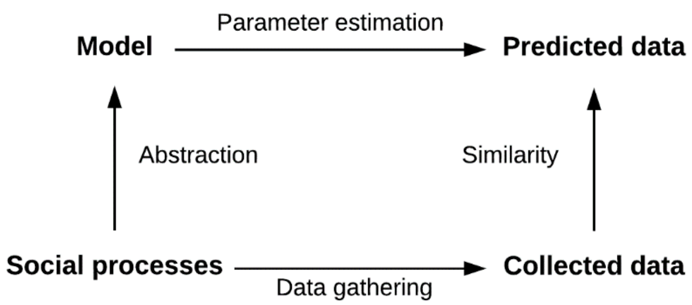

Figure 15: The logic of statistical modelling as a method (adapted from: Gilbert & Troitzsch 2005: 15)

By contrast, in social simulation, the modeller can create direct ontological correspondence (Squazzoni 2000: 199), i.e. (re)produce elements of a real-world phenomenon and variable relationships, and produce their own data to learn about the effects of variables. Hence computer simulation seeks to recreate the perceived conditions of the real world as much as possible, while concurrently remaining abstract enough to allow for a deep understanding of the underlying mechanisms of the real-world phenomenon. The target for simulated data thus lies not in making statistical inferences, but rather in causal explorations with reproducible conditions.

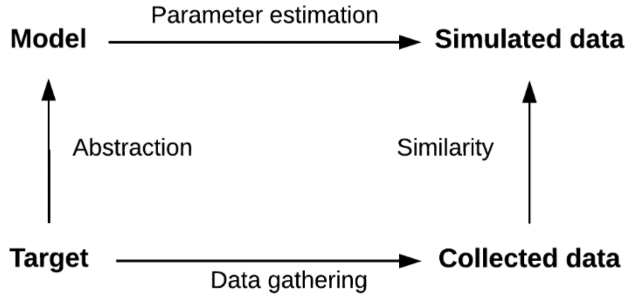

Figure 16: The logic of simulation as a method (adapted from: Gilbert & Troitzsch 2005: 15)

Social simulation follows an idealised five-stage process that begins with the conceptual model and the coding of the same into software code, the result of which is the computational model. The latter serves as the basis for the design of experiments that are subsequently used to elucidate the model's mechanism behaviour and effects. The findings are then analysed to understand more about the phenomenon in the real-world context and potentially provide input for theory building and further empirical investigations. The continuous process of validation, i.e. the assessment of the appropriateness of model choices vis-à-vis the real-world phenomenon, context, and the theoretical knowledge available always runs in parallel alongside.

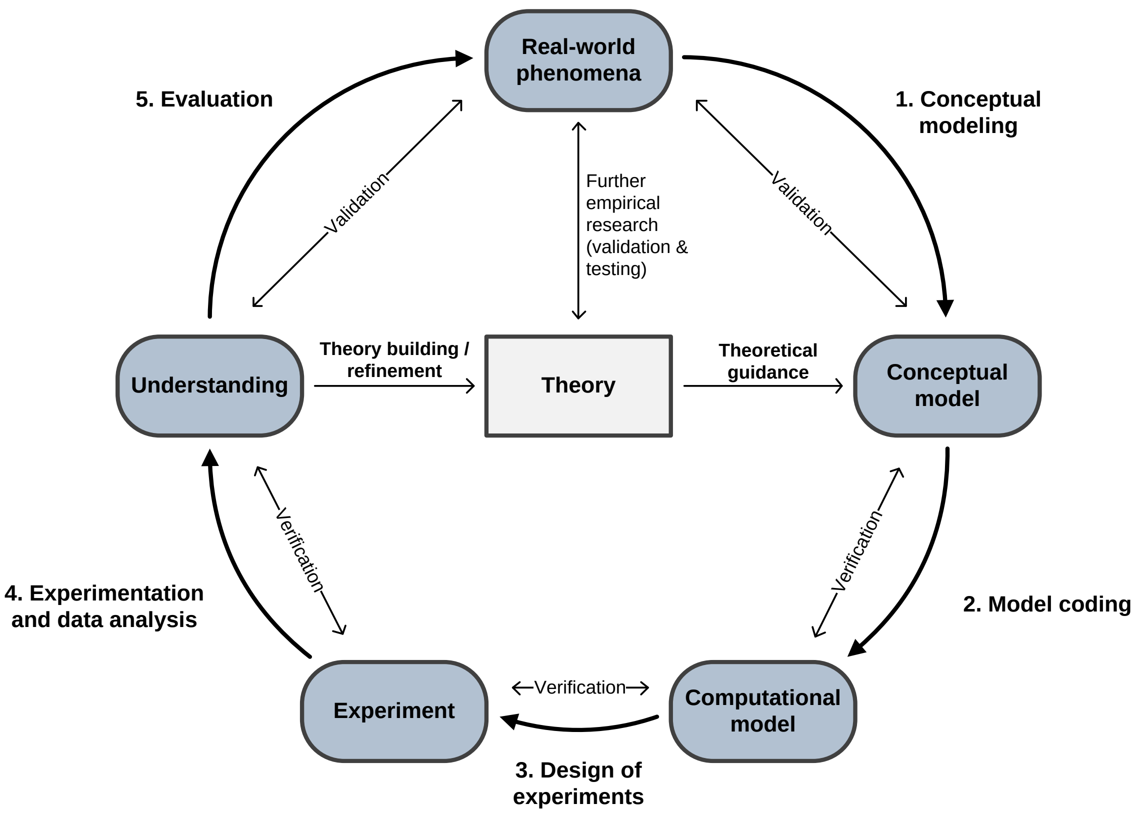

Figure 17: Phases of simulation research (adapted from Meyer 2012: 67) [26]

Section 2. 6, above, developed an integrated explanatory framework designed to explain the real-world phenomenon of path dependence in interorganisational networks – the first step in conceptual modelling. The second step of conceptual modelling, i.e. decisions regarding how to represent the framework's elements and how to code them, the actual computational models and its experiments, are presented together in Sections 4. 3 and 4. 4 respectively. However, first it is important to identify the type of model appropriate for the task, since several different modelling types have been developed in the context of social simulation methods which are suitable for simulating social systems. Those which are potentially suitable for this research projects include four types. The following section substantiates the choice of agent-based modelling (Gilbert 2008) and briefly differentiates this

[26] This illustration in Meyer (2012: 67) is based on Wijermans 2011; Harrisson et al. 2007; Helmhout 2006; Robinson 2004; Balci 1998.

method from the other three.

4. 2. 3 Which type of social simulation approach is purposive?

Agent-based modelling (hereinafter referred to as *ABM*) is a suitable social simulation modelling approach for the present research purposes. ABM is a computational method that enables a researcher to create, analyse and experiment with models (Squazzoni 2010: 199) composed of a complex system of agents and their relations which interact within an environment (Macal & North 2010: 152). The method works like a theoretical experiment and permits re-running, systematically alternating initial settings and replication (Edmonds & Hales 2005: 209). As advocated by Vergne and Durand (2010: 749-751), ABM allows for **specifying the initial conditions**, **contingencies**, i.e. smallness of events and their **non-ergodicity**, and facilitate the **integration of positive feedback mechanism** and processes that dynamically **unfold over time**, i.e. ABM includes timeline-thinking rather than a single orientation – all important requirements for a study of path dependence in interorganisational networks.

Furthermore, the present research is concerned with the actors (the sociological term) within networks. The concept of agents (the computational terminology) is the closest ontologically-corresponding representation (Snijders, van de Bunt & Steglich 2010: 46). Agents can be implemented as **heterogenous** with regard to individual characteristics, internal logics, particularities, and behavioural rules. Agents can interact differently based upon their heterogeneity and influences from their reactive (social) environment (Squazzoni 2010: 199) and ABM permits an adequate representation of the interaction of agents (Conte & Paolucci 2014: 2). Additionally, since ABM imposes no a priori restrictions on the type of **decision-making logics** of the contained agents (Hedström & Ylikoski 2010: 63), it allows agents to mimic real-world information processing and enables the **emergence** of a social structure (Macy & Willer 2002: 155ff.).

ABM thus facilitates a purposive representation of real-world agency and agent heterogeneity. This is an important advantage of ABM required for the task in hand: the explanatory framework – and the literature it builds upon – indicate that firms' individual characteristics influence their networking behaviour. The case study also revealed effects of differences among the firms, e.g. a firm with attractive resources or partners will be more sought-after as a networking partner than others. Embedding such empirical results within systematic experimentation is another strength of ABM (Hedström & Ylikoski 2010: 63).

Moreover, ABM is the technique most capable of representing Coleman's 'bathtub' model of the scientific discovery of social mechanisms by connecting multiple levels (see Chapter 1): studying a collective situation with individual characteristics influencing individuals' behaviour and ultimately creating an emergent pattern at the higher level of social aggregation. This makes the method suited for modelling the complex, dynamic nature of social mechanisms by describing the behavioural logics of agent behaviour (Gilbert & Troitzsch 2005: 11-12) that let the system *emerge*, rather than designing an assumed 'society' and social structure (Wooldrige 2002: 3). Presently, the research question explores which characteristics and behaviour of agents may lead to a network lock-in. It is thus crucial to be able to fully represent these two levels adequately (Gilbert & Terna 2000: 60) and to represent the constituent macro-micro-macro level linkages through social mechanisms (Hedström & Swedberg 1996: 297).

Other simulation approaches focus on one or some of these aspects but deviate from ABM in respects that are important for the present work. The popular System Dynamics (SD) modelling approach, for instance, also deals with a social system, embedding the progression of time and feedback processes. In contrast to ABM, however, SD employs aggregate level variables and parameters rather than the micro-level processes of ABM (Heckbert, Baynes & Reeson 2010: 42). SD is rooted in formalistic differential equations models, rather than in behavioural logics or rule-based behaviour, and does not permit a great deal of agent heterogeneity (and no development of that during the run, such as agent learning) by comparison with ABM (Gilbert & Troitzsch 2005: 27). SD models focus more frequently on the production of a final state in key variables, e.g. world population, resource usage and pollution, as in the famous Club of Rome models (Troitzsch 2013: 14), rather than overall system behaviour. As a result, they are less concerned with the mechanisms of interacting agents, moving away from subject agency to a system focus (Heckbert, Baynes & Reeson 2010: 42). This macro-level focus makes understanding the interaction of agents difficult, especially with regard to social mechanisms, and renders SD non-purposive in the present context. It should be noted, however, that for many, more macro-oriented social science and economic applications, SD models are very useful.

Microsimulation techniques are based on available empirical data to represent the mechanism under study (Brenner & Werker 2007: 234). Compared to SD, they are stochastic rather than deterministic in nature at the individual level (Gilbert & Troitzsch 2005: 58) and focus exclusively on the 'upward causation' in the bathtub model, i.e. the influence of the micro-level on the macro, but not the opposite direction (Troitzsch 2013: 15). They allow for changes in the composition of individuals, just not for interaction or the aggregate (ibid.: 19). Microsimulations are typically used for modelling and forecasting the effects of governmental policy-making while taking into account demographic and population changes (Mannion et al. 2012: 1.2).

Cellular automata models (CA) can be considered a specialised sub-group of ABM (Heckbert, Baynes & Reeson 2010: 43) with the defining features being that agents are organised in an explicit geographical space on a two-dimensional grid in which they interact with each other based on simplistic rules (Troitzsch 2013: 17). CA models can represent social networks situations using mobile agents (Heckbert, Baynes & Reeson 2010: 43), but agents' overall behaviour is limited to changes in their states, and they lack the ability to adapt their behaviour over time (ibid.: 42). CA's focus on the explicit representation of space is used in simulations in which locality plays a role (irrelevant to the present research project) and these models thus rely heavily on visual representations, such as in the famous Game of Life (Gilbert & Troitzsch 2005: 122). In sum, it is therefore unsurprising that applying Heckbert, Baynes and Reeson's (2010: 42) decision tree to the current research question gives rise to the conclusion that an ABM is the most suitable method for the task at hand.

4. 2. 4 What agent-based model to build?

Searching Google Scholar for simulation models of path dependence does not produce many relevant results beyond Vergne and Durand's (2010) call to use simulations in studies of path dependence. However, there have indeed been some notable model contributions from the Berlin 'Pfadkolleg' Research Centre. These include Meyer (2012), whose ABM models a two-sided platform market with mutually dependent network effects on producer and consumer side that exhibited path dependence lock-ins in technology diffusion. The model includes consumer communication based on an inter-agent network, but the scale-free network structure is utilised as a non-adaptive input, rather than allowing for the emergence of network structures sought in the present research. Seidel's (2013) agent-based model studies the influence of an NK-environment – a mathematical simplification of a complex system as a three-dimensional space in which agents search peaks (e.g. Levinthal 1997) – on individual-level and organisational-level learning effects that give rise to path dependence due to local search rigidity. The model embraces these two levels of aggregation, but no explicit or developing network structure. Petermann (2010) uses an ABM to model path-dependent organisational hierarchy institutions that inhibit organisational change. The model used no network structure arguments or implementation thereof, but points towards interorganisational settings as an interesting avenue for future research (Petermann 2010: 241). The model of Roedenbeck and Nothnagel (2008), while studying economic network effects, is a mathematical simulation which does not embrace any social structure arguments or ABM.

Outside the 'Pfadkolleg' realm, Leydesdorff (2001) studies networks effects, but includes no explicit social structure in his CA model of the cultural diffusion of technologies leading to lock-ins, building on Arthur's (1989) original model of path dependence. Janssen and Jager (1999) use CA to model consumer behaviour in the adoption of technological options. They include agent cognition, social comparison, heterogeneity, e.g. agents' "taste," but no network structural arguments or elements.

Simulation models which implement aspects of network structure development are often as far removed from the present research question as the path dependence simulation models described above. In his review of agent-based simulation usage in OMS, Fioretti characterises network simulation studies as "bottom-up, actor-to-structure" (2012: 230) approaches rather than the former analytical top-down (social) network analyses. After designating simulations focusing on networks between companies as "organizational ecologies" (ibid.: 232), he refers to a set of CA models when addressing the question of how local vs. global interaction of companies determines their success (Lomi & Larsen 1996, 1998). As detailed above, CA studies are not suitable for the present enquiry due to their explicit focus on space, locality, and their effects.

Other examples of network modelling include many supply or production chain analyses such as Datta, Christopher and Allen (2007) who model the resilience (adaptability) of networks through which production factors flow. However, other, similarly-oriented studies on the diffusion of innovations, such as Rahmandad and Sterman's (2008) famous study, typically represent network typology as a static property of agent interaction (Kiesling et al. 2012: 198) even though in the real world (and in present modelling requirements) this is dynamic in its development.

A different, albeit popular approach is to use simulation as a tool to understand the development of empirical (social) networks. Examples include Koskinen and Edling (2012), who feed a so-called actor-based statistical model of interlocking directorates with data from companies traded on the Stockholm stock exchange and find that the mechanism of peer-referral is central to the development of that network. Several more studies employ this stochastic actor-oriented framework for network evolution (Snijders 2005) using the SIENA (*Simulation Investigation for Empirical Network Analysis*; Snijders et al. 2007: 5, emphasis added) software to make statistical inferences in dynamic network models based on statistical tools such as Markov-chains, the Robbins-Monro process, and the method of moments (Snijders & van Duijn 1997: 493). This SIENA approach differs from the present research in that it serves a different purpose, namely explaining the development mechanisms of real-world, empirical social networks – which are used as feed-in data – through the simulation of their hypothetical network developments. Here, in contrast, the goal is to model abstract network developments to understand a real-world phenomenon whose matrix network data is not readily available.

Of the models that explicitly employ *ABM* approaches for networks among companies, important contributions are made by scholars working with the so-called SKIN framework (Simulating Knowledge dynamics in Innovation Networks; Pyka, Gilbert & Ahrweiler 2009: 104). Beckenbach, Briegel and Daskalakis (2009) study the spread of knowledge in regional innovation systems, but they treat network structure outcomes merely as by-products. Pyka, Gilbert and Ahrweiler introduce the concept of a "kene" (2009: 106) (similar to a meme; Dawkins 1999: 192) as a combination of letters that represent a firm's ability to measure the degree to which cooperation in innovation networks leads to knowledge spill-overs for other agents (firms). Their model uses heterogeneity in actor size and strategy as manipulations in combination with heterogeneity of actors' attractiveness as explanatory factors in their simulation. They find, among other things, that differences in strategies play a key role in the development of network structure (ibid.: 115). While Cowan and Jonard (2009: 142-

143) initially discuss social capital from the perspectives of bridging and closure (2009:128), their model ultimately only measures clustering in consequence of knowledge-sharing behaviour such as preferential attachment which produces skewed network structures.

Later contributions using the SKIN model once again implement agents' heterogeneous connecting strategies to demonstrate the way in which network structure characteristics like clustering foster certain knowledge practices such as exploration (Blom & Hildrum 2014: 42). Müller, Buchman and Kudic (2014: 79) take a similar perspective on modelling micro-level processes and strategies and their effect on macro structure. They focus on the mechanisms of homophily and preferential attachment for triad closure (rather than alliances) and are concerned with the scale-free properties of the simulated network structure. However, they implement network development as path-dependent *per se* by using the preferential attachment mechanism. All SKIN-based models study the overall network structure but are not concerned with strategic alliances or networks. Moreover, they use a market-oriented knowledge diffusion optimisation perspective, with some even focusing exclusively on the effects of policy interventions such as tax incentives for fostering research investment (e.g. Korber & Paier 2014) or the effects of the EU's Horizon 2020 programme (Ahrweiler et al. 2014). Overall, these models consider network effects merely as a side-effect and are more intervention-oriented rather than understanding-oriented. Also, the SKIN models necessarily use a mathematical market model as part of the simulation. Such a market is not required to comprehend the network dynamics central to this research. It thus remains unclear how the SKIN framework could easily be adapted for a more rule-based ABM such as the one required for the present purpose.

To my present knowledge, no agent-based simulation models of explicitly emergent network structures focusing on network dynamics such as path dependence (or related phenomena such as rigidity, over-stability, over-embeddedness etc.) currently exist, and, specifically, not without additionally including market model aspects like transactions which are of no explanatory value for this study. As a result, it is necessary to build an entirely new model for the present research. However, where noted, this does find inspiration in and draws on the other models described above.

An important feature of the model required to represent the developed explanatory framework is the matching of cooperation partners as a basis for creating network relationships of interest. In the OMS literature on interorganisational networking, few partner selection routines are discussed explicitly (one exception is the dyadic diversity-driven alliance portfolio approach proposed by Jiang, Tao & Santori 2010), but some matching mechanisms have been explored in simulations. The well-established preferential attachment mechanism (Barabási & Albert 1999) initially looked like a suitable candidate. However, since it requires agents to only connect to the most central node, it has path dependence 'hardwired' into the network dynamics in terms of a type of Matthew effect (Merton 1968). Other matching mechanisms include human marriage microsimulation (as reviewed in Perese 2002) and agent-based simulations of marriage markets (e.g. Walker & Davis 2013). These simulations are used for predicting a relationship (duration) based on a number of social factors, but typically only one side accepts or rejects a match. Lastly, there is a team-building model (Guimera et al. 2005; Bakshy & Wilensky 2007) wherein agents are matched to teams based on their newness to an industry and then (a little simplistically) at random.

All these matching mechanism examples, however, build their matching algorithm on the characteristics of (human) individuals, such as homophily and personality, which are not suitable in the present context of interorganisational networks. I thus intend to develop a customised matching mechanism drawing on the ideas of attractiveness scores developed in the SKIN model (Pyka, Gilbert & Ahrweiler 2009).

In conclusion, the existing models reviewed above do not allow for easy adaption to the present study or are constructed with such a different focus that they are unable to contribute a great deal in terms of answering the current research question. The development and programming of a customised model that satisfies the present needs will therefore be undertaken in the following. For this purpose, I selected the programming language and toolkit NetLogo (Wilensky 1999) based on its scientific functionality and ease of learning for programming beginners (Railsback & Grimm 2012: XIII), integrated development environment for agent-based modelling (Macal & North 2010: 158), integrated, highly reliable ability to systematically execute simulation experiments (Railsback, Lytinen & Jackson 2006: 618), proven ability to work well in network modelling (Berryman & Angus 2008) and its excellent documentation and function libraries.

4. 3 SimPioN[27] – A model of network path dependence

Simulating Path dependence in inter-organisational Networks

This section describes the design of SimPioN, a simulation model of path dependence in interorganisational networks. The description follows the 'ODD+D protocol' for outlining and detailing the model and its experiments (Müller et al. 2013; which is based on Grimm et al. 2010, itself an update of Grimm et al. 2006). This model description approach is fast becoming a common 'standard' form used in the description of computer simulation models. One of its clear advantages is that it follows a structured, systematic way of detailing a model's elements and their interaction processes which permits the integration and unification of the diverse model description styles across scientific fields. Other than documentation, a further purpose of the ODD+D model description is to enable reproducibility and transparency. The model's actual code can be found in Appendix C.

4. 3. 1 SimPioN – overview

This first overview shows the fundamental building blocks that constitute the model. These include the purpose, the basic elements, and processes of the model. The design concepts and methods used are subsequently described, followed by an account of the implementation decisions taken in the programming stage.

4. 3. 1. 1 I.i: Purpose

A) I.i.a: What is the purpose of the study?

The SimPioN model aims to abstractly reproduce and experiment with the conditions under which a path-dependent process may lead to a (structural) network lock-in in interorganisational networks. As discussed in Chapter 2, path dependence theory is constructed around a process argumentation regarding three main elements: a situation of (at least) initially non-ergodic (unpredictable with regard to outcome) starting conditions in a social setting; these become reinforced by the workings of (at least) one positive feedback mechanism that increasingly reduces the scope of conceivable alternative choices; and that process finally results in a situation of lock-in, where any alternatives outside the adopted options become essentially impossible or too costly to pursue despite (ostensibly) better options theoretically being available.

[27] The simulation modelling exercise received substantial inputs from Nanda Wijermans, and initially from Thomas Weißgerber (R.I.P.), in terms of model conceptualisation and design, programming, experimentation, and data analysis for which I am extremely grateful.

More specifically, the purpose of SimPioN is to advance our understanding of lock-ins that arise in interorganisational networks from the network dynamics involving the mechanism of social capital. This mechanism and the lock-ins it may drive have been shown above to produce problematic consequences in terms of a loss of organisational autonomy and strategic flexibility, especially in high-tech knowledge-intensive industries that rely heavily on network organising.

This model aims to formalise the workings of this social capital mechanism, which I used as an explanatory mechanism in the network realm to extend path dependence theory. SimPioN also serves to explore the way in which the structural dynamics unfold over time, thereby implementing the theory's process perspective on social capital as characterised by interacting cognitive, relational, and structural dimensions as an explanatory process for a (structural) network lock-in. The model analysis seeks to highlight the conditions of the social mechanism under which firms become locked-in in consequence of a path dependence process driven by social capital and starting from an (at least initially) non-locked-in situation.

B) I.i.b: For whom is the model designed?

The target audience for this model is four-fold: firstly, the model is part of my PhD thesis and, as such, is targeted at the team of my supervisors and appraisal committee. Furthermore, the target audience for the model essentially constitutes OMS researchers interested in path dependence, network dynamics, or social capital. The model thus creates a bridge between and provides a basis for fruitful discussions among these three researcher groups which are often unconnected despite a common research interest.

4. 3. 1. 2 I.ii: Entities, state variables, scales

A) I.ii.a: What kinds of entities are included in the model?

To represent the main elements of the integrated explanatory framework (Chapter 2), the SimPioN model comprises three main components: agents, links, and alliance groups that together form an operating environment.

Agents represent the firms that are situated in an inter-industrial, interorganisational network environment. The agents are characterised by individual and network characteristics, their preferences, and limitations. The individual characteristics include an agent's *age*, *size*, *resources*, whereas the network characteristics of each firm are represented by *the number of connections, (Betweenness) centrality* and *alliance memberships*. Each agent has certain *preferences* for connecting to *alliances*. In their search for a cooperation partner, they can favour other firms' characteristics (individual, social or both), while being restricted by their network *reach* (the network path steps required to reach another agent in order to consider them as an object of connection), *the number of connections* that can be made in each tick, and the number of *alliance memberships* and *number of network connections* an agent can have. Lastly, an agent has a *strategy* to assess which other agent(s) it would like to connect to.

Links represent a cooperation tie between firms. These cooperation ties can reflect learning, research and development, information sharing, accessing resources etc., but are kept abstract as simple (not multiplex) undirected links. Links are equipped with the two agents at either end and have properties that reflect the *age* of the connection and the project-time/*duration*.

Alliances are "groups" of linked firms that an individual firm can become a member of by connecting to another member agent. Alliances reflect firms that are connected in terms of sharing a certain characteristic, e.g. jointly created assets, industry block behaviour, aligned R&D, shared goals etc. Alliances are characterised by their *number of members*, *density*, and a *stability* in memberships.

The agents are represented as individual objects, whereas the alliance and environment are represented on an aggregated level as global variables and/or functions. As such, neither the alliances nor the environment can "act," only agents can. Alliances exist by having members as a precondition and membership of the alliances appears as a property in the agents' characteristics. The environment is merely represented as the web of links. The table in the next subsection details the variables by which the model elements are defined, characterised and which values they can assume in the computation. The class diagram below this shows the variables and their relationship as implemented.

B) I.ii.b: By which attributes are these entities characterised?

The following attributes (variables) are employed in the model to define and specify the entities in the class diagram:

	Variable	Description	Value range	Initial value
Firms	firm-age*	Age of the firm (measured in simulation ticks).	1-endSim	0
	firm-size	Size of the firm (abstract representation of company size parameters such as number of employees, market capitalisation etc.).	1-1,000	X - uniform distribution
	firm-resource	Resources of the firm (abstract representation of a firm's resources, e.g. know-how, finances etc.).	1-1,000	X - uniform distribution
	firm-slots	The maximum number of connections a firm can have at any given point in time	1-100 (defined as 0.1 * firm-size)	X
	firm-	Number of connections a firm has at a given point in time	0-(firm-slots)	Output variable

	numCon-nections*			
	firm-cen-trality*	Prominence of a firm in its network (measured as Betweenness centrality, see Equation 8).	0-1	X
	firm-alli-ance-member-ship*	Firm's alliance membership(s) (represents the alliances in which a firm becomes member by connecting with another firm that is already an alliance member).	list of 1,2,3,4,5	DoE
	firm-prefer-ence	Preferences (individual, network, both) of a firm that makes perceived other firms more/less attractive to connect to. (represents the orientation of a firm's preferences towards either an alter's individual characteristics, their network characteristics, or both equally).	{individual, network, both}	DoE
	firm-strategy	Strategy that guides firm's choices (represents the mode in which firms search for potential partners).	{optimising, satisficing, desperate}	DoE
	max-new-connection	Maximum amount of new connections a firm can enter in each tick.	1-(0.01*max(firm-size)) = 1-10	X
	max-alli-ance-mem-bership	Number of alliances a firm can be member of in parallel	1-5	3
	firm-reach	Perception range of perceiving other firms as potential cooperation partners (represents network steps, i.e. maximum visible network path length; setting 0 represents not perceiving their network and setting 2 represents perceiving connections of their connections).	{0,2}	2
	lifetime-with-out-links	Number of ticks a firm can survive without having connections	0-inf	Normal distribution (mean=104; s.d.=52)
	min-attrac-tion	Defines the minimum attraction model for the satisficer agents	0-1	0.5
Link	link-age*	Duration of a connection between 2 firms	1-endSim	0

		(represents the duration of a cooperation tie counted across any number of consecutive projects, counted in simulation ticks).		
	project-time	Committed duration of collaboration (represents the time that a co-operation link is established for, counted in simulation ticks; the link will not be reconsidered during this time); allocated at a random draw between 8 and 104 ticks.	8-104	Uniform distribution
Alliances	numMembers*	Number of firms in each alliance (counts the agents connected to and via other agents to the original alliance hub (potentially indefinite path length).	0-numFirms	X
	density*	Alliance density (measures the number of connections among members of an alliance / max possible connections within the alliance).	0-1	X (see Table 21 for equation)
	stability*	Indicates whether the alliance is stable (counted as no changes in memberships for the last 104 ticks).	True / False	X
	dominance*	numMembers / numFirms (represents the coverage of one alliance across all firm agents and serves as a measure for its dominance vis-à-vis other alliances).	0-1	X
Environment	max-available-alliances	Number of alliances available in the environment	2-5	5
	numFirms	Number of firms present in the environment.	1-100	100
	AwarenessRange		1-INF	30
Notes: an initial value is only given for constant variables; DoE implies that the value depends on the experimental design (for design of experiment details see Table 22). X indicates that an initial value is not relevant as this variable is based on other variables.				
(Legend: * = dynamic; **bold = network attribute)**				

Table 16: SimPioN, entities and attributes

The class diagram in Figure 18 shows the relations of the variables specified in Table 16, above.

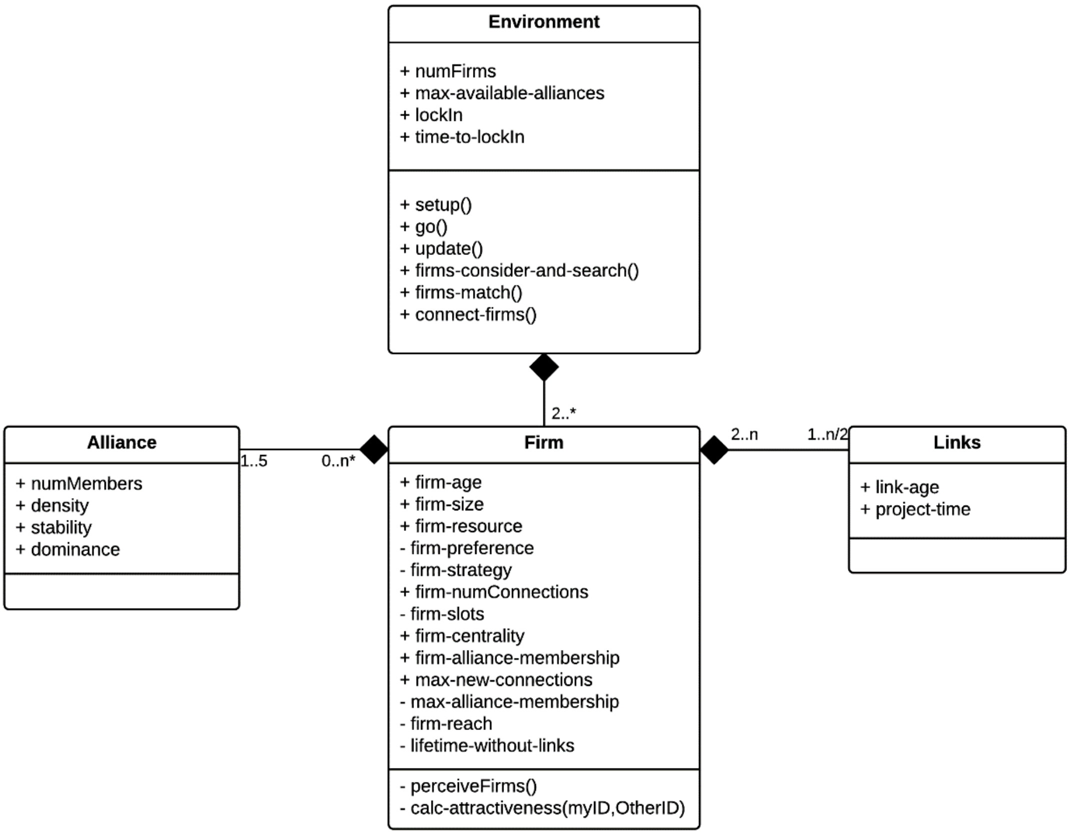

Figure 18: SimPioN, class diagram with state variables

Note that the choices regarding dynamic or constant variables (size, resource etc.) were made to enable a study of the effects of different initial values of variables of interest, such as firms' size and resource composition, on the occurrence of a lock-in. These are, of course, simplifications of the real world, justified by the need for the ability to entangle model effects. Other variables were kept constant to reflect the environment's boundaries, i.e. simplification by excluding details to keep the object of study simple yet complex enough for the purpose at hand, e.g. firm-reach, lifetime-without-links, max-available-alliances.

C) I.ii.c: What are the exogenous factors / drivers of the model?

The model has no exogenous factors that drive it. The model is driven purely by the internal dynamics of the inter-firm network.

D) I.ii.d: If applicable, how is space included in the model?

The model is not spatially explicit, which means that there is no link to real-world (or virtual) geographical locations or environment representations. The agents reside in an abstract 'networking partner sphere' that does not require spatial explicitness (see arguments against using Cellular Automata models, above). The network structure that develops over time represents the (social) environment of the agents. The network structure thus defines a social space represented as relational distance, i.e.

having a connection to another agent via other agents (measurable as path length), vs. not having a connection to others. There are two variables, however, that affect agents' ability to perceive other firms: `awareness` and `reach`. These variables operationalise the agent characteristic of being boundedly rational, i.e. they reflect the fact that it takes time for agents (and real-world firms) to consider networking partners, negotiate terms of cooperation and connect to these other firms. They are defined as follows:

- The `awareness` variable of agents represents their ability (and restriction) to perceive other agents in the model environment. This variable represents the number of agents per tick that a considering firm can place into its consideration set as potential networking partners. This variable implements an element of agents' bounded rationality and reflects their boundedness in the total possible number of firms they can know or rather consider per tick. Since connection candidates are contacted from this list, `awareness` influences the set of other firms that a firm can link with.

- The `reach` variable of agents represents their ability (and restriction) to perceive other network members through their links. Reach is defined as network path-length steps and is an initial setting that sets the perception 'depth' of an agent's network beyond its immediate connections (which it can obviously perceive). As an example, a setting of `reach`=2 means that an agent can perceive the alters of its alters, up until the number defined by the `awareness` variable (see above). Reach is another reflection of agents' bounded rationality and influences the set of agents to connect with.

E) I.ii.e: What are the temporal and spatial resolutions and extents of the model?

There is no direct ontological correspondence of simulation time (ticks) and real-world empirical time. However, to support thinking and interpreting the model's behaviour, one could consider one tick (simulation time) as a week of empirical development (real-world time). This should clearly be understood only as an approximation, since simulation time is explicitly not designed to represent real-world timescales. This approximative interpretation emanates chiefly from the case study example where the unfolding of certain events (e.g. the finding of a cooperation partner for a code implementation project, or other platform contributions) partially matched those of a tick in the model.

4. 3. 1. 3 I.iii Model process overview and scheduling

A) What entity does what, and in what order?

SimPioN is a synchronous agent-based simulation, i.e. it includes time as discrete periods.[28] After the initialisation of the simulation (creating firms and alliances based on experimental interface settings), each advancing tick (simulation time step) causes the agent firms to seek, (re)consider their network partners and then (re)connect with other firms; all measures are updated, and the time advances one step (tick +1). Figure 19, below, reflects the main process of moving through time. The subsequent subsections describe each of the contained functions in greater detail, including the theoretical/empirical foundations for the design choices.

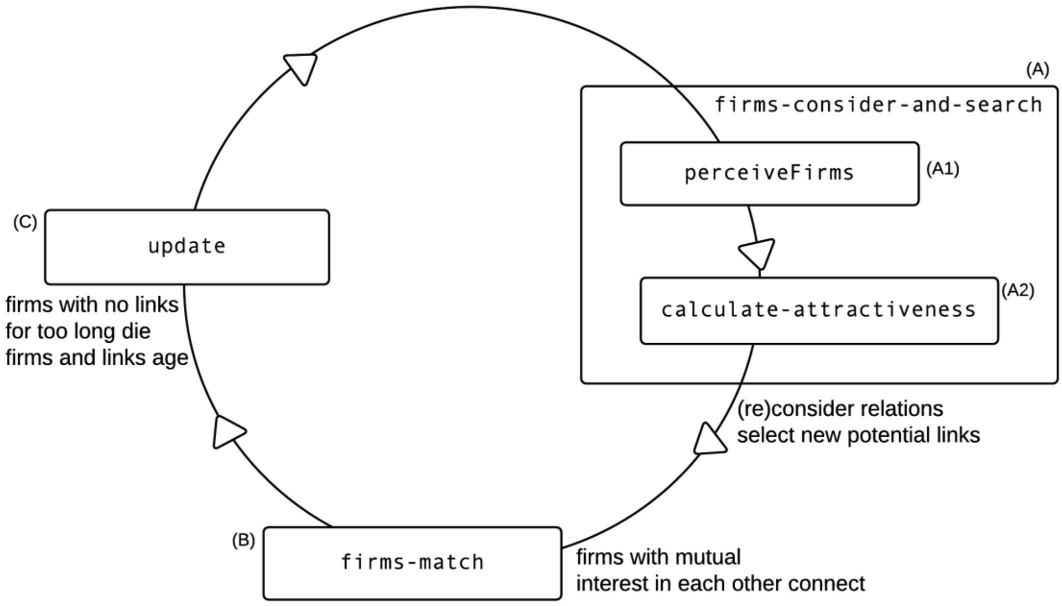

Figure 19: SimPioN, process diagram

B) Firms-consider-and-search

The first step in the overall model execution process is the function that firms 'think' about their wish to connect, potential connection partners and their attractiveness. If firms have unoccupied slots available to connect to network partners, they are automatically triggered to try to connect to other firms. This function creates a 'wish list' of link candidates for a focal firm: each firm creates a list of link options (see ***perceiveFirms()*** below) and then calculates the attractiveness of each option (see ***calc-attractiveness()*** further below).

[28] Discrete synchronous simulations are a standard way of representing the progression of time in ABMs. (Discrete) event-based simulations are an alternative way of representing the progression of a simulation model and trigger activities of agents based on the occurrence of certain predefined events.

Similar to the real world, some firm characteristics are perceived as universally attractive by all potential partner firms (e.g. an interesting resource offer or a potential partner's other connections), while other aspects depend largely on the perceiving firm's characteristics (what can a firm gain from a partner that it does not yet have? Here, size-attraction follows the logic of such a subjective comparison, see below). Hence, the attractiveness scores calculated in the model represent one firm's unique 'subjective' perception of other firms. Thus, there is heterogeneity among firms regarding the perceived attractiveness of a potential partner firm. Depending on an individual firm's partner-selection `firm-strategy` the firm then selects `X` (=number of free slots) connection options based on the attractiveness scores:

- `firm-strategy` = optimising => selects `X` most attractive options, starting from the ordered list with the most attractive currently perceived firm first.
- `firm-strategy` = satisficing => selects `X` first options that meet the minimum attraction level, making an unordered list of options from potential candidates.
- `firm-strategy` = despairing => selects `X` random options (=firms with free slot) without considering their attractiveness any further.

I. perceiveFirms()

This function generates a list of those firms' IDs that a firm will consider as potential cooperation partners. It mimics that (theoretically) a firm can perceive any other firm in the world but is limited in how many firms it will consider (`awareness-range`) and that a firm is more likely to perceive firms that it already knows directly or indirectly (`reach`). The length of the list of potential cooperation partners is thus set by the variable `awareness-range` whereas the variable `reach` determines how this list is filled:

- `reach` = 1: firm agents start filling the list with firm agents that they are directly connected to, i.e. agents only see their own connections (this is presently not used as an experimental setting since existing partners are in the awareness list by default).
- `reach` = 2: firm agents start filling the list with their directly connected partner firm agents and the connection partners of their connection partners.
- `reach` = 3: in addition to the `reach` = 2 list, firm agents start filling the list with other firm agents including the connection partners of their connections' connection-partners (this is presently not used as an experimental setting).

Any possible option left (empty space in the list) is filled with random agents that the firms 'happen to meet'. Note that if a firm has no connections (which is often the case in the beginning of its existence in the world), it will 'meet' and potentially connect with other firms at random at first, given that the lack of an influential network also means lack of that network's influence.

II. calculate-attractiveness():

This function calculates the attractiveness score [0,1] of a firm (B) from the subjective perception of a searching firm (A). A's assessment of B's attractiveness is based on a reference to firm A's own attributes (size, preference, allianceMembership) in combination with the individual and network-related attributes of firm (B) (age, size, resource, number of connections (degree centrality), Betweenness centrality, familiarity, allianceMembership).

$$\text{attractiveness} = \frac{\sum \text{weight}_{\{\text{ind,soc}\}} * \text{attribute}_{\{\text{ind,soc}\}}}{\text{numFactors}}$$

Equation 2: SimPioN, attractiveness function

Where:

$$\text{numFactors} = \begin{cases} 3 & \text{individual} - \text{pref} \\ 4 & \text{network} - \text{pref} \\ 7 & \text{both} \end{cases}$$

Equation 3: SimPioN, attractiveness weighing factors

An individual firm's general preference for its alters' characteristics `firm-benefits-preference {INDIVIDUAL-PREF|NETWORK-PREF|BOTH}` defines which of the attributes are of interest and play a role in the attractiveness function, i.e. the preference sets the weights in the equation. The choice of this equation was made in favour of a compensatory multi-attribute decision-making model, akin to a compensatory utility function that often finds use in science for modelling decision functions (e.g. Meyer 2012: 80) and is inspired by ideas of using attractiveness thresholds to introduce heterogeneity (Pyka, Gilbert and Ahrweiler 2009). SimPioN thus contains agent heterogeneity in both agents' attributes *and* in the assessment of their alters' attractiveness.

- `INDIVIDUAL-PREF`: focus is placed only on individual attributes, i.e. age, size, resource of the other. The weight in the equation is set to `1` for individual attributes and `0` for network attributes.
  A firm with preferences for individual characteristics will engage in a search for other firms and assess their suitability and availability by focusing only on alters' individual characteristics such as resources, size and age, e.g. if the firm is searching for cooperation partners mainly for resource access reasons or in order to benefit from their size legitimacy and market power advantages, or from their experience (e.g. Gulati, Nohria & Zaheer 2000: 203).

- `NETWORK-PREF`: the focus is placed only on network attributes, i.e. numConnections, centrality, allianceMembership and familiarity of a connection. The weight in the equation is set to `1` for network attributes and `0` for individual attributes.

A firm with preferences for network characteristics will engage in a search for other firms and assess their suitability and availability by focusing only on alters' network characteristics such as their network size, their visibility within the network, their ability to broker, or their membership of a particular alliance, e.g. if the firm is mainly interested in the legitimacy gained or information flow induced by connection to the other or by having access to the membership of the alter's network (e.g. Burt 2005:17-21; Ahuja 2000b: 322; Coleman 1990: 302-318).

- `BOTH`: focus on both individual and network attributes. The weight in the equation is set to `0.5` for each, maintaining a total attractiveness score of `1` if both individual and network attributes are assessed as fully satisfactory.

  A firm with preferences for both network and individual characteristics will engage in a search for other firms and assess their suitability and availability by focusing on neither aspect exclusively, but pursue a blended approach to assess alters, e.g. if the firm is interested in learning from an alter's experience who also plays an important role in the same alliance as the assessing firm.

The literature is divided with regard to the reasons for networking (see Section 2. 3. 4. 2) and hence what characteristics of a firm are attractive for potential network partners and how they are evaluated. Some contributions argue that firms seek similar partners – a network argument akin to homophily and/or reputation arguments in social networks (e.g. Müller, Buchmann & Kudic 2014: 78-80) – while others suggest they seek diversity (e.g. Jiang, Tao & Santori 2010, Lin et al. 2008: 186). Additionally, it is not universally accepted which attributes are perceived and evaluated as absolutes, i.e. (un)attractive considered only in the potential partner, and which attributes are perceived and evaluated through a relative comparison of the assessing firm with itself, e.g. as complementarity/diversity seeking etc.

Additionally, this may depend on a firm's own strategy such as exploration/exploitation, their stage of development, or even their industry uncertainty (discussed e.g. in Ahrweiler, Gilbert & Pyka 2011: 68-69; Mellewigt & Decker 2014; the contested arguments by Diestre & Rajagopalan 2012; Beckmann, Haunschild & Phillips 2004 etc.). It thus appears prudent to implement an attractiveness function that makes use of several characteristics and employs both the individual and the network characteristics of agents, and utilises both absolute and relative evaluations. The weighting differences in the preferences thus serve to represent some heterogeneity in the agents' awareness of each other and allow for experimentation with the effects of agents focusing on only either or both categories of characteristics. Hence, the three preference settings above were derived for the experiments that seek to reflect an overall and abstracted tendency among firms for what they seek in others.

Overall, a firm's perceived attractiveness is thus calculated on the basis of the following seven characteristics and evaluation rules:

a) **Age-based**: the older a firm is, the more attractive it appears as a partner.

$$\text{age} - \text{attraction} = \frac{\text{firm} - \text{age}}{\text{ticks}}$$

Equation 4: SimPioN, age-attraction

In the real world, a firm's age reflects its survival fitness, adaptability, and its overall standing in the market: the longer it exists, the better it has managed its survival amidst potentially turbulent market conditions, uncertainty, and competition. Age is also used to signal reliability and tradition to customers in advertising such as "family-owned since 1889" etc. Age can thus be considered a proxy for the experience, reliability, importance, and overall prominence of a firm (Stuart 2000: 795, 805). As discussed in the empirical case study of smartphone platform alliances (Chapter 3), for instance, one of the arguments for firms to engage with networking partners was to tap into the experience and influence of established players such as *Google*, i.e. not the youngest agents, but the incumbents whose age (in relation to their industry) signals their experience.

The calculation of the attractiveness factor of a firm's age is performed as the quotient of `firm-age` over `ticks`. The division by the number of ticks is used both for making the attractiveness function coherent and to index `firm-age` to the duration of the existence of the model run as in the real world.

b) **Resource-based**: the more resources a company holds, the more attractive it is.

$$\text{resource} - \text{attraction} = \frac{\text{resource}}{\text{max} - \text{resource}}$$

Equation 5: SimPioN, resource-attraction

Seeking others' resources was named as one of the most important motivation for firms' networking in the literature review on interorganisational research in OMS (e.g. Das & Teng JoM 1998: 28; Gulati, Nohria & Zaheer 2000: 203; Garrette, Castañer & Dussauge 2009: 886; Walker, Koput & Smith-Doerr 1996; Podolny & Page 1998; Oliver & Ebers 1998). Thus, including resources as a factor in the attractiveness function was an essential choice. Similarly, when studying the empirical field of smartphone platform alliances, accessing others' knowledge and information technology capabilities was a decisive factor in determining the basis for cooperation between alliance members. Resources and their attractiveness are used here as a necessarily abstract concept. Based on the theoretical arguments, this is generally held to be more resources are better than less resources. To allow firms to assess potential networking partners *objectively* against a standard among other options, the potential partner's resource level is divided by the maximum level of resources available from any firm in the model environment.

c) **Size-based**: any firm larger than the perceiving firm is more attractive and the larger the better. However, when a firm is large itself, it finds all sizes attractive.

Equation 6 represents this in functional form:

$$\mathrm{size-attraction} = \begin{cases} 0.2 & \mathrm{theirSize} \leq \mathrm{mySize} \\ 1 & \mathrm{mySize} > \mathrm{FIRM_{MEDIUM}} \\ 0.8 * \dfrac{\mathrm{otherSize}}{\mathrm{FIRM_{MAX}}} & \mathrm{otherSize} \geq \mathrm{mySize} \end{cases}$$

where

$$\mathrm{FIRM_{MAX}} = 999$$

and where

$$\mathrm{FIRM_{MEDIUM}} = 666$$

Equation 6: SimPioN, size-attraction

Firms across the world's industries differ in their sizes. Firm sizes are typically measured in characteristics such as stock market capitalisation, market share or number of employees, turnover etc. and size is reflected in companies' importance. Firm size is an attribute that can be perceived externally and is often used to denote a firm's level of stability, prosperity, or power: depending on industry and market, a certain size represents a stable organisation, or the growth (rate) of a firm indicates market success, etc. Even policy regulation and market stimulation are often tailored to denominations such as Corporations or Small and Medium-sized Enterprises (for a definition of SMEs: e.g. European Union 2016).

The size of a firm can thus serve as a proxy allowing a potential partner firm to assess whether a potential network partner has the means to engage in a fruitful cooperation tie and exchange the desired resources for the duration of the link, for instance. Whereas resources (the previous attribute) relate to the capabilities of a firm, the size is a specification of the visibility/signal of stability and continuation. Due to its importance as an indication of the economic status of a company, firm size is often included in empirical OMS research as a control variable or explanatory variable (e.g. McEvily & Zaheer 1999) and is considered to play a role in firms' alliance management capabilities (Wang &

Rajagopalan 2014: 243). Pyka, Gilbert and Ahrweiler (2009) also use heterogeneity in firm size in order to manipulate the attractiveness of actors in their model.

The inclusion of size within the individual attractiveness factors is implemented through a comparison relative to the assessing firm's own size. This is relevant because, to employ a global comparison e.g. only big firms (in absolute terms) are attractive, big firms would only choose to link among themselves. However, real-world examples indicate that big firms frequently link with smaller firms (even to the extent that they eventually purchase them), because of the uniqueness of their know-how, staff, products/services etc. Furthermore, the case study above and other research shows that smaller firms, in particular, seek links with larger entities to gain in influence and profitability (Stuart 2000: 803), whereas larger firms are mainly interested in extending their network size or finding a very specialised partner that fulfils certain specific tasks that a large firm is unwilling or unable to (re)create in-house, e.g. due to a core competency-oriented strategy or for patent protection reasons. Hence the size attraction aims to represent this behaviour: a small firm chiefly finds comparatively larger firms attractive; a medium-sized firm also finds larger firms attractive; and a big firm finds smaller, medium-sized and big firms attractive. Furthermore, size is an indicator of firms' capability to entertain a number of network relations. It follows that the total number of links a firm can hold in the simulation is directly related to its size and introduces some heterogeneity among forms.

d) **Link-based**: the more links a firm has, the more attractive it appears. In a functional form, the attraction is represented as the relative number of links an agent has (linksOther) and the maximum links that a firm can have (MAX-SLOTS):

$$\text{connection} - \text{attraction} = \frac{\text{linksOther}}{\text{MAX} - \text{SLOTS}}$$

where

$$\text{MAX} - \text{SLOTS} = 10$$

Equation 7: SimPioN, connection-attraction

As far as network-related attractiveness factors are concerned, an important question is who a firm would structurally benefit from connecting to. Connecting via others (a broker/hub) is a typical behaviour of networking firms as revealed by both the literature (Burt 2000; Burt 2005:17-21) and the case study. Accordingly, creating links with a well-connected partner allows a firm to (at least partially) exploit the benefits of that other's brokerage social capital and engage in building social capital from closure. For the assessing firm, it is thus sensible to connect to the biggest brokers they deem available in order to allow themselves to reap the benefits of that hub's connections (Ahuja 2000b: 322).

This connection-attraction is based on the Degree Centrality principle, according to which all of a node's undirected links are counted. In this case, since the model utilises only undirected links, filtering out doublets is not necessary, and the variable assumes the simple calculated value of the number of links of an assessed firm agent as their network characteristic of network-attraction. An assessment in relation to the assessing firm's own network links appears unnecessary, since even other well-connected hubs would benefit from still more connections and the resource flows exchanged through them in the real world.

e) **firm-centrality**: the higher an alter's *Betweenness* centrality, the more attractive that firm appears.

Centrality measures indicate a node's prominence in its network and this prominence be measured in several different ways: Degree Centrality – measured as the number of undirected links (see link-based attraction, above) – essentially counts the number of links a node has in the network, revealing how well that agent is connected. Betweenness centrality, in contrast, measures more precisely how partners (of partners) are connected overall. It is calculated as the aggregated (average) shortest distance for any pair of nodes to hypothetically link through a focal node. The more often the shortest paths of such links go through the focal node, the higher that node's Betweenness centrality value. Betweenness can thus be considered a node's network value bestowed upon it by the node's partners' partners and thus indicates the connectivity options' attractiveness.

Betweenness Centrality of a node k can be denoted by the equation:

$$\mathrm{Cb(k)} \sum_{j \neq k \neq i} \frac{\sigma_{ji\,(k)}}{\sigma_{ji}}$$

Equation 8: SimPioN, Betweenness Centrality (drawing on Mutschke 2013: 370)

where $\sigma_{ji}$is the sum of the number of shortest paths from node j to node i, and $\sigma_{ji}(k)$denotes the number of those paths that pass through k (Mutschke 2010: 370; formula as implemented in NetLogo's network extensions.[29]

Here, Betweenness is used as a measure for a node's relevance/prominence in the network as a connector through which others are connected. Research has revealed that high Betweenness Centrality is often correlated with success and being known in the network (ibid.: 374). High Betweenness is

[29] NetLogo's network extensions can be accessed via its online documentation information: http://ccl.northwestern.edu/netlogo/docs/nw.html#clustering-measures

thus attractive for potential partner firms since it connotes the ability to connect to more remote network partners through a hub node and make themselves more relevant to others as a by-product of being connected to the 'highly between' firm.

f) **alliance-based**: alters that are part of the same alliance are perceived as more attractive than those who are not.

$$\text{alliance} - \text{attraction} = \begin{cases} 0, & \text{myAlliance} \neq \text{otherAlliance} \\ 1, & \text{myAlliance} = \text{otherAlliance} \end{cases}$$

Equation 9: SimPioN, alliance-attraction

Alliance membership is a further important network-related characteristic of a potential partner firm. `Alliance-attraction` assumes the value of `1` if a potential partner is a member of (one of) the same alliance(s) that the assessing firm is a member of, i.e. the variable takes into consideration the assessing firm's own membership. In this sense, it is a subjective variable, even if the membership of the potential partner is objectively observable for the agents. The reason for increasing the attractiveness score of a potential partner in the case of aligned alliance membership is twofold:

a) Connecting to a firm with the membership of the same group would allow the assessing firm to exploit the potential benefits of social capital from closure in the sense that other members offer a level of social control over the potential partner and thus reduce their ability to default on the relationship (Coleman 1990: 302-318).

b) The building of influential interorganisational network alliances, i.e. industry blocks and similar cohesive agent clusters, can be a goal for firms to increase their dominance vis-à-vis other players or alliances, e.g. as a vehicle to push for technological leadership, higher market share, regulatory influence – all with the ultimate goal of increasing firm performance (Duysters & Lemmens 2003; Gomes-Casseres 1996).

g) **familiarity-based**: the more familiar the firm, the more attractive.

$$\text{familiarity} - \text{attraction} = \frac{\text{link} - \text{age}}{\text{firm} - \text{age}}$$

Equation 10: SimPioN, familiarity-based attraction

The final attractiveness factor implemented is necessarily based on agents' subjective assessment. A firm's past experience of working with an alter is captured by the term 'familiarity'. Familiarity is the consequence of an existing/past link between two cooperation partners. Research has shown that familiarity is an important factor in the assessment of potential networking partners and can increase the probability for linking repeatedly, and even lead to stable relationships (Gulati 1998: 303). The argument of continuing or re-establishing known relationships is based on the 'familiarity breeds trust' reasoning (ibid.). Accordingly, familiarity makes new linking outcomes more predictable, enables mutual learning, but can also increase mutual dependence in mainly the cognitive and relational dimensions of social capital. In that sense, this familiarity characteristic is located between the individual partner characteristics and their network characteristics.

The familiarity-attraction is calculated as the quotient of `link-age` over the assessing firm's `firm-age` (in ticks). The familiarity of a potential network partner is made relative to the assessing `firm-age`, because it is necessary for comparing an assessing firm's set of relationships among each other. Hence dividing the `link-age` by the assessing firm's firm-age allows for the representation of a link's relative familiarity vis-à-vis other links, i.e. making it subject to the past lifetime of the assessing agent.

In summary, the variables involved in the attractiveness calculation are as follows:

Variable(s)	Role in firms-consider-and-search
firm-slots **firm-numConnections**	Affect whether an agent is able (and generally willing) to connect. Together, the variables determine how many free slots are still available and thereby whether the agent can establish a new link in a given tick.
firm-benefits-preference	Affects the selection of potential link candidates. Influences how an evaluating agent with free slots calculates the attractiveness of an alter as potential partner firm.
firm-strategy	Affects the strategy for selecting firms that agents will ask to link with from their list of potential candidates: the rationale can be optimum-oriented (maximising), can be to find a 'good enough' cooperation partner (satisficing), or to find any alter firm to connect with (despairing strategy).
awareness-nr **reach**	Affects the scope of firms that an agent could connect to (awareness range), but also which ones they will most probably connect to (reach, their perception of current partners' partners). It reflects the perception of others and the higher probability of connecting to those others that an agent is already connected to either directly or indirectly in their network path.
<u>individual:</u> firm-age, firm-resource, firm-size **<u>network:</u> link-age firm-centrality, allianceMembership**	Affect the attractiveness of a firm from the perspective of an evaluating firm. The assessment of these attractiveness components depends on an assessing agent's firm-strategy and their firm-benefits-preference (see above).

Table 17: SimPioN, key variables involved in *firms-consider-and-search*

The overall attractiveness is weighted according to firm's firm-benefit-preference, i.e. whether an agent is individual-oriented (e.g. chiefly seeking access to a resource or a connection partner's legitimacy through size or age), network-oriented (e.g. chiefly seeking to connect to become part of a larger overall network group or access a partner's network contacts), or both factors are weighted as equally important. The overall value is divided by 7, the total number of factors, so that no single factor can dominate the attractiveness perception that one agent has of another.

C) Firms-match

After the firms have identified whether and who they would like to connect to (A1 and A2), the stage of establishing or maintaining the links (B) takes place. This function mimics a matching process, in which each firm has the opportunity to ask another firm to connect, i.e. ask the first firm on its connection-wish list that it is not yet connected with. A firm will approach a particular other firm only `IF` it has free slots itself `AND IF` the other firm also has space for new connections, i.e. has free slots, and the maximum number of new connections (`max-new-connections = 0.01 * firm-size`, which results in 1-10 per tick depending on the size of the firm[30]) has not been reached yet in a given tick. The acceptance of the request is similarly based on the other firm's strategy:

- an `optimising` firm will connect only IF the alter is a member of their present connection wish-list (`connectionCandidates`) `OR` has an even higher attractiveness than the ones on top of its connection wish list. This strategy of optimising the relationships partners, e.g. maximising utility, follows the "standard" model of boundedly rational decision-making that is firmly established in social science (e.g. Eisenhardt & Zbaracki 1992).

- a `satisficing` firm, when asked, will establish a link if the other's attraction is satisfactory, i.e. the attraction score must be higher than the `MIN-ATTRACTION` threshold (as suggested by e.g. Simon 1997: 295ff.; Lin et al. 2008: 185). The threshold is defined as `0.5`, which constitutes the half-way point between the two more extreme strategies of optimising or despairing, i.e. accepting even a link candidate with `0.0` attractiveness score, at worst (see also: sensitivity analysis in Section 4. 7).

- a `despairing` firm will always establish a link with any other agent when asked by them `IF` it also has free slots. This is, of course, an extreme case example to represent firms that are desperate to connect with others for reasons of e.g. depending on certain resource access (Bae & Gargiulo 2004 :844), or firm survival in cases of legitimacy-seeking or effectively required membership to alliance blocks that entails certain essential benefits (Gomes-Casseres 1996).

[30] This is a choice for computational performance.

The logic according to which firms execute such a process of deciding on networking partners remains somewhat unclear in the literature. Decision-making is typically studied in consumer behaviour, managerial, or economics contexts and the strategy literature often assumes rationality as maximising behaviour without explicitly testing for other decision-making models. Making exact representations using only a single decision-making model for networking firms is thus difficult, especially since the empirical case study findings and theoretical arguments from the literature indicate a variety of motivations for networking, which similarly imply a variety of types of decision-making logic. It remains important with regard to path dependence research, however, whether and in which way the occurrence of lock-ins depends on firms' decision-making rationale. For the purposes of this model, I thus decided to implement the above three prototypical decision-making strategies.

Overall, during one tick all firms have an opportunity to connect and can possibly (be) ask(ed)/invite(d) (by) another firm to establish a link together. A firm can only gain `MAX-NEW-CONNECTIONS` connections per tick.

Variable(s)	Role in firms-match
firm-strategy	Affects how firms consider (accept/reject-procedure) an invitation for linking with another firm. This rationale varies from wanting to connect to the most attractive firms (optimising), to attractive enough firms (satisficing), or to connect to any firm that asks (despairing).
connectionCandidates	Represents the firm's wish list of firms it wants to connect to. This list is used to ask/invite another firm to establish a link together and to check if an asking agent is on it (in case of optimising strategy).

Table 18: SimPioN, key variables involved in *firms-match*

D) Update

Advances time in the simulation (ticks). The population of firms and links are set to age and/or dissolve. If a firm hasn't been connected for `linkless-lifetime` ticks (defined by the experimental settings, here set to a normal distribution between 52 and 104 ticks) that firm stops existing, meaning that the agent ceases to exist in the model, and it can no longer connect to others or be listed as a connection partner in another agent's wish list. The firms that continue to exist also continue to age, including their presently established links.

Variable(s)	Role in update
number of links, linkless-lifetime	Determines whether a firm will continue or cease to exist.
firm-age, link-age	These variables represent the age of a firm and link and are increase by 1 every tick as long as they exist.

Table 19: SimPioN, key variables used in *update*

4. 3. 2 Design concepts, theory background

As described in the 'purpose' section of this ODD+D, the aim of SimPioN is to improve our understanding of network path dependence and especially the social capital dynamics driving the lock-in situation in interorganisational networks. To that end, the model reflects the core concepts of the explanatory framework detailed in Section 2. 6. This involves:

- Representing initially non-ergodic starting conditions in the network relations and alliance situation of agents, and the whole network structure.
- Representing the positive feedback mechanism of social capital that accounts for the past developments in the relations between agents and within alliances and can (potentially) drive:
- the lock-in of the network situation, i.e. to a fixed set of relations for an individual agent, to an alliance, and of the whole network.

4. 3. 2. 1. II.i Theoretical and empirical background

A large part of the exercise in creating SimPioN consequently lies in 'translating' the necessarily more abstract conceptualisations of the explanatory framework (Section 2. 6) into adequate and specific simulation model elements that can be represented in software code and used for experimentation, i.e. including variable behaviour rules.

The choices made have profound consequences for the functioning of the model and consequently for the data and findings created by it. A solid level of transparency as regards this process can be achieved by detailing the basis for the variables, processes, and other model elements established in the explanatory framework. This exercise aids in making the connections between theory and model explicit, while maintaining concision in the representation of theory in the model chapter. Furthermore, certain model elements or corresponding variable values or value ranges draw on the empirical case study of Chapter 3, in which I studied two strategic interorganisational networks in the smartphone industry to inspire and illustrate the workings of the model.

Several model ingredients are required in order to implement a version of the explanatory framework on path dependence in interorganisational networks:

- organisations, i.e. firms
- network ties, i.e. links between firms
- a function for connecting, i.e. establishing a link between firms
- a function for allowing agents to find each other and match for connecting
- a function for disconnecting firms, i.e. erasing a link when no longer needed
- output measures to capture the situation of agents, the emerging groups, and the whole network

These elements of the explanatory framework were 'translated' into the following model elements:

Model element	Theory element
agents	Represent firms and other organisations
firm-size	Signals reputation and overall capabilities to other agents – relational dimension of social capital
firm-age	Signals experience and trustworthiness – relational dimension
firm-resource	Represents the agents' dependence on others' resources – cognitive dimension of social capital.
number of connections / degree centrality	Signals direct connectedness, influence on information flow – structural dimension
betweenness-centrality	Signals indirect connectedness, potential for linking to other new partners through a hub – structural dimension
alliance membership	Signals alliance membership of a firm to others, permitting agents to seek network closure – structural dimension
links	Cooperative ties among partnering firm agents
"duration of connection" (familiarity)	Agents mutually learn from each other – cognitive level. Trust through mutual experience – relational dimension.
firms-match	Firms search for suitable partners according to their search criteria and strategy, then identify their favourites and make requests and decisions for connecting – firm cooperation links

Table 20: SimPioN, model elements & theory elements

A) II.i.a: Which general concepts, theories or hypotheses underlie the model at the system level or at the level(s) of the submodels (apart from the decision model? What is the link to complexity and the purpose of the model?

The SimPioN (Simulation of Path dependence in interorganisational Networks) model is a first formalisation and implementation of the explanatory framework developed in the present study (Section 2. 6) which provides an integrated structural and process explanation for network path dependence in interorganisational networks using social capital as the driving mechanism of path dependence. This framework is characterised by specifying the interaction over time of the cognitive, relational, and structural dimensions of social capital that have been integrated above as an explanatory mechanism for a network-structural lock-in. Thus, the explanatory framework reflects three streams of thought within Organisational and Management Studies:

- **Network approach:** observing and identifying a network-structural lock-in as an important emergent phenomenon with problematic implications for firms (e.g. Zaheer, Gözübüyük & Milanov 2010; Walker, Kogut & Shan 1997).

- **Path dependence theory:** the school of thought specifying path dependence and lock-in, providing theoretical concepts that explain the process of agents' decreasing scope for action and the mechanism that can drive it (largely building on Sydow, Schreyögg & Koch 2009).

- **Sociology, specifically social capital theory:** detailing a relevant mechanism in a structural process perspective that is used in SimPioN to drive a structural lock-in of network agents to their (sub-)network, or rather (sub-)groups of agents. As such it also adds specificity and operationalisation of path dependence theory applied to networks of firms (Burt 2001; 2005; Coleman 1990; Nahapiet & Goshal 1998).

B) II.i.b: On what assumptions are agents' decision-making model(s) based?

The agents in the model represent organisations such as firms in an interorganisational network. Their tasks are to assess other agents' suitability as networking partners, to connect to such alters, to disconnect from other firms, and to form part of alliance or exit. Alliances change over time in terms of their members, coverage in the whole network and their internal structural properties. Alliances are not 'active' beyond agents' perception of their existence, i.e. they are not agents themselves and perform no own actions. To reflect this overall generic structure, the following assumptions were made:

I. Firms have an incentive to be connected

Firms will seek to connect if they have the ability to connect, i.e. free capacities for connecting (`firm-free-slots > 0`). They then search for potential partners and get in touch with a suitable candidate to agree whether to establish a connection or not. This need for connecting is derived from the most cited theoretical arguments of resource need (e.g. Das & Teng 1998b: 28), the network alliance concepts regarding the attainment of influential contacts (e.g. Vanhaverbeke & Noorderhaven 2001), market power (e.g. Gulati, Nohria & Zaheer 2000: 206-207), risk or uncertainty avoidance/reduction (e.g. Hoffmann 2007: 827; Gulati & Gargiulo 1999: 1441), and mutual learning and knowledge creation among companies (Oliver 2001: 468; Powell, Koput & Smith-Doerr 1996; Podolny & Page 1998: 62-63; Kale, Singh & Perlmutter 2000). Moreover, the empirical findings from the smartphone industry case indicate a division of labour among firms and the inability of firms to establish platforms (software ecosystems) all by themselves (see Sections 3. 2 and 3. 3, above). The resulting criteria for connecting are outlined above in the above subsection, "calc-attractiveness."

II. Firms do not survive for long without being connected

If firms remain unconnected for a longer duration of time (`linkless-lifetime`) they cease to exist and leave the model environment. This demise of firms is based upon the (reverse) arguments for connecting from the theory, e.g. the need to access other's resources, to build strategic alliance blocks etc. for avoiding 'detrimental loneliness' or 'organisational death' (Gulati, Nohria & Zaheer 2000: 203; Grandori & Soda 1995: 186; Oliver 2000) or, alternatively argued, to improve their own chances of survival (Brass et al. 2004: 806). Further, the empirical findings (Sections 3. 2-3. 4, above) indicate that firms strategically rely upon one another to produce software code contributions and thus create the cooperative alliances for establishing the platforms. Hence the strategic choice of 'going it alone' did not arise and was excluded from the present model.

III. Firms differ

Empirical observation and research insights indicate that firms differ, often strongly, from each other with regard to several characteristics. The literature is debating which differences make firms interesting to others (as discussed e.g. by Beckmann, Haunschild & Phillips 2004; Lin et al. 2008; Pyka, Gilbert and Ahrweiler 2009; Jiang, Tao & Santoro 2010; Ahrweiler, Gilbert & Pyka 2011; Diestre & Rajagopalan 2012; Mellewigt & Decker 2014; Müller, Buchmann & Kudic 2014; etc.). While scholars remain divided about the precise relevancy of characteristics and the nature of the effects these have, they are unanimous in that firms differ from each other, even if not making that assumption explicit in many cases.

Examples of the aforementioned include their individual properties such as age, size, resources, and capabilities, their (emergent) network characteristics such as centrality, connections, and alliance memberships, but also their strategies, search preferences for engaging with others and their perceptions of them[31]. To reflect these important differences, unlike many other simulations models that assume and use homogenous agents, I assume that firm agents are heterogeneous in their characteristics and vary these systematically in the experimental settings. The reasons for implementing the individual and network characteristics as well as the different strategies and preferences and the possible values and functioning rules these characteristics can assume are detailed above in '`calc-attractiveness`' and '`firms-match`'. As with the other assumptions, heterogeneity serves the purpose of real-world relevancy, but also acts as a vehicle to produce scientifically interesting differences in network structures to bring about (or not) the phenomenon of lock-in that can aid our understanding of its occurrence.

IV. Firms do not consider all other firms as potential partners and perceive them differently

I assume that firms are unable to consider all other firms in the model environment when deciding what alters to connect with. This implementation reflects real-world limitations in time and knowledge, and aggregated cognitive capabilities, since establishing connections and maintaining them takes time and effort, and firms might typically not have (all) other firms on their radar. This limitation relates to the theoretical concept of bounded rationality (Simon 1957). Much research on behavioural rationales points in the direction of agents' boundedly rational perception and decision-making in dynamic systems such as networks (Sterman 2000: 26-27; Simon 1957; and see above). To

[31] Further concepts could include: capabilities, network partners, culture, leadership style, risk management/portfolio approach, access to financial instruments, learning, relevant governing bodies inside and outside the organisation, stakeholders, business models, supply chain position etc.

formalise this bounded reality in the SimPioN model, agents are restricted in their perception from considering all other agents (awareness-range) and are more likely to observe the alters in their individually unique network than random others (reach). As implemented, firm agents perceive others with the following bounded rationality restrictions on their perception[32]:

- **awareness range:** being boundedly rational means that firms in the model have restricted knowledge and cognitive capacity and cannot process and assess all their potential partners regarding their suitability for a match. Such limitations exist in humans (see e.g. Dunbar 1992 for a seminal study) and the reasoning is here extended to firms: firms are considered to be limited in their awareness, perception, time, and resources available for identifying new connection partners. In SimPioN, agents thus have limited processing capacity and restricted knowledge, and cannot consider all other firms as potential candidates for connecting. Agents are restricted to perceive a maximum of 30 alters (`awareness-range`) per tick. Hence, by default, agents at first seek new partners via their established relations' relations and afterwards randomly fill their list of potential partners with those outside their (indirect) links. The agents have the following restriction of within-network access (`reach`) of contacts of their contacts.

- **reach:** if and when firms connect to new partners via their existing alters (e.g. via a broker/hub in the network) rather than via random new connections, they are limited in terms of the depth of perception of their alters' network paths. Reach is limited to 2 in the present experiments, meaning agents can perceive their alters' alters, but cannot penetrate further along their network paths. Reach and awareness-range in combination thus not only affect the overall number of alters that an agent can perceive, but also whether these 30 are within the existing network and how many "outsiders" are added randomly to their list of potential candidates.

- **subjective perception of alters' attractiveness:** whether an alter is attractive to an assessing firm is based on the characteristic of both the assessing ego and the alter. As described above in the attractiveness function, the assessment of the attractiveness of an alter firm is based on several variables, some in relation to the assessing firm itself, some in relation to the network. The perception of attractiveness is thus subjective in the sense that it is unique to each firm and to each perceiving firm and thus boundedly rational in, at the most, a subjective sense, not an objective whole-world sense.

[32] This is an interpretation of a 'boundedly rational actor' approach with a network focus. A 'truly' rational actor would have full knowledge of the full network at all ticks. This, however, would be unrealistic (for reasons above), and not technically feasible as the resulting programme would take disproportionately large amounts of computing time to assess attractiveness and optimising across all possible firms every tick.

In general, it is important to acknowledge that agents' decision-making (and by extension the attractiveness function and the boundedly rational perception of alters) is not the focus of attention of this study. Agentic decision-making is primarily a vehicle for introducing the mechanisms discussed in theory (e.g. the incorporation of past events, building a network from previously unconnected actors, allowing for a lock-in to alliances) into the model to be able to move beyond an alternative decision-making model of e.g. entirely random connections or oversimplifications such as the oft-used preferential attachment mechanism. Although often only implicitly assumed, there are thus valid scientific reasons for not letting agents be fully (objectively) rational. Agents' and especially firms' decision-making, however, warrants much further research, especially as far as the ways in which firm agents were implemented here is concerned.

C) II.i.c: Why is/are (a) certain decision model(s) chosen?

Three decision-making strategies have been chosen to represent the three distinct assumptions regarding how firms may decide to connect with other firms. These three (despairing, satisficing, maximising) are implemented to reflect the differing knowledge (or lack thereof) regarding the ways in which firms (as aggregate entities of individuals) make decisions on connecting, disconnecting, and maintaining links with other firms. The three decision models allow for systematic experimentation of the influences of the decision models on the network structures and can thus trigger a discussion on their effects and validity.

D) II.i.d: If the model/submodel is based on empirical data, where does the data come from?

The SimPioN model draws inspiration from the empirical case study referenced above but does not employ any specific empirical data to calibrate the model. Sources of inspiration include limiting the available alliances to a total number of 5, thus also following Meyer (2012), and restricting the number of possible links per firm per tick. Also, using the analogy of one tick to loosely represent a week of real-world time exploits impressions of networking efforts from the case study. Similarly, the differing project durations and the duration range, and the demise of unconnected firms after 104 ticks without connection, are inspired by the case study but are not based on any explicit finding.

E) II.i.e: At which aggregation level was the data available?

Explicit empirical data was not used, and insofar as the case study inspired elements of the model functioning, this was available at firm level or the more overall macro network level.

4. 3. 2. 2 II.ii Individual decision-making

A) II.ii.a: What are subjects and objects of the decision-making? On which level of aggregation is decision-making modelled? Are multiple levels of decision-making included?

The agents decide individually whether or not they want to connect and, if so, who to (accept to) connect to, and whether to re-establish a relationship. They take into consideration other agents around them in the virtual environment but make no decisions across levels of analysis or aggregation other than factoring the alliance membership of potential partners into their attractiveness assessment.

B) II.ii.b: What is the basic rationality behind agent decision-making in the model? Do agents pursue an explicit objective or other success criteria?

SimPioN agents seek to connect to others if and when they have free slots. Which other agent they want to connect to (wish and accepted a request) depends on their assigned decision models' selection process (strategy): despairing, satisficing, or optimising. When despairing, 'any firm' is acceptable to connect to; when satisficing, 'any firm above a certain attraction' level threshold is suitable for connecting; when optimising, only the most attractive alters in agents' perception are considered suitable connection options. Since agents are triggered to fill their slots, this signifies an implicit goal and success criterion, whereas not having been connected for 104 ticks causes agents to cease existence, hence an implicit measure of lacking success.

C) II.ii.c: How do agents make their decisions?

In SimPioN, the agents (firms) make three individual decisions: 1) whether they will connect or reconsider a connection, 2) what other agent they would want to connect to, on the basis of which they derive whom they will ask to connect to and 3) when asked to connect, whether they will accept a collaboration (link establishment).

- **Choice 1; to (re)connect this tick, or not:** a firm always seeks to connect if it has `free-slots`. If one of the projects (connections) is going to end in a given tick, the firm will always reconsider this connection.

- **Choice 2; which firms are potential connections (wish list):** of the alters that a firm agent perceives, it will consider which alters it would like to establish a connection with. Each firm agent makes a 'wish list' of a length that is at least the number of free slots or the number of firms under consideration for continued relationships. This selection process depends on the strategy a firm has been assigned, i.e. optimising, satisficing, or despairing, in combination with how attractive it perceives the alter firm to be. An optimising agent selects the number of firms with the perceived highest attractiveness scores and ranks them accordingly in their wish list. A satisficing agent selects the first firms that are attractive enough for entering their wish list, i.e. reach the minimum threshold. A despairing firm selects the first firms since any firm will suffice as connection partner. Figure 20 visualises this decision process.

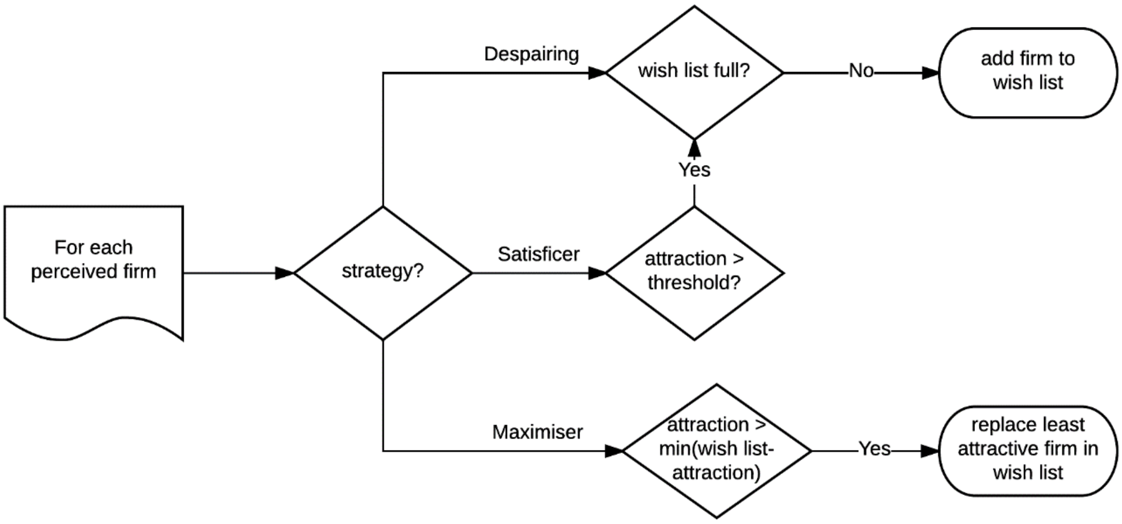

Figure 20: SimPioN, agent decision-making when asking

- **Choice 3; if asked, connect or reject:** if an agent is asked to connect by an alter, it will connect (or not), based on its strategy and how attractive it perceives the inviting agent to be. However, it will only consider a request if it has itself not already exhausted the `max-new-connections` (`0.1*firm-size`) limit in that tick for forging connections. A maximising agent accepts the invitation to connect only if the asking firm is either already on its wish list `OR` it is more attractive than any member of its current wish list. A satisficing firm will accept any asking firm that is attractive enough than the minimum threshold. A despairing firm will accept any request for new connections until it has filled all `free-slots` or `max-new-connections`. See Figure 21 below, for the visualisation of this decision process.

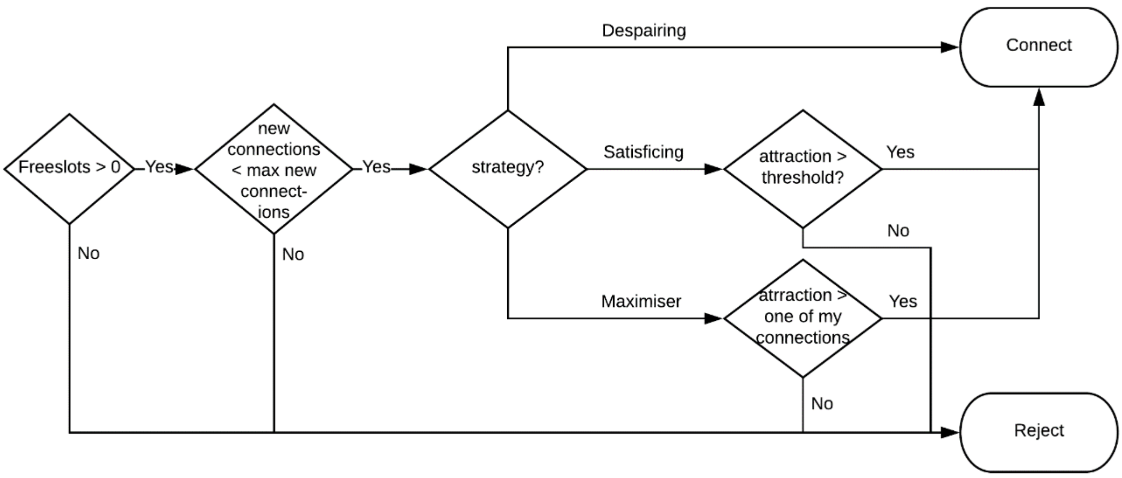

Figure 21: SimPioN, agent decision-making when being asked

D) II.ii.d: Do agents adapt their behaviour to changing endogenous or exogenous state variables? If yes, how and why?

The firm agents adapt their connection behaviour based on the changing individual perception of the attractiveness of other agents. Their perception of attractiveness is informed by changes in their network structural position, i.e. their endogenous network attributes: numConnections, centrality, allianceMembership and familiarity of a connection. Exogenous variables that have behavioural effects are not included in the model.

E) II.ii.e: Do social norms or cultural values play a role in the decision-making process?

Norms, values etc. are not included in the model. However, this would be a worthwhile future extension, since arising norms can be a relevant part of the social capital mechanism of path dependence in networks, as pointed out above as part of the explanatory framework.

F) II.ii.f: Do spatial aspects play a role in the decision-making process?

Space in a geographical sense does not play any role in the model. However, a resemblance of 'social distance' is included in the model in the variable `reach`, which determines how far along a network path agents can perceive their alters.

G) II.ii.g: Do temporal aspects play a role in the decision-making process?

Temporal aspects play a role insofar as the age of a firm in the model (ticks) environment is included in the calculation of their attractiveness in the age-attraction, and time in ticks is considered in the familiarity-attraction, the project-duration, the restrictions of how many partners can be considered and connected to per tick, and the ticks themselves. Real-world time outside of the model does not play any role within the model, since its goal is to be an abstract representation of the explanatory framework's elements.

H) II.ii.h: To what extent is uncertainty included in the agents' decision rules?

There is no uncertainty implemented with regard to the decision-making processes.

4. 3. 2. 3 II.iii Learning

A) II.iii.a: Is individual learning included in the decision-making process? How do individuals change their decision rules over time in consequence of their experience?

There is no explicit agentic learning implemented in this model. However, the agents' characteristics rules are affected over time through e.g. the variable `link-age`: firms that collaborate (have a link) find each other more attractive as they build a relation over time, need lesser starting-up time with that known partner than with a new one based on their joint experience in collaborating etc. The characteristics thus affect agents' behaviour, but actual learning is not performed.

B) II.iii.b: Is collective learning implemented in the model?

The model does not implement any decision-making at any collective level. Only the collective characteristic of (joint) alliance membership influences the individual assessment of an alter's attractiveness and therefore the likeliness of an agent seeking to connect with it.

4. 3. 2. 4 II.iv Individuals sensing

A) II.iv.a: What endogenous and exogenous state variables are individuals assumed to sense and consider in their decisions? Is the sensing process erroneous?

Agents sense only the variables within the model that pertain to the attractiveness of other agents. The ability to perceive other agents for connecting or reconsideration is limited (`awareness-range=30` firms) and agents reach into their existing network only up to a path length of 2 (`reach=2`). However, there is a degree of randomness in building the wish lists, if and when agents fill remaining spaces on their wish lists at random.

B) II.iv.b: What state variables of which other individuals can an individual perceive? Is the sensing process erroneous?

Agents perceive the variables that together account for another agents' attractiveness: size, age, resource, links, Betweenness, alliance membership and familiarity through previous connectedness. Other than the above restrictions on perceiving other agents in general, there are no errors in the perception.

C) II.iv.c: What is the spatial scale of sensing?

Sensing occurs at an individual level only; agents only see other agents. While perceiving other agents' alliance membership status might be considered as perceiving a collective entity, the lack of knowledge on the respective other members (unless they are part of the present connections or their alters), and the fact that the alliance is not itself an entity that could perceive any variable in the model shows that no implementation of collective entities exists. Spatially, in principle, agents can perceive all other agents. However, the actual agents taken into consideration for connecting or reconsideration are limited (`awareness-range=30` firms) and agents reach into their existing network only up to a path length of 2 (`reach=2`).

D) II.iv.d: Are the mechanisms by which agents obtain information modelled explicitly, or are individuals simply assumed to know these variables?

Sensing, or perceiving, other agents is carried out by the agents individually and the calculation of other's attractiveness is individually subjectively performed by the agents internally. While the process of decision-making based on the derived attractiveness scores is explicitly modelled, the process by which agents acquire this information is implemented as *ex machina*, i.e. it is no explicit process of the agents acquiring that information through an activity – the computer informs agents of the values for assessing other's attractiveness.

E) II.iv.e: Are costs for cognition and costs for gathering information explicitly included in the model?

Sensing in SimPioN involves no cost. Hence agents make no cost-benefit calculations that could lead to a reduction in cognition efforts based on costs.

4. 3. 2. 5 II.v Individual prediction

A) II.v.a: Which data do the agents use to predict future conditions?

Agents in SimPioN do not make any predictions with regard to future states of themselves or of the model.

B) II.v.b: What internal models are agents assumed to use to estimate future conditions or consequences of their decisions?

Agents make no estimations or assumptions about the future; they only use implied expectations that are reflected in the perceived attractiveness of one firm to another assessing firm on which the latter bases its connection options.

C) II.v.c: Might agents be erroneous in the prediction process, and how is it implemented?

Since no prediction of future states occurs, no errors can be made in any such process.

4. 3. 2. 6 II.vi Interaction

A) II.vi.a: Are interactions among agents and entities assumed as direct or indirect?

The interactions among the agents involve asking and accepting/rejecting an offer to link. For the working of the mechanism, please refer to the respective subsection on the process and the decision-making processes above.

B) II.vi.b: On what do the interactions depend?

The interactions themselves are not based on specific input variables, apart from the characteristics perceived for assessing attractiveness and the basic need to connect. The interaction is then triggered depending on the ranking or threshold level, and on the agent's strategy.

C) II.vi.c: If the interactions involve communication, how are such communications represented?

Communication among the agents is carried out rather abstractly, without the requirements of (representing) any real-world communication processes. Agents are basically given the information they seek by the computer (observer in NetLogo). They do not communicate in a manner resembling human communication wherein the process may influence the communication outcome.

D) II.vi.d: If a coordination network exists, how does it affect the agent behaviour? Is the structure of the network imposed or emergent?

The network is the main focus of the model and is fully emergent. No network structure is predetermined or fixed throughout simulation runs. This makes this model rather unlike many other models where e.g. scale-free or small-worldness is a predetermined exogenous factor, because for the present purposes, network structure must necessarily be endogenous. The network does not necessarily coordinate communication, it only provides the structure upon which the agents can perceive each other and is created when they connect to each other.

4. 3. 2. 7 II.vii Collectives

A) II.vii.a: Do the individuals form or belong to aggregations that affect and are affected by the individuals? Are these aggregations imposed by the modeller or do they emerge during the simulation?

The agents in the model can become members of up to a maximum of 3 network alliances by connecting to an alter that is already a member. The aggregate itself does not act, perceive, calculate, or affect the agents by actions. They influence the agents' decision-making in terms of signalling the potentially common alliance membership of agents, and thus form part of attractiveness to agents assessing other agents as regards potential connections. The memberships emerge during the simulation, with only the initial 5 alliance members (the five largest agents in terms of `firm-size` for each alliance) allocated during initialisation, although depending on the experimentation scenario (initialisation), there may be more members.

B) II.vii.b: How are collectives represented?

The alliances exist only as emergent outcomes, not as active 'actors.' Alliances represent collectives. Every firm can be part of any alliance, i.e. become a member. Membership of an alliance can only happen when a firm connects to a firm that is already a member of the alliance. When a firm has no connections anymore with anyone in the alliance the alliance membership dissolves. Equally, if an alliance loses all its members, it dissolves and ceases to exist in that model run.

4. 3. 2. 8 II.viii Heterogeneity

A) II.viii.a: Are the agents heterogeneous? If yes, which state variables and/or processes differ between the agents?

Agents are heterogeneous in respect to the following state variables: firm-age, firm-size, firm-resource, firm-slots (which are related to firm-size), and the emerging network parameters that are ascribed to them: centrality, Betweenness, alliance membership and the relationship-specific variable of familiarity. Depending on the experimental scenario, firms also differ with regard to firm-strategy, firm-benefits- preference. Future research options could also vary firm-reach and project-duration.

B) II.viii.b: Are the agents heterogeneous in their decision-making? If yes, which decision models or decision objects differ between the agents?

Agents differ in their perception, strategy, and their preferences, all of which influence their decision-making process and its results. Optimising agents, for example, perceive their environment, rank potential partners according to their subjectively perceived attractiveness and seek to connect accordingly, whereas satisficing agents fill their perceived environment with agents that meet a minimum threshold and do not order their connection wish list. For more details, please refer to Subsection 4. 3. 1. 3.C).

4. 3. 2. 9 *II.ix Stochasticity*

A) II.ix.a: What processes (including initialisation) are modelled by assuming they are random or partly random?

There are several sources of randomness, i.e. stochasticity included in the model at various processes and stages. One part occurs in the initial settings of agent attributes:

- **firm-size**, **firm-resource**, **firm-age** can be set to be normally or uniformly randomly distributed.

And more sources of stochasticity occur during an experimental run:

- **perceiveFirms():** to perceive other firms for considering them as potential connections, only a restricted number of other firms are considered (awareness-range). The selection of firms within the awareness-range varies from fully random to partially random, based on the setting for 'reach'. `Reach` indicates whether a firm will consider other firms in its network down a path of two steps or not. In the present experimental settings, `reach=2`. Thus, an assessing agent first considers alters that it is already connected to, but where their projects are also about to end, i.e. maintain options, and the firms that are the connections of its connections. If there is 'awareness space' left, it will add other firms at random.

- **firms-consider-and-search():** in case `firm-strategy=despairing` the connection candidates enter the connection wish list at random, i.e. the firm will ask random agents to start a project with and establish a cooperative link.

4. 3. 2. 10 *II.x Observation and emergence*

A) II.x.a: Which data is collected from the ABM for testing, understanding, and analysing it, and how and when is it collected?

The values of these output metrics (dependent variables), depends on the initial settings of an experimental run, i.e. the independent variables, and the control variables that the model is sensitive to. Data is collected throughout all ticks of the model for tracing the model's experimental behaviour. The data is written into a data text file for later analysis. For the analysis, the following aspects form the key output measures with regard to the research question and the explanatory framework:

Level of operation	Variable	Description
System / Global	*Lock-in*	The system is considered locked-in when there are fewer than 5 alliance entries or exits each per tick for 104 ticks (~ two years).
	Time to lock-in	The number of ticks that a model run took before considered a lock-in.
Alliance	*Density* 0-1	The closure of an alliance measured as its internal network density, defined as: $allianceDens = \frac{\#interMemberConnections}{\#possibleMemberConnections}$ where: $possibleMemberConnections = \frac{n*(n-1)}{2}$
	Dominance	The coverage of one alliance across all agents in the environment serves as a measure for the dominance of one alliance vis-à-vis the other alliances: $allianceDom = \frac{numMembers}{numFirms}$
	numMembers	The number of members of each alliance

Table 21: SimPioN, overview of response variables

B) II.x.b: What key results, outputs or characteristics of the model are emerging from the individuals? (Emergence)

The purpose of this model is to (re)create situations of network lock-ins for studying the system dynamics and experimental settings leading to it. Hence the key output measures focus on representing the system level adequately. The system level results emerge from the aggregation of the alliance outcomes and indicate the whole network situation. Derived from path dependence, one key aspect is the stability of the system which, applied to the network of alliances, can be translated as the absence of alliance exits or entries, i.e. here, the absence of agents disconnecting from an alliance, or entering it by connecting to one of their member agents. Further, I trace the closure of the network alliances, since, as elaborated above, the development of closure within the alliances is one of the key aspects of social capital-driven path dependence. Furthermore, it is interesting with regard to ‘alliance competition’ (aka industry blocks) to trace the amount of existing alliances (those with members) and their share of the total agents, i.e. their individual ‘dominance’. Lastly, in the network situations that do end in a lock-in, I trace the time that the system runs before the stability period designated as a lock-in arises to gain an understanding of how early (or late) said stability occurred given the experimental settings.

4. 3. 3 Details

4. 3. 3. 1. Implementation details

A) III.i.a: How has the model been implemented?

The model was implemented in the programming language and agent-based modelling toolkit NetLogo v6.0.4 (Wilensky 1999-2018) and comprises 1031 lines of software code. A screenshot of the model and the NetLogo user interface with SimPioN loaded and running, is shown below:

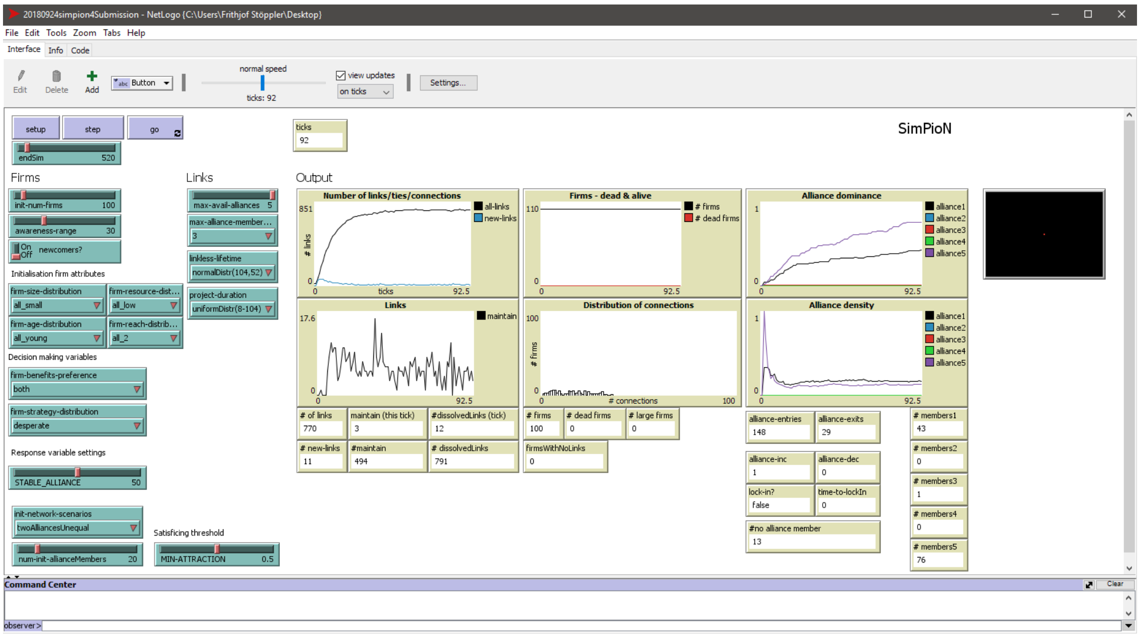

Figure 22: SimPioN, NetLogo interface while in operation

B) III.i.b: Is the model accessible, and if so, where?

The SimPioN model software code will be made available online for free open-source download on the model sharing platform www.comses.net after the publication of this study. It can also be found in Appendix C, including the URL to CoMSES to the downloadable code.

4. 3. 3. 2 III.ii Initialisation

A) III.ii.a: What is the initial state of the model world, i.e. at time t=0 of a simulation run?

At `t=0` of the model, the model environment is populated with firm agents and the five largest firms gain their status as alliance founders. In experiments where historically-existing alliances are present, their founders and the initialised number of random members each initialise one random connection to another agent. Apart from that, no links and alliance memberships are present at initialisation. The firms begin their activities of perceiving, evaluating, and connecting upon the commencement of `t=1`. More details can be found in Table 24 in Section 4. 4. 3.

B) III.ii.b: Is initialisation always the same, or is it allowed to vary among simulations?

There is considerable variance in the initialisation which is based upon the experimental settings: I vary the individual variables, the initial network scenarios and the key assumptions on agents' decision-making strategy and their preferences regarding characteristics of their alters. For more details, please refer to Section 4.4, below.

C) III.ii.c: Are the initial values chosen arbitrarily or based on data?

Of the initial values few are chosen arbitrarily, and few were inspired be the empirical findings in Chapter 3. Most variables, however, were based on theoretical arguments or on their ability to answer the research question, as indicated in Table 24 in Section 4. 4. 3.

4. 3. 3. 3 III.iii Input data

A) III.iii.a Does the model use input from external sources such as data files or other models to represent processes that change over time?

No input data from external sources or data files was used for the purposes of the experimentation to answer this study's research questions with the SimPioN model.

4. 3. 3. 4 III.iv Submodels

A) III.iv.a: What, in detail, are the submodels that represent the processes listed in 'Process overview and scheduling'?

The experiments employ the maximiser, satisficer, and despairing agent decision-making behaviour models (strategy) which can be considered submodels of SimPioN. Their more detailed description can be found above in Sections 4. 3. 1 and 4. 3. 2.

B) III.iv.b: What are the model parameters, their dimensions and reference values?

The selected model parameters and initialisation settings can be found in Table 24 in Section 4. 4. 3, which details the model parameters for the experimental setup.

C) III.iv.c: How were submodels designed or chosen, and how were they parameterised and subsequently tested?

The reasoning for each parameter and variable setting is listed in Table 24 in Section 4. 4. 3.

4. 4 Design of Experiments

After building the model, which is already a precision-inducing (Vergne & Durand 2010: 750) exercise, the next stage involved extensive debugging and testing extreme initial settings to assess the behavioural logic for inconsistencies and verifying the behaviour both at micro (agent) level and macro level (the overall system). Both processes occurred both iteratively during the implementation stage as well as in a final model assessment stage.

Having thus verified the model internally, it is possible to use it to simulate the relationships between variables, and, in this case, the relationships of firms among each other. Since social simulation is a means of combining formal modelling with controlled experiments, this section establishes the standards for experimentation and details how the experiments were set up to answer the research questions.

The Design of Experiments reflects the experimentation with the model so that it can adequately explore the complex interactions of the model parameters that drive agent behaviour, their interaction, and to allow for the emergence of the interesting structural results such as the nonlinear kind of lock-in characterised in path dependence theory. The Design of Experiments constitutes a means of providing transparency for the performance of the experiments and to allow for conclusive and reproducible findings. The standards for producing such a systematic experimentation vary, not least due to the young nature of social simulation as a method, and the need to individually assess each model. A suitable model proposed for the Design of Experiments follows an idealised seven-stage process (Lorscheid et al. 2012: 30):

1. Formulate objective of simulation experiment
2. Classification of variables
3. Definition response variables and factors
4. Selecting appropriate factorial design
5. Estimation of required number of runs
6. Performing simulation experiments
7. Analysing simulation data and effects

Here, the Design of Experiments is organised according to this seven-stage logic, but with three variations. Firstly, step 2 "Classification variables" includes the response variables from step 3. Secondly, the remainder of step 3 and step 4 are taken together to form step 3 "Definition of factors and factorial design." Finally, the steps 6 and 7 are discussed together (but consecutively) with the respective experiments in the separate Section 4. 5 and in the concluding discussion of the experiments in Section 4. 7.

The analysis of all simulation outputs and all other associated data processing and diagram generation was performed using the RStudio 1.1.419 (RStudio Team 2018) implementation of version 3.5.1 of the R language for statistical computing (R Core Team 2018).

4. 4. 1 Formulate objective of simulation experiment

The objective of the simulation experiment is threefold: firstly, this study set out to explore "Why, under which conditions and by what processes can the interorganisational networks in which firms participate become path-dependent?" The 'why' was answered by the integrated explanatory framework and substantiated by the case study. The more precise conditions and processes under which such network lock-ins occur with the alliances' network dynamics unfolding over time, however, will be studied in more depth through the experimentation with the SimPioN model. SimPioN is itself a specification and implementation of the theoretical arguments put forth by the literature and the explanatory framework developed.

Secondly, the experimentation with the framework implementation as SimPioN involves the measurement, analysis, and interpretation of data in order to provide an understanding of the model behaviour, and the consequences and implications for the development of theory on network lock-ins. This process involves the aspects of the relative share of lock-ins generated by a given experimental setting, the time it takes for these lock-ins to occur, the resulting density of the generated alliances relationships and their standing as regards the competition with several other alliance groups.

Thirdly, the experimentation serves to compare the effects of several implementation choices regarding the often implicit or even contradictory behavioural assumptions made in the literature. These include the relevance of agents' individual characteristics compared to their network characteristics from the perspective of an assessing, potential partner firm, the effect of strategic behavioural options such as maximising, satisficing, and despairing agents, the effect of combining strategies with differing preferences of agents (individual, network, both), and, lastly, the effect of three different initial alliance membership distributions. From the three objectives, I derive the following experimental setup as shown in Table 22, below.

Experimental design		Experiment 1 Base case, Individual characteristics	Experiment 2 Changing the behavioural assumptions			Experiment 3 Changing the historical network setups
			A	B	C	
Individual characteristics	Firm-age	{low, high}	{low, high}	{low, high}	{low, high}	{low, high}
	Firm-size	{low, high}	{low, high}	{low, high}	{low, high}	{low, high}
	Firm-resource	{low, high}	{low, high}	{low, high}	{low, high}	{low, high}
Network setups	Init-network-scenario	None	None	None	None	{oneAlliance, twoAlliancesEqual, twoAlliancesUnequal}
Assumptions	Strategy	Maximising	Satisficing	Despairing	{Despairing, Satisficing, Maximising}	Maximising
	Preference	Individual	Individual	Individual	{Individual, Network, Both}	Network
250 repetitions for each experimental setup.						

Table 22: SimPioN, experimental design

4. 4. 2 Classification of variables

As indicated in the objectives for experimentation, studying the effects of the model elements' behaviour requires key aspects of the model to be varied systematically – the *independent variables*. Other variables are included in the model to make it function, or to set certain boundary conditions. They do, in that sense, affect the results, but since they are not varied systematically and kept constant at fixed values throughout the model runs, they are considered *control variables*. Lastly, the so-called *outcome variables* or *dependent variables* are the means of capturing the model's behaviour and results since they record the response of the model to the variation of the independent variables and are thus dependent upon their values. The definitions of the response variables are detailed above in Table 21 in Section 4. 3. 2. 10.

#	Independent		Control		Dependent
1	firm-age-distribution	8	max-new-connections	16	Lock-in
2	firm-size-distribution	9	firm-reach-distribution	17	time-to-lock-in
3	firm-resource	10	project-duration	18	memberRanking
4	firm-preference	11	max-available-alliances	19	allianceDensity
5	firm-strategy	12	max-alliance-membership		
6	link-age	13	awareness-range		
7	init-network-scenarios	14	linkless-lifetime		
		15	init-num-firms		

Table 23: SimPioN, classification of variables

4. 4. 3 Definition of factors and factorial design

Developing an experimental setup for a simulation experiment would not be complete without specifying the values that the independent variables and the control variables are assigned at the initialisation of a model run. This creation of meaningful variations of the independent variables and reasonable control variables is essential for the model to produce a behaviour relevant to the research objectives as detailed above. Of course, theoretically, exploring the entire value space, i.e. using any possible variation of variable values would be possible. However, this possibility exists only in theory, and only for particularly simple models, since such an endeavour would be far too computationally expensive for more complex agent-based model such as SimPioN.

The factorial design is thus the means required for creating such variations in a systematically varied way. Here, the modeller defines which values, value intervals, distributions, or other properties the independent and control variables can assume. These settings are operationalised in the simulation program's NetLogo behavioural space setup, which is a tool for managing the model experimentation systematically.

The experimental design for SimPioN aims to understand the overall behaviour of the model and thereby that of the implementation of the explanatory framework. Therefore, the individual variables have been set at representative low-and-high settings, following a generic 2k factorial design reasoning using extreme values of variables to gain an understanding of the model's behaviour under those settings. However, to also explore the role of the underlying assumptions, the three possible variations are included for both preferences and strategy so that their effects can be compared meaningfully. The factorial design for the SimPioN experiments is detailed in the following table.

	Variable	Factor range	Factor levels used	Reasoning / explanation
Independent	firm-age-distribution	{young, medium, old}	{all_young, all_old} ={uniform[1-52], uniform[156-364]}	Extreme low and extreme high values provide a good understanding of the influence of this variable on overall model behaviour, including agent decision-making.
	firm-size-distribution	{small, medium, large}	{all_small, all_large} ={uniform[1-333], uniform[667-1000]}	
	firm-resource-distribution	{low, medium, high}	{all_low, all_high} ={uniform[1-333], uniform[667-1000]}	
	firm-strategy-distribution [H]	{maximise, satisfice, despair}	{all-maximise, all-satisfice, all-despair}	Theory-driven variable implementing the three distinct assumptions on agent decision-making behaviour. Permits the exploration of the effect of these assumption within the context of the development of structural lock-ins in this study.
	firm-benefits-preference [H]	{individual, network, both}	{individual, network, both}	
	init-network-scenarios	{oneAlliance, twoAlliancesEqual, twoAlliancesUnequal}	{oneAlliance, twoAlliancesEqual, twoAlliancesUnequal}	Three different scenarios in which the simulation starts with existing network structure. Permits the exploration of the explicit role of network history on the development of structural network lock-ins.
Control	linkless-lifetime [C]	1-INF	normalDistr(104,52)	Boundary condition for agents' existence. Firms can survive without links for tick durations between 52-156 (approx. representing 1-3 years or real-world time). Affects the speed of pattern development in the simulation.
	project-duration [C]	1-INF	uniformDistr(8-104)	Boundary condition for project duration, i.e. links between agents. Can vary strongly (inspired empirically) between 8-104 ticks (approx. representing 2 months and 2 years). Affects the speed of pattern development in the simulation.
	firm-reach-distribution [C]	{0,2,3}	all_2	Reflects bounded rationality in perceiving alters across social distances. 2 for assessing the influence of agents considering their 2nd degree alters.
	max-alliance-membership [C]	1-5	3	Boundary condition for agents' group memberships. Arbitrary value but required to restrict alliance memberships especially of large agents so that agents cannot become member of all alliances, which would always stabilise the model environment and let all runs ending in lock-ins.

	max-avail-alliances [C]	2-5	5	Reflection of stylised industry context facts following the example of Meyer (2012) which also used 5 alliances in technology industries.
	init-num-firms [C]	1-INF	100	Reflects a stylised industry context with many players. 100 agents represent a large enough number to allow for diversity and is still low enough in terms of computational capacity to be able to run.
	awareness-range [C]	1-INF	30	Reflects bounded rationality by limiting agents' awareness of alters in the model environment, i.e. the agents are not omniscient. At the same time, it reduces computational costs.
	max-new-connections [H]	1-(0.01*max(firm-size))	1-(0.01*max(firm-size)) = max. 10	Boundary condition for agents' ability to forge new links. Reflects heterogeneity of agents in their ability to simultaneously establish several new relationships. Pragmatic choice for establishing these differences based upon agent-size, just like firm-slots.
	min-attraction	0-1	0.5	Reflects the minimum attraction level of alters considered by satisficing agents in experiments using this strategy as an initial setting.
C – Variables set to be the same (homogeneously) for all firm agents H – Variables that were set to differ (heterogeneously) for the firm agents				

Table 24: SimPioN, initialisation of independent and control variables

4.4.4 Estimating the required number of runs

SimPioN is a non-deterministic simulation model with stochastic elements that must be run sufficiently many times in order to provide stable performance. This means that one run per experimental setting is not enough to produce stable results and, ideally, a model should perform unlimited numbers of repetitions of every experiment, based on the law of large numbers that lead to statistically stable effects with more repetitions. Unlimited runs are not feasible for obvious reasons, and it is thus important to identify the minimum number of runs required, especially as SimPioN is already a computationally-expensive simulation model.

I perform this calculation following the systematics suggested by Ritter et al. (2011). This involves calculating the minimum number of runs (N) based on the standard error of means (SEM) within a defined confidence interval, as specified in Equation 11. In addition, I use a visual inspection to identify the stabilising of the cumulative mean of the outcome variable time-to-lock-in at system level.

$$\mathrm{SEM} = \frac{\mathrm{Variance}}{\mathrm{N}} = \frac{\mathrm{standardDeviation}}{\sqrt{(\mathrm{N})}}$$

Equation 11: SEM method for calculating the minimum number of runs N (Ritter et al. 2011)

I determined that the number of runs for this experiment should, as a minimum, be 140 repetitions per experimental setting (scenario). This result is based on a confidence interval of 95% given a sensitivity for the response variable that allows for distinguishing between a time-to-lock-in of $+/-\ 4$ ticks[33] (approximating a month of analogous real-word time).

Figure 23 shows a plot of the cumulative mean of time-to-lock-in against the increasing number of runs for the experimental scenario that requires the most repetitions. Time-to-lock-in variable varies greatly, as can be observed in the cumulative means for the lower amounts of repetitions. By means of visual inspection of the plot and adding a sensitivity band (orange dotted lines) of 4 ticks around the cumulative mean of 10.5, we can observe the calculated minimum amount of 140 runs leading to a sufficiently stable cumulative mean for the experiments with this simulation model. All experimental conditions were hence repeated 250 times (to allow for some overprovisioning), and the simulation experiments results are thus based on the entirety of these 250 repetitions.

[33] This sensitivity is specified to represent a meaningful difference that the outcome metric should be distinguished upon, with a confidence interval of 95%.

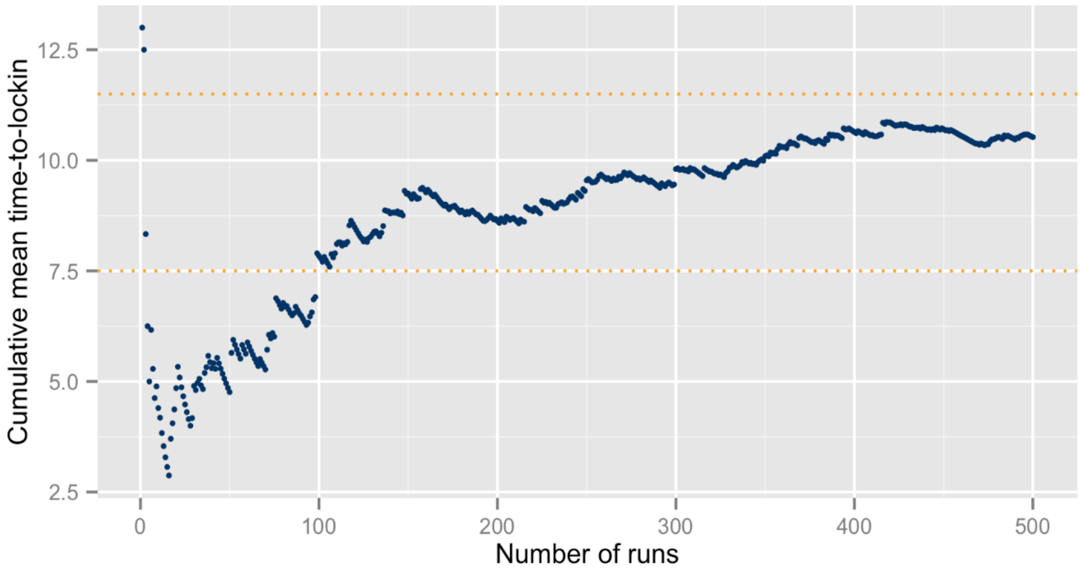

Figure 23: SimPioN, stabilising cumulative mean of 'time-to-lock-in' with increasing number of runs

4. 5 Experimental results

The experiments described above are scenarios designed to represent several stages of increasing model experimentation complexity. The model implements the explanatory framework which broadly identifies two categories of variables as aspects setting in motion the path dependence effects of the social capital mechanism: firms' individual characteristics, and firms' network characteristics. Hence these effects require separate exploration, starting with a focus on individual characteristics and finally with a focus on network characteristics.

The findings are represented here in the same order as in Section 4. 4. 1. The discussion of the results is as follows: the presentation and detailing of findings are followed by their interpretation in the light of the model and, finally, a reflection of the same against the background of the literature and the developed framework. After the results section, the model chapter concludes with an overall discussion of the model experimentation, its relevance, and implications.

4. 5. 1 Experiment 1: maximising only on individual characteristics: a base case

The experimental base case seeks out the isolated effects of the individual characteristics on the system state of lock-in, isolated from network effects. For this purpose, I select the maximising strategy (the most-used decision model in OMS research) combined with agents' preferences set to only individual characteristics. Further, I explore the 'extreme' settings with firm-size set to `all_small` / `all_large`, firm-age set to `all_young` / `all_old`, and firm-resource varying between `all_low` and `all_high`. Strategy is set to `maximise`. Benefits-preference is set to `fully-individual`, meaning that agents still perceive emerging network characteristics of their alters and factor them into their attractiveness assessment, but these variables are weighted with `0`, meaning they do not influence the assessment of alters' attractiveness. Given that agents do not employ others' network-related characteristics in their decision-making and only assess their constant individual characteristics, their network characteristics have no effect on the attractiveness of other agents. This experiment further displays the basic structure for the analyses of the subsequent experiments.

	Factors			Factor levels
Individual	Firm-size-distribution	all_small	all_large	2
	Firm-age-distribution	all_young	all_old	2
	Firm-resource-distribution	all_low	all_high	2
Network	Firm-strategy-distribution	Maximise		1
	Firm-benefits-preference	Individual		1
	Init-network-scenarios	-		1
Simulation settings	Design points:	8	Total runs:	2,000
	Repetitions:	250	Duration:	520 ticks

Table 25: SimPioN, Exp.1; initialisation settings

4. 5. 1. 1. Occurrence of lock-ins

The first relevant outcome is the occurrence of lock-ins produced by the experimental runs across the experiments initialised settings.

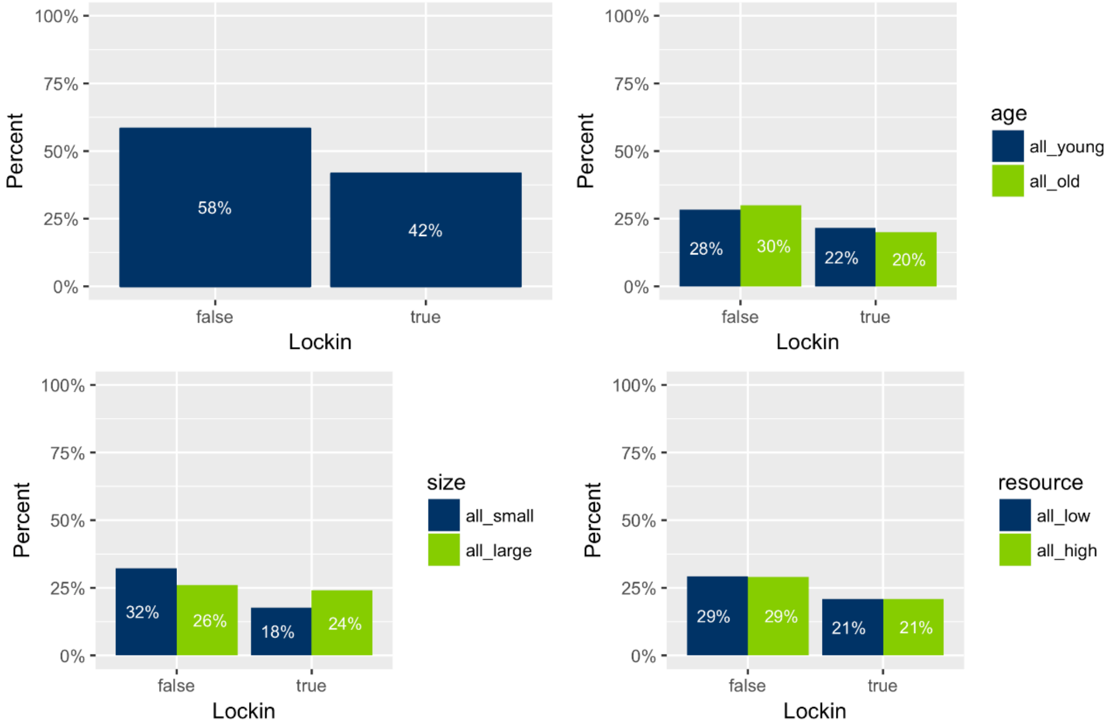

Figure 24: SimPioN, Exp. 1; lock-in occurrence, frequency statistics

Figure 24 displays four lock-in frequency results for Experiment 1, focusing on the effects of individual agent attributes and individual-oriented agent preferences on lock-in. The top-left segment shows the overall lock-in frequency distribution between `true` (=lock-in) and `false` (=no lock-in) and the other three segments show the results broken down by the manipulated factors. The result of this experimental setup with 250 repetitions is that 42% of the runs result in lock-ins and 58% of the runs result in systems that did not lock-in. The findings are then separately presented for the occurrence of lock-ins for each combination of firm-age, firm-size, and firm-resource, and as part of the overall share of lock-ins in Table 26.

For firm-resource the frequency statistics spread out evenly across the two design points, with `all_low` firms and `all_high` firm-resource scenarios accounting for 21% of lock-ins each. For combinations with firm-resource, a systematic influence of either low or high are not visible. This indicates no isolated systematic influence of firm-resource on system lock-in.

Firm-age is of similarly low influence on system lock-in with `all_young` firms-age locking-in slightly more often (22%) than `all_young` firm-age scenarios (20%). They also lock-in more often in combination with the other factors, except in the scenario with `all_large` firm-size and all_high firm-resource where the all_old firms scenarios lock-in more often than young scenarios. Firms are perceived by alters in reference to the duration of the run and older firms appear more attractive than younger firms to assessing alters. Maximising agents seeking (to continue) connections with older alters appears consistent with that implementation since the combination with the all_large and all_high makes the firms especially attractive to (continue to) connect with, implying a stronger lock-in tendency. Furthermore, the combination of all_old and with all_low and all_small stands out since it is the combination leading to the overall lowest amount of lock-ins. Here it appears that the old age of the firms cannot compensate for the overall stronger effect of firm-size on attractiveness.

Experiment 1: lock-in occurrence						
	Firm-Strategy: Maximise			Initial-network-scenario: None		
	Firm-Preference: Individual			(All design points, rounded percentages)		
	Firm-size	Firm-resource	Firm-age	% Lock-in	% non-lock-in	lock-ins % of all runs
1	all_small	all_low	all_young	38	62	4.8
2	all_small	all_low	all_old	32	68	4
3	all_small	all_high	all_young	36.4	63.6	4.5
4	all_small	all_high	all_old	35.2	64.8	4.4
5	all_large	all_low	all_young	51.6	48.4	6.5
6	all_large	all_low	all_old	44.8	55.2	5.6
7	all_large	all_high	all_young	46.8	53.2	5.9
8	all_large	all_high	all_old	48.8	51.2	6.1
	All design points			42	58	41.8

Table 26: SimPioN, Exp. 1; lock-in occurrence, design point frequencies

Firm-size manipulations exhibit more variance and indicate that scenarios with firm-size set to all_large results in more locked-in final system states (24%) than those with all_small firms (18%), while overall small firm-size scenarios lock in the most across all design points. Agents maximising partner attractiveness based on individual characteristics lock-in more often in all_large firm-size scenarios than in all_small firm-size settings since all_large firms are more attractive than smaller ones. This finding can additionally be explained as a result of the comparatively higher number of free slots that are allocated to large agents (1/10th) of firm-size. This allows larger firms to hold more connections simultaneously. Hence, they have more options for maintaining many parallel connections and can also be connected to more alliances compared to small-firm scenarios. This makes frequent entries and exits overall less likely. In consequence, these settings become locked-in more often than those with all_small firm-size where due to a lower availability of firm-slots, agents can connect to fewer alliances simultaneously. Conspicuous combinations with the other two factors are the one with all_low firm-resource and all_young firm-age where large firm-size appears to compensate and dominate the other two factors and leads to the comparatively highest number of lock-ins of all factor level combinations. It is here that the effect of the available firm slots is the largest, since the other two factors are unattractive and would not really lead to over-stability of the overall network. The second similarly noticeable combination is with `all_high` firm-resource and `all_old` firm-age where all three factors lead to high attractiveness of the agents and thus high connectivity in the network. Since size is not the only influential factor here, the amount of lock-ins is slightly lower than for the previous combination.

The overall finding of 42% percent lock-ins follows the expectation that a more stringently assessing maximiser strategy, overall, leads to relatively fewer lock-ins than pure chance would predict (i.e. 50:50). This a situation generally in keeping with the claim of path dependence theory that lock-in is a rare situation. The 42%, when divided according to the initialisation settings, do suggest, however, that smaller and to less extent also older firm-age scenarios lock-in more often than larger and younger scenarios.

4. 5. 1. 2. Time-to-lock-in

When further examining the system setups that exhibit lock-ins, an interesting aspect is the question of how soon after initialisation of the run these systems do lock-in. The time available before lock-in, in the real-world, implies a time-frame during which firms could potentially perceive the arising lock-in situation and attempt to avoid, mitigate, or remedy it. The findings for the combined eight data points are presented in Figure 25, below.

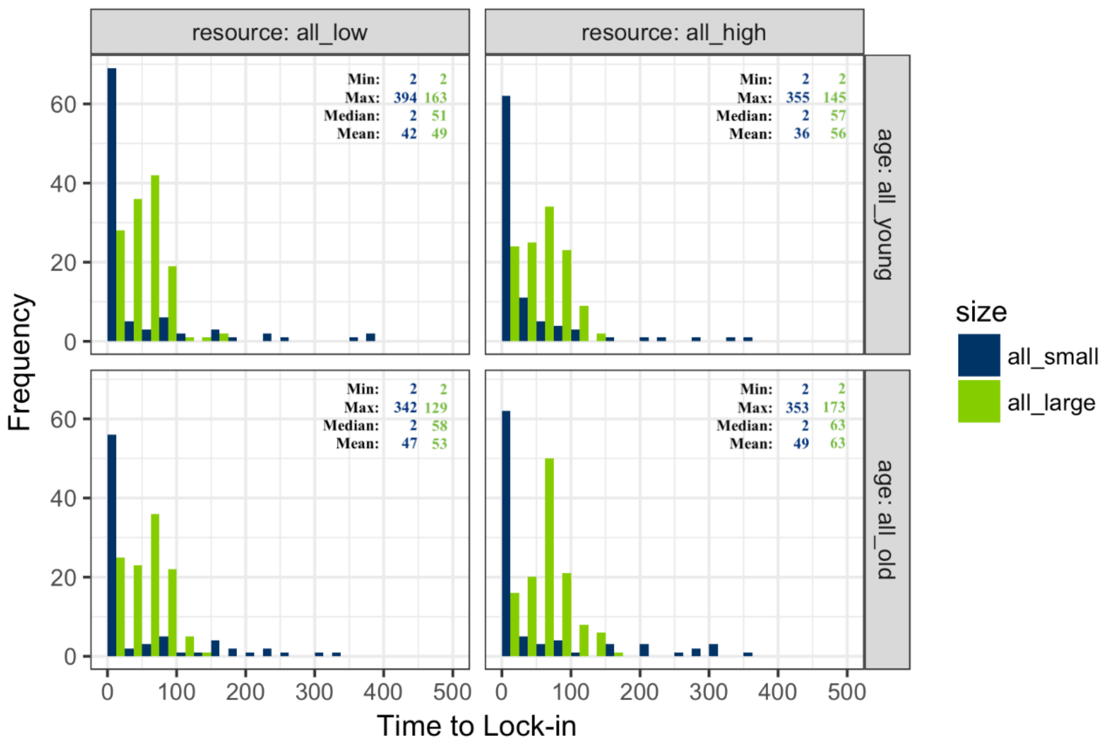

Figure 25: SimPioN, Exp. 1; time-to-lock-in

Figure 25 selects the runs where lock-ins occurred in the experimental outcomes and details their time to lock-in, i.e. the number of ticks that the model ran before entering the 104 tick (≈ 2 years) period of full system over-stability (fewer than 5 alliance exits and entries per tick overall) that has been defined as the lock-in for the simulation. The combination of the factor settings allows for a deeper analysis of the combined causes for systems speed to lock-in. The four results diagrams show bar plots with the bars indicating the frequency of time-to-lock-in for the given scenario. The two colours represent the variation of firm-size and the four quadrants showing the scenarios with the other two factor settings for firm-age and firm-resource.

As a main finding, most simulation runs lock-in before reaching 100 ticks of run duration. The majority of the runs that lock-in very early are the scenarios with `all_small` firms with a median duration of only 2 ticks vs. more than 50 ticks for other design points and also lower mean run durations between 36-49. However, `all_small` scenarios are also the ones that produce some outlier runs that take much longer to lock-in as indicated by the much higher maximum values of over 300 ticks.

The `all_large` scenarios also almost all lock-in before 100 ticks but they have a considerably larger spread within that space than `all_small` with multiple peaks and vs. just one main peak and also with higher mean values for time-to-lock-in. That smaller firms are faster to lock-in can be explained by the attraction function in which any firm is equally attractive if larger than an agent itself. In these `all_small` scenarios, the other factors take more effect than firm-size, but small firm-size still means they have fewer slots to fill and are thus faster in overly-stable systems in the majority of runs. The outliers can be explained by the fact that project durations do also end in these scenarios, and while large firms have the ability to sustain more parallel relations, small firms do have to reconsider based on the fast that their equally small cooperation partner might no longer be available based on filled slots.

Both firm-age and firm-resource demonstrate a smaller impact on time-to-lock-in with only the `all_old` scenarios generally locking-in slower than `all_young` scenarios, which appears consistent with the general occurrence of lock-ins in these scenarios. Older age does aid in distinguishing agents' attractiveness from younger ones, that allows alters to choose more carefully and these scenarios thus take longer to lock-in. `all_high` firm-resource also plays a role in the scenarios with `all_large` size and `all_old` age: these runs exhibit the longest times to lock-in and the latest large-firm peak and highest mean) time-to-lock-in – not surprising given the overall higher attractiveness of those firms which allows for more fluctuation. The reverse combination of `all_young`, `all_small` and `all_high` are the overall fastest to lock-in, while the combination of the same with `all_low` is slightly slower, probably given agent's overall even lower attractiveness in this scenario, requiring agents to seek (new) partners for longer.

Overall, then, while larger firms lock-in more often than small ones, they take longer to do so, which holds across all firm-resource and firm-age manipulations. Small firm scenarios, while locking-in faster in general, also have the furthest outliers taking substantially longer to lock-in. High resource levels mean faster lock-ins when combined with young age, but slowest lock-ins when combined with old age for both small and large firms. `all_young` scenarios universally lock-in faster than `all_old` scenarios across all factor combinations.

4. 5. 1. 3. Alliance density and time-to-lock-in

The developed explanatory framework (see Section 2. 6) places emphasis on (increasing) alliance density as a symptom, driver, and (partial) cause of network lock-ins. It is thus relevant to examine how dense the networks in lock-in situations become over time. Density is an indicator of the share of realised relationships within a network, here within alliances. Figure 26 exhibits histograms of the alliance density of all locked-in runs at the end of the run on the ordinate and with the tick at which lock-in occurred on the abscissa. The values on the ordinate can thus be understood as percentages of the total possible relationships within an alliance. The transparency of the dots representing the runs' data points allows for identifying overlaps (darker areas of the histogram) and whether the colours green (`all_large`) and blue (`all_small`) have mixed.

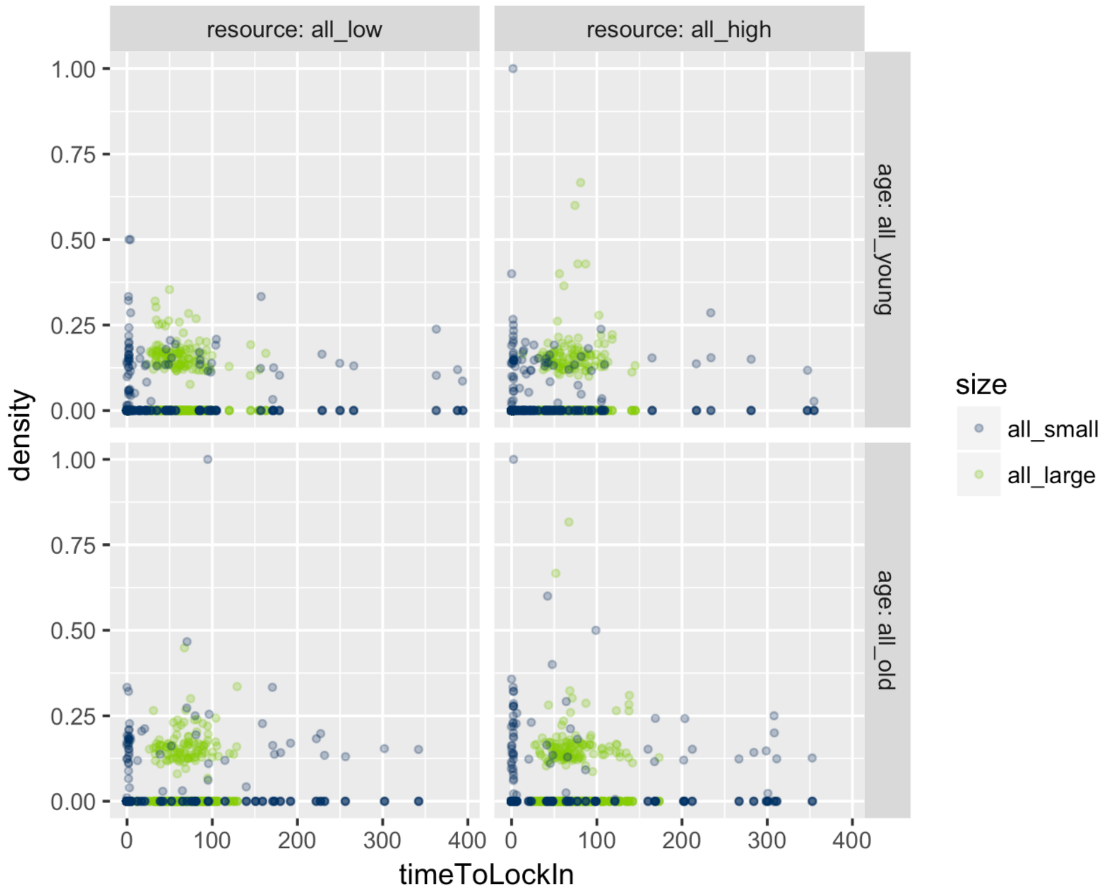

Figure 26: SimPioN, Exp. 1; density at time-to-lock-in, scatterplots

The four diagrams in Figure 26 display generally similar scenarios. The alliances in the locked-in runs exhibit densities clustering between approx. d=0.125 and d=0.25, so between 12.5% and 25% of realised relationships within their alliances after run durations of approx. 50-120 ticks.

A noticeable difference exists again for the size-varied scenarios with all_large scenarios achieving higher densities than all_small ones. This appears consistent with the ability of larger firms to maintain more simultaneous connections which allow them to realise more relationships of the potential relationships within an alliance. All_small scenarios, while locking-in faster, albeit with more outliers, can attain similar densities, but in far fewer of the runs. The overall highest densities are attained in the combination of all_large size, all_high resource and all_old age where a small cluster of runs lock-in with densities around d=0.30 with outliers even exceeding d=0.50. Given that this scenario is also the one with overall slowest times-to-lock-in, the scenario appears to allow firms to establish more connections over time, consistent with the expectations from implementation.

The all_small scenarios realise far fewer connections within the overall network, locking-in faster but with more spread over time, although the majority of runs lock-in fast. Also, they exhibit many of the outliers with late lock-in times between tick 150-400 with similar densities as those locking-in much faster. Further, all_small scenarios produce more locked-in runs with near-zero density, indicating that often only an alliance founder remains alive towards the end of the run.

The finding on resources echoes those of the results above, namely that it has little influence on the outcomes, also for densities. Some all_high resource runs appear to allow for more alliances reaching higher densities than all_low runs, especially for the combination with all_old and all_large, also the scenario taking the longest to lock-in. The effect of age is somewhat less pronounced. Runs with all_old firms take longer to lock-in and have many outliers mainly for all_small firms, but many of these appear to lock-in at relatively low density levels.

Overall, then, the maximising agents appear to create the densest networks when they are large and have high resources levels. Against this background, it is interesting that very few runs actually produce fully connected alliances of d=1.0 (only for all_small firms), while many more appear to result in a density approximating or equalling zero. This latter result is caused by the fact that the diagram displays all existing alliances at the *end* of a run, also those with no remaining connections, with at least their initial member surviving thus far.

Having studied the whole network results regarding how dense alliances are at the end of their runs, the aggregation level one step deeper - looking into the alliances– is also of interest. Densities broken down by the membership share of the alliances (their dominance) makes the interpretation of the densities more meaningful to assess the structure underlying the whole network level of analysis.

4. 5. 1. 4. *Intra-alliance density and dominance*

Lastly, having detailed the developed densities across all runs towards their end, it is important to consider how big these alliances are in terms of membership numbers and how their sizes relate to their density. To analyse this aspect, the alliances need to be aggregated in a manner which allows for systematic comparisons across all simulation runs, since, obviously, one alliance is never the same across more than one run.

Hence alliances of all runs are ranked according to their membership size, i.e. indicating their dominance in the overall network vis-à-vis the competitor alliances from largest to smallest and are plotted in groups against their densities. The scatterplots consequently display the resulting alliance densities ranked according to alliance size across all runs, and each dot represents one of the size-ranked alliances of each run. The colour gradient of the dots represents an alliance's membership size from green (low) to red (high), subdivided into the runs that locked-in and those that did not.

Figure 27: SimPioN, Exp. 1; intra-alliance densities, ranked scatterplots

When the runs of maximising, individual-oriented agents produce no lock-ins, they interestingly never have outcomes with all five alliances surviving to the end of the run. The absence of any data points also indicates that even their initialised founding members must have exited the simulation due to lacking connections for too long. While only one most dominant (first-ranked) alliance usually remains, these alliances attain similar density levels as runs that do lock-in, but with far fewer members. This effect is triggered by the fact that not many firms survive in non-locked-in scenarios in general, and that many runs resulted in near-zero membership, i.e. only few members survived.

For the runs that did lock-in, some exhibited five alliances towards the end, albeit not many and then without many members. The typical 'main' alliance attracted the majority of firms, with medium density levels around the `d=0.15` level with some outliers above 30% density.

Some high membership alliances remain in the second rank with similar densities. The third and fourth rank are mainly occupied by small and very small alliances. The few data points indicate no noteworthy level of density at the end of the run for alliances 4-5. Additionally, a high number of runs results in the largest alliance accounting for more than 75% of agents in the environment, indicating a large network of almost all agents. For the second largest alliance group (and all smaller ones), many runs lead to lock-ins with a medium to high share of members, but the densities are spread further and a few reach density levels as high as `d=1.0`. Such high-density levels with (as defined) all possible relations being realised are typically the result of very small alliances as indicated by the green shade of the dots. This would appear logical for larger member firms that have enough network slots available to realise all connections of all possible connections. For the third rank, dominance is lower overall, but attained densities remain similar to the first ranks.

A further trend appears to be that the lower the rank (i.e. size of the alliances at the end of the run), the higher their density. This result stems from the smaller number of firms in these alliances that allows more readily for realising more of the possible connections. The alliances with a high number of members, can rarely reach such higher densities, as comparatively more connections necessarily remain unrealised.

Of course, some of the findings are a consequence of aggregating across all experimental conditions, e.g. the highest density levels of `d=1.0`. However, is it clearly an interesting result, that in the case of the maximising agents apparently only two, sometimes three, larger alliances exhibit medium densities, and also only for those runs that have become locked-in. The implication is that in the case of the smallest alliance, even the founding members (who is initialised to start the alliance) do not survive in the majority of runs. Moreover, the fourth and fifth ranks do not see large alliances in their ranks because all agents are limited to a maximum of three alliance memberships and that results in red dots only being displayed in the fourth and fifth ranks.

There also appears to be a trade-off between becoming locked-in with other members and not surviving at all. Notably, though, the fourth and fifth largest alliances only survive at the price of very low density, similar to the third-ranked alliances. In the real world, they would thus not be able to reap the benefits of dense cooperation. By comparison, the biggest alliances reach densities of about `d=0.10-0.25` if the runs lock-in, which is related to the overall larger size of the largest alliance accounting for often more than 75% of all remaining agents. This results in overall more possible connections, and a higher level of realised connections, but apparently not often beyond `d=0.25`.

Figure 28, below, breaks the intra-alliance findings down by the influence of size and resource, the latter of which was found above to produce denser alliances than outliers when high. As the diagram indicates, the findings remain similar to the ones above with `all_large firm-size` being the overall strongest influence on dominant alliances in the first rank locking-in at density levels between `d=0.10 – d=0.20`. The lower ranks see data points for `all_large` scenarios, which makes sense given larger firms' ability to connect to more agents than small ones and thus being able to sustain up to three larger alliances more easily. High resource levels appear to increase density outliers, especially in `all_small` firm scenarios but with smaller alliances sizes. Some even reach the `d=1.0` level. This indicates that smaller firms with high resources can compensate the lacking firm-size to some extent, but at the price of alliance size.

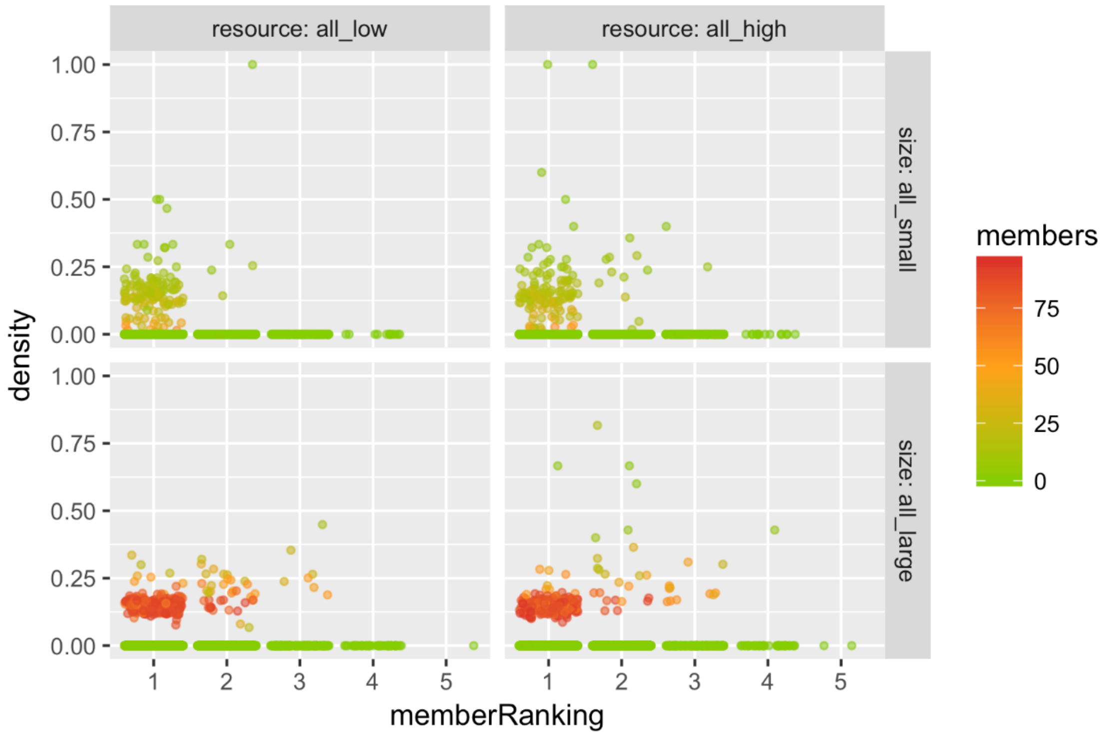

Figure 28: SimPioN, Exp. 1; intra-alliance densities, ranked scatterplots, by factors

4. 5. 1. 5. Discussion

Overall, the results from the base case experiment of maximising agents with benefits-preference focused entirely on the individual characteristics reveal some interesting systematics. Consistently with path dependence theory claims, lock-ins occur less frequently (44%) than non-lock-ins, and less often than chance would predict.

Scenarios with `all_large` firms lock-in more often than `all_small` scenarios, and they take longer to do so because these firms have more free slots to connect and consequently the network takes longer to lock-in. While firms' resources hardly play any systematic role in producing lock-ins, firm- age does and scenarios lock-in more often when firms are younger than when they are old, and `all_young` firms are also quicker to do so, especially when interacting with `all_high` resource settings.

Small and large firm scenarios produce similar densities, but small firms exhibit more variance over time-to-lock-in to generate these densities. High-resource runs appear to attain higher densities than low-resource ones. In most runs, the smaller alliances do not survive or exhibit very low levels of density, often around zero. This points towards a trade-off of either becoming locked-in at a medium to high density alliance and surviving or surviving with only very few network connections, leaving firms comparatively isolated or even ceasing to exist entirely for lack of connections.

Of course, the scenarios are somewhat artificial in that all firms contained are of a certain size, age or resource level (and their combinations), but the indications remain: small, older firms, while taking longer, lock-in most often, albeit still less than 50%, as chance would indicate. There further appears to be a trade-off between becoming locked-in and surviving at all, as many alliances remain without members or in many cases cease to exist based on lack of members.

The combination of small, young firms with high resources is, of course, not merely theoretical: the many VC-financed high-tech start-ups are small but have considerable resources available, both in money and in skills despite their young age. They are faster to lock-in with more spread, but eventually produce fewer lock-ins than other combinations. A subsequent empirical study could seek to identify if and under what conditions smaller firms may be faster to join alliances that lock-in faster, with overall smaller alliances sizes, but higher density. Such a study would be an intriguing in order to identify a strategy allowing small firms to potentially gain access to the benefits of larger interorganisational networks, while maintaining the high level of density that is elemental for the start-up context in which many are working. Larger incumbents, in turn, would be well-advised to seek their alliances carefully, given that they lock-in the most often, but typically in large alliances with many members, but low density and consequently limited benefits from dense cooperation ties. Although, of course, individual firms may still be able to establish close cooperation with some alters, despite overall density being low.

4. 5. 2 Experiment 2a: satisficing strategy and individual characteristics

Experiments 2a and 2b address the question of 'what role do the assumptions on strategy and preferences regarding firm decision-making behaviour play in the occurrence of lock-ins, time-to-lock-in and attained densities?

In the first of these experimental settings, I vary the settings for the strategy of the firms to `satisfice` while holding all else equal, as in Experiment 1. I expect this change of decision-making behaviour to create more lock-ins overall and also across all scenarios. Additionally, I expect that the runs' lock-in will occur more quickly, since the assessments of partners is less nuanced than for the maximising agents, and thus should become locked-in often and relatively fast, also achieving higher density levels.

	Factors			Factor levels
Individual	Firm-size-distribution	all_small	all_large	2
	Firm-age-distribution	all_young	all_old	2
	Firm-resource-distribution	all_low	all_high	2
Network	Firm-strategy-distribution	Satisfice		1
	Firm-benefits-preference	Individual		1
	Init-network-scenarios	-		1
Simulation settings	Design points:	8	Total runs:	2,000
	Repetitions:	250	Duration:	520 ticks

Table 27: SimPioN, Exp. 2; initialisation settings

The results follow the structure above, with an initial description of lock-in occurrences according to the individual characteristics, the time-to-lock-in, density and time-to-lock-in and the intra-alliance densities and concluding with a discussion of the findings.

4. 5. 2. 1. Occurrence of lock-ins

When manipulating the firm-strategy to "satisfice", the situation with regard to lock-ins looks radically different from the maximising strategy: scenarios now lock-in in 85% of the runs, indicating a much greater tendency for overly stable alliance networks when strategising as satisficers. The (anticipated) much higher percentage of lock-ins is a direct result of the strategy employed by the agents when making their cooperation decisions, since no other alteration was made in the experimental setup. Interestingly, the other experimental variations on their own appear to be of no systematic consequence to the occurrence of lock-in. The influence of the satisficing strategy appears to push aside those of the other experimental variables size, age, and resource.

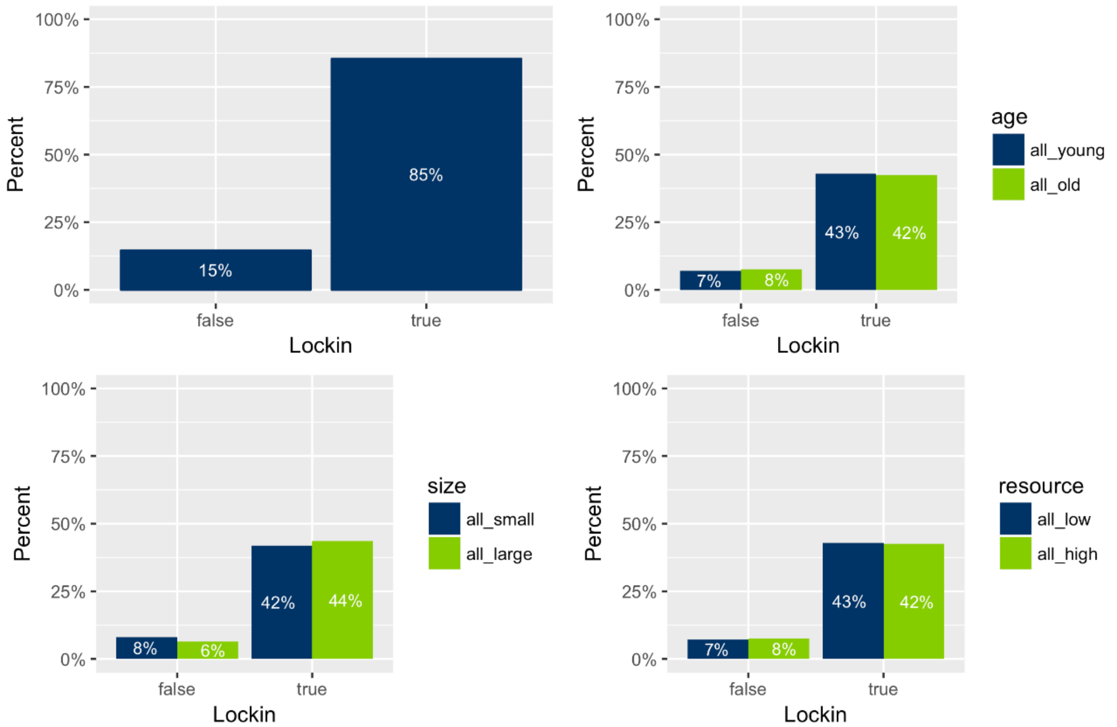

Figure 29: SimPioN, Exp. 2a; lock-in occurrence, frequency statistics

The results in more detailed form can be found in the following Table 28:

Experiment 2a: lock-in occurrence						
	Strategy: Satisfice			Initial-network-scenario: None		
	Firm-Preference: Individual			(All design points, rounded percentages)		
	Firm-size	Firm-resource	Firm-age	% Lock-in	% non-lock-in	lock-ins % of all runs
1	all_small	all_low	all_young	86	14	10.8
2	all_small	all_low	all_old	83.2	16.8	10.4
3	all_small	all_high	all_young	82.4	17.6	10.3
4	all_small	all_high	all_old	83.2	16.8	10.4
5	all_large	all_low	all_young	89.2	10.8	11.2
6	all_large	all_low	all_old	84.8	15.2	10.6
7	all_large	all_high	all_young	86.4	13.6	10.8
8	all_large	all_high	all_old	88	12	11
	All design points			85	15	85.5

Table 28: SimPioN, Exp. 2a; lock-in occurrence, design point frequencies

The only noticeable difference is exhibited for the manipulation of `firm-size`, where `all_large` scenarios again lock-in slightly more often than `all_small` ones. The two scenarios locking-in the most are both `all_large` firm-size ones, the highest 89.2% combined with `all_young` firm-age and `all_low` `firm-resource` where the effect of size is strong because the other variables signal low attractiveness; and the second highest with all_high resource and all_young age where size appears to matter more strongly than the all_high resource. Yet, all_small scenarios when combined with all_young age and all_low resources also lock-in comparably often at 86%, while the lowest lock-ins are produced by all_small, all_high resource, and all_young age. Overall, it appears that even size has no clear systematic influence given the satisficing strategy of connecting agents, but it can lead to more lock-ins when size is large and fewer lock-ins when size is all_small (for certain combinations), consistent with the availability of free slots derived from firm-size.

The interpretation of the lock-in occurrence data is thus difficult without consulting the other metrics gathered (below) that reveal the effects of the interacting experimental variations. The near absence of individual characteristics' influences - apart from firm-size – draws attention to the satisficing behaviour where, from an assessing agent's perspective, an alter fulfils (or not) the minimum conditions for connecting, i.e. attractivenessScore≥0.5. At that point, if the alter suffices, the agent will connect, irrespective of which individual characteristic leads to the alter's value of 0.5. Hence there are likely to be compound (interaction) effects of the characteristics which lead to the attractiveness score.

4. 5. 2. 2. Time-to-lock-in

Overall, the time-to-lock-in plots indicate much shorter run durations before locking-in. The medians are only minimally shorter than for the maximising agents, but the maximums are much lower and most runs lock-in before 50 ticks, indicating that agents' strategy of satisficing speeds up the process of becoming locked-in quite substantially.

The time-to-lock-in results are similarly distributed as in the maximiser experiment, but much faster to lock-in. Again, all_large firm-size scenarios overall take the comparatively longest time to lock-in, with the median time-to-lock-in above 30 ticks in all combinations. This is more than 30 ticks longer than the all_small firm-size scenarios, and also approx. 10-15 ticks faster than the equivalent runs for the maximisers. Also, similarly to the maximisers, the all_large firm-size scenarios produce hardly any outliers. The picture looks rather different for all_small scenarios where the median time-to-lock-in is similarly short as for the maximisers but with much lower maximums and mean times-to-lock-in, they continue to exhibit more outliers than all_large scenarios, especially in combination with all_old firm-age and all_high firm-resources. This is an indication that especially in the high resource scenarios firm-size appears to be the major impact factor compared to firm-age and firm-resource. What is also interesting is that all_large runs exhibit a lock-in in two 'waves', with the first just above 10 ticks and approx. 1 third of the runs, and a second wave at about 50 ticks with two thirds locking-in. By comparison, the maximisers were distributed over 4-5 peaks of lock-in 'waves.'

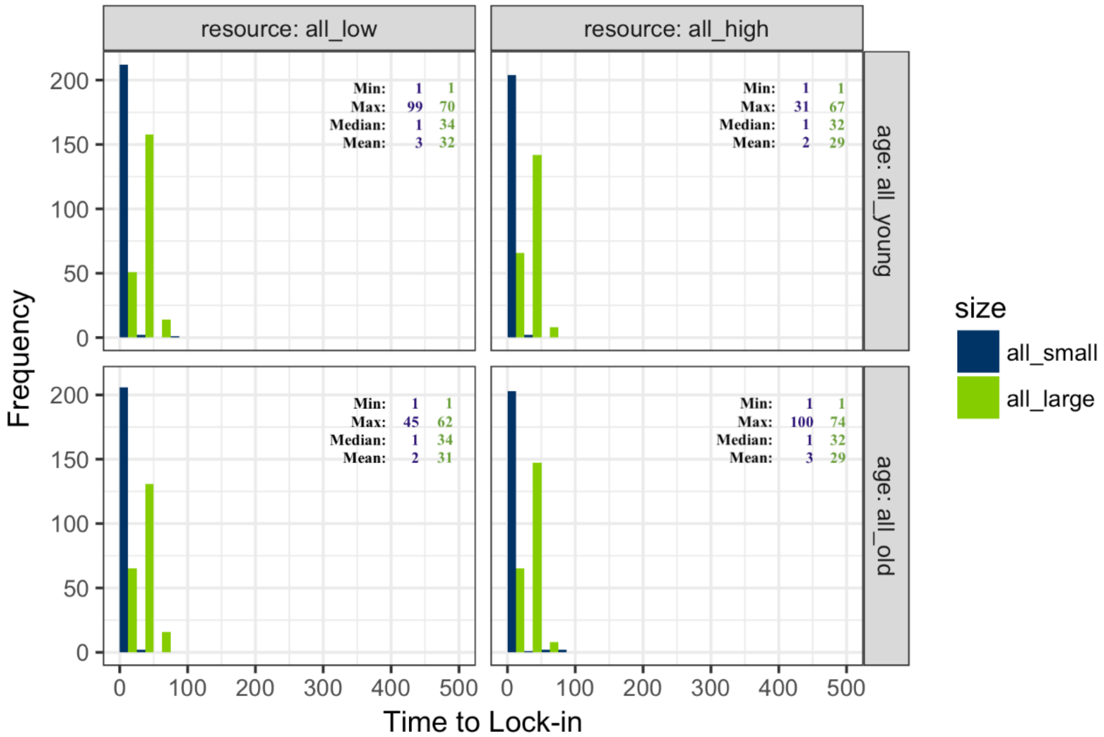

Figure 30: SimPioN, Exp. 2a; time-to-lock-in, bar plots

Firm-age and resource have no isolated systematic effect on time-to-lock-in but, when combined, they exhibit a minor systematic influence which minimally increases the maximum time-to-lock-in for both small and large firm scenarios in the combinations `all_old`, `all_high` firm-resources and `all_young` plus `all_low`. This is probably a result of interacting with the other high (lower) factor values that are perceived as (less) attractive by assessing alters, thus leading to slower times-to-lock-in. This points towards the compensatory nature of the attractiveness function: `all_old` firm-age and `all_high` firm-resource partially compensate for the relatively less attractive `all_small` firms, thus increasing time-to-lock-in slightly, since firms need to reassess their alters despite only considering the minimum threshold `min-attraction≥0.5`.

4. 5. 2. 3. Alliance density and time-to-lock-in

This next analysis once more serves the purpose of detailing the time-to-lock-in with the resulting alliance densities at the end of the run in more depth. As we can see from the diagram, it scales slightly differently than the same one for the maximisers. This is due to the lack of outliers with time-to-lock-in beyond 100 ticks. At first glance, this slightly 'enlarged' view of the scatterplots shows that the satisficing agents are not only much faster to lock-in their system than the maximisers, but also achieve much higher levels of density at lock-in. This is at around the `d=0.6` level, with most runs falling between `d=0.3` and `d=0.75`. Several outliers even attain the `d=1.0` level, albeit fewer than the outliers with `d=0` density.

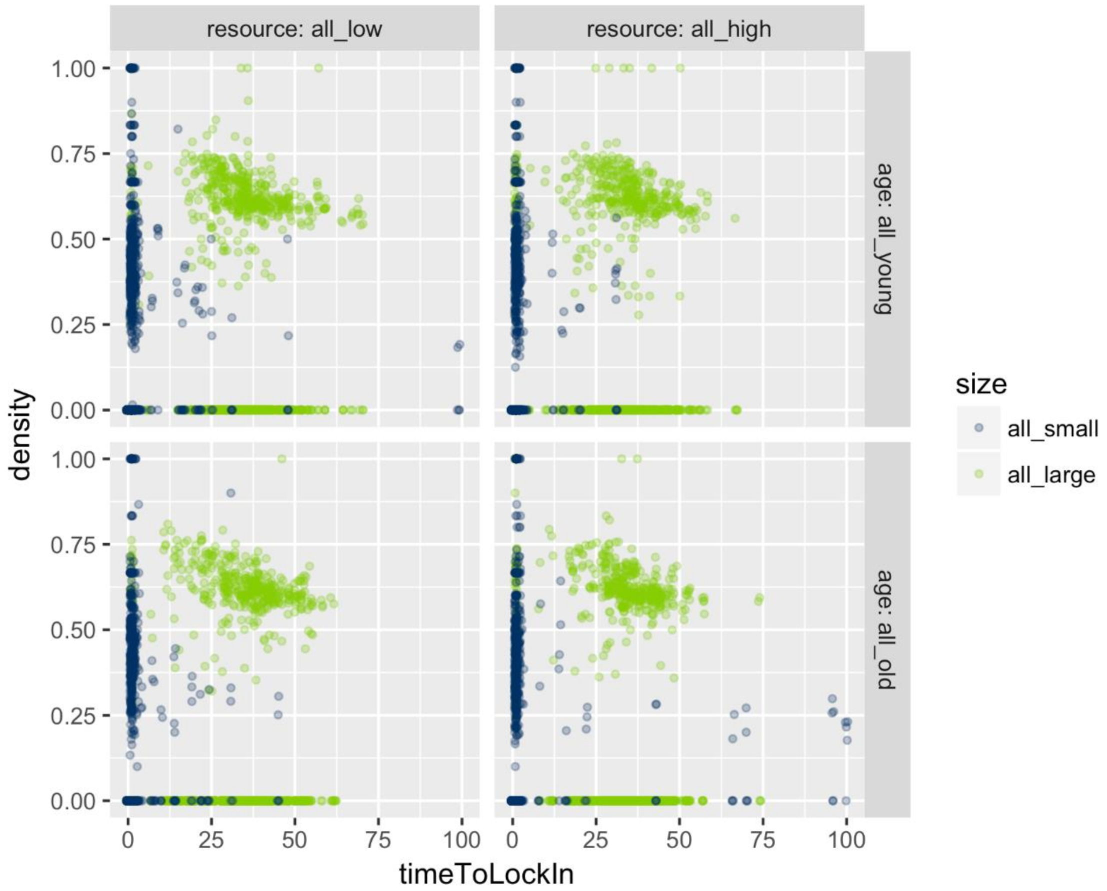

Figure 31: SimPioN, Exp. 2a; density over time, scatterplots

Just as for the maximisers, the satisficing strategy leads to slower lock-ins for `all_large` firm scenarios than for `all_small` firms, and also at a higher variance (but even higher here) in the densities at the end of the run. Overall, it is interesting that larger clusters of `all_large` firms scenarios reach higher density levels than `all_small` firms that appear to cluster around `d=0.5` rather than `d=0.6`. Runs with all_small settings attain and slightly lower densities between `d=0.25` and `d=0.6` than `all_large` that mostly fall between `d=0.5` and `d=0.75`. This again points towards the higher ability of large firms to uphold simultaneous connections and thus being able to attain a higher degree of closure (density) of the alliances since more slots imply that more connections of the possible connections are realised, especially for satisficers that only analyse the minimum threshold of a partner candidate.

Similarly, the time-to-lock-in outliers are mostly small firm runs with medium densities attained. The density outlier reaching `d=1.0` for `all_small` scenarios are all at very early ticks, and all later ones are `all_large` runs which are also more numerous, underlining the effect of `firm-size`-based available slots. More high-density runs fall into the `all_old`, `all_high` scenario where the densities also appear to take the longest to reach the high levels for both small and large firm-size scenarios.

With regard to firm-resources, `all_high` scenarios produce slightly higher densities on average and also slightly longer run durations to lock-in with `all_old` firm-age locking in at denser levels than `all_young` firms. The higher levels of density can be explained by satisficing agents accepting more relations than the maximisers when being asked to connect. The overall faster time-to-lock-in is at least in part a consequence of the former: more possible relationships overall, requiring lesser reconsideration and making a continuation of relations more likely, especially for large firm scenarios.

4. 5. 2. 4. Intra-alliance density

Given that the densities in the time-to-lock-in revealed much higher levels of densities for the alliances of satisficing agents, it is reasonable to expect that the ranked alliance diagram will similarly reveal more density, and probably more spread within the ranks.

Figure 32: SimPioN, Exp. 2a; intra-alliance densities, ranked scatterplots

The scatterplot output shows that for the 15% of runs that do not lock-in, the third – fifth places in the alliances ranks always remain empty. This indicates that no more than two alliances ever survive until the end of run. Also, the first two alliances appear to have nearly no members, with density levels approaching zero at the end of the run. This is most likely a measuring artefact from the time of measurement, since these firms cannot survive much longer without at least minimally one connection. The indication is thus that unless a satisficer run becomes locked-in, agents do not connect sufficiently to survive to the end of the run.

For the runs exhibiting lock-ins, some runs interestingly have all five alliance ranks populated, indicating a survival of all five alliances with members. Clearly, however, the smallest alliance rank shows far fewer data points with higher densities than the others four ranks. Generally, the amount of data points per rank decreases the lower the rank becomes, i.e. the most runs are in the first rank, then fewer in the second etc.

While the satisficers thus exhibit a similar general distribution of one main alliance with the most members, the differences when compared with the second and third are far less pronounced than for the maximisers. It appears that satisficing agents not only connect much denser than maximisers, but they also allow for the survival of more than just one large alliance at the cost of the others, but often maintain at least three relatively large ones, with outliers at both density extremes for the ranks 1-4. More of these outliers become locked-in at the `d=1.0` density level, and as before these are all rather light-green shades indicating alliances with few members. The survival of many more alliances indicates that, from an alliance-building perspective, the satisficing strategy means less of the trade-off between size, density, and survival than in the maximiser case. Survival and more connections keep more alliances in existence towards the end of the run, despite the most agents being gathered within one dominant alliance network. Similarly, while for the maximisers, the price of not being a member of these large and dense constructs was typically firm/alliance death, many more alliances and agents appear to survive when using the satisficing strategy.

Interestingly, the largest alliances produce densities clustering between the `d=0.35` and the `d=0.75` level with many more large-member alliances between these two levels than smaller-ranked alliances, indicating that these are runs with `all_large` scenarios, where firms have many available slots to forge many connections and thus stabilise around the `d=0.6` density level. However, when additionally studying the distribution of data points divided by the factor manipulations for firm-size and firm-resource (above there was hardly any effect of firm-age), in Figure 33, below, an intriguingly different pattern emerges.

In the `all_small` scenarios, all alliances ranks remain much smaller and attract only up to medium numbers of agents with densities clustering between `d=0.25` and `d=0.6`. In sharp contrast, the `all_large` scenarios attract many more members to the alliances in all ranks and also have densities clustering between `d=0.5` and `d=0.75`. The effect of firm-size appears to be that `all_large` firms, because they have more slots for connecting, and also realise far more of them than `all_small` firms scenarios can and do.

For the reverse case of `all_small` scenarios, the finding can be explained as a result of the comparatively lower number of free slots that are allocated to small agents (1/10th) of firm-size. This allows smaller firms to hold fewer connections simultaneously. Hence, they have less options for maintaining many parallel connections and thus can be connected to a lower number of alliances compared to large-firm scenarios. This makes frequent entries and exits less likely overall. In consequence, these settings become locked-in more often than those with `all_large` firm-size where due to a greater availability of firm-slots, agents can connect to more alliances simultaneously and more often.

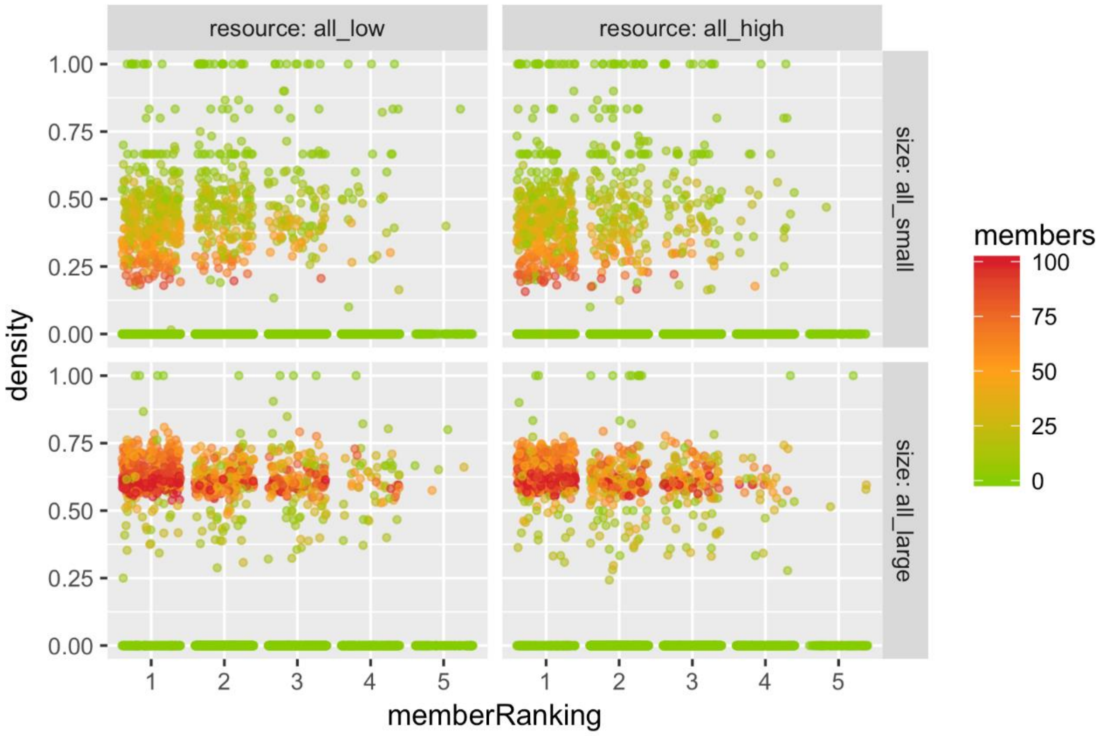

Figure 33: SimPioN, Exp. 2a; intra-alliance densities, ranked scatterplots, by factors

The finding on firm-size thus conform to expectations from model design, since one would expect larger firms with more slots available to realising more of the possible connections given that they are satisficing and not maximising. The findings also show a further model design feature. In runs in which an alliance in the first rank has a red dot indicating an alliance with close to 100 members, the second alliance rank would not be filled, given that there can only be 100 agents in the world. Given that all ranks are filled and have alliances with higher densities, this indicates that the higher densities in the lower ranks are then are a result of the fact that large firms hold sufficient numbers of slots to fill in order to realise connections with more than one alliance, which they can do for up to three alliances. Hence the first three ranks hold the most and also the densest data points.

Furthermore, the influence of `all_high` firm-resource on alliance density appears to be positive for both `all_small` and `all_large` firm-size scenarios. For smaller firm runs it leads to slightly more data points in the 4th and 5th alliance rank and with some higher-density outliers than for the same ranks in `all_low` resource scenarios. In combination with `all_large`, it leads to higher dominance across all ranks, with alliances accounting for more members.

4. 5. 2. 5. Discussion

The overall higher occurrence of lock-ins was to be expected given that satisficing agents do not scrutinise their alters to the extent of ranking them according to attractiveness like maximisers, but instead choose to connect with any of those meeting the minimum attractiveness threshold of `min-attraction = 0.5`. Meeting this threshold through the aggregate attractiveness of the individual characteristics appears to reduce the influence of these individual characteristics on their own – only `firm-size` plays a small systematic role in lock-in occurrence.

From the time-to-lock-in diagrams, we learn that the change of strategy considerably speeds up the time-to-lock-in with almost all scenarios locking-in before 50 ticks. Median time-to-lock-in is above 30 ticks for `all_large` runs which is approx. 30 ticks longer than `all_small` scenarios, and also approx. 15 ticks slower than the equivalent runs for the maximisers. Also, the minor effect of `all_old` means scenarios take slightly longer than `all_young` scenarios to lock-in, similarly to the maximiser runs. `all_high` resources also continue to exert a similar influence on longer time-to-lock-in.

The much shorter time-to-lock-in can be attributed to the workings of the threshold level in the attractiveness assessment and the satisficing strategy, where agents, when unable to distinguish meaningfully between alters, default to connect to overall less suitable alters than the maximisers. While `firm-size` continues to play the most important role with regard to time-to-lock-in, firm-resource, in a contrast to the maximisers, assumes more importance than the age levels.

Small firm scenarios again exhibit more outliers than `all_large` scenarios, especially in combination with `all_old firm-age` and `all_high firm-resources`. `all_large` firm scenarios produce higher densities and more outliers with the highest densities. The much higher densities produced by agents' networking activities are a further indication of the satisficing agents' increased willingness to connect with lower-scoring alters when compared to the maximising agents. In consequence, the networks stabilise much earlier than the maximisers, but more alliances and more agents also tend to survive until the end of the run. It thus appears that the benefit in the trade-off between connecting to less suitable alters and 'going it alone' is a higher survival rate of alliances and of firms.

4. 5. 3 Experiment 2b: despairing firms and individual characteristics

Lastly, for the individual-preferences scenarios, the experimental settings are set to the despair-ing strategy to test the behaviour of the experiments when almost all decision-making logic is disabled. Agents in despairing strategy mode emulate the behaviour of companies that have no option but to be connected to others. In the real world, this would either be the case if they lack substantial production factor inputs, technology, or know-how, or rely on the political or market clout of other firms to push their own commercial agenda. This is the case for many firms in the manifold technology-driven platform alliances that are at the forefront of technological innovations such as smartphones, as illustrated by the case study above.

	Factors			Factor levels
Individual	Firm-size-distribution	all_small	all_large	2
	Firm-age-distribution	all_young	all_old	2
	Firm-resource-distribution	all_low	all_high	2
Network	Firm-strategy-distribution	Despairing		1
	Firm-benefits-preference	Individual		1
	Init-network-scenarios	None		1
Simulation settings	Design points:	8	Total runs:	2,000
	Repetitions:	250	Duration:	520 ticks

Table 29: SimPioN, Exp. 2b; initialisation settings

4. 5. 3. 1. Occurrence of lock-ins

This is the final experimental setting for the agents focusing solely on the individual characteristics in their attractiveness assessment of other agents. In this setup, agents neglect any ranking of their alters and do not even restrict their wish list to those that reach the minimum threshold. Instead, they accept connection partners merely based on available free slots for forging links. With regard to the occurrence of lock-ins, the runs produce an almost identical picture to the satisficing agents, with only minimal differences.

The despairing agents produce the same shares of lock-in runs as the satisficers. Still, 15% of runs remain not locked-in and some of the scenarios have different outcomes. The differences between the scenarios with size, age, and resource levels are rather nuanced with mostly 1% differences between the individual effects, except again for firm-size where all_large firm scenario runs lock-in 3% more often. These small differences appear adequate given that agents have basically no means of acting on the differences of alters' attractiveness. Some part of the variance is also due to the added influence of stochasticity.

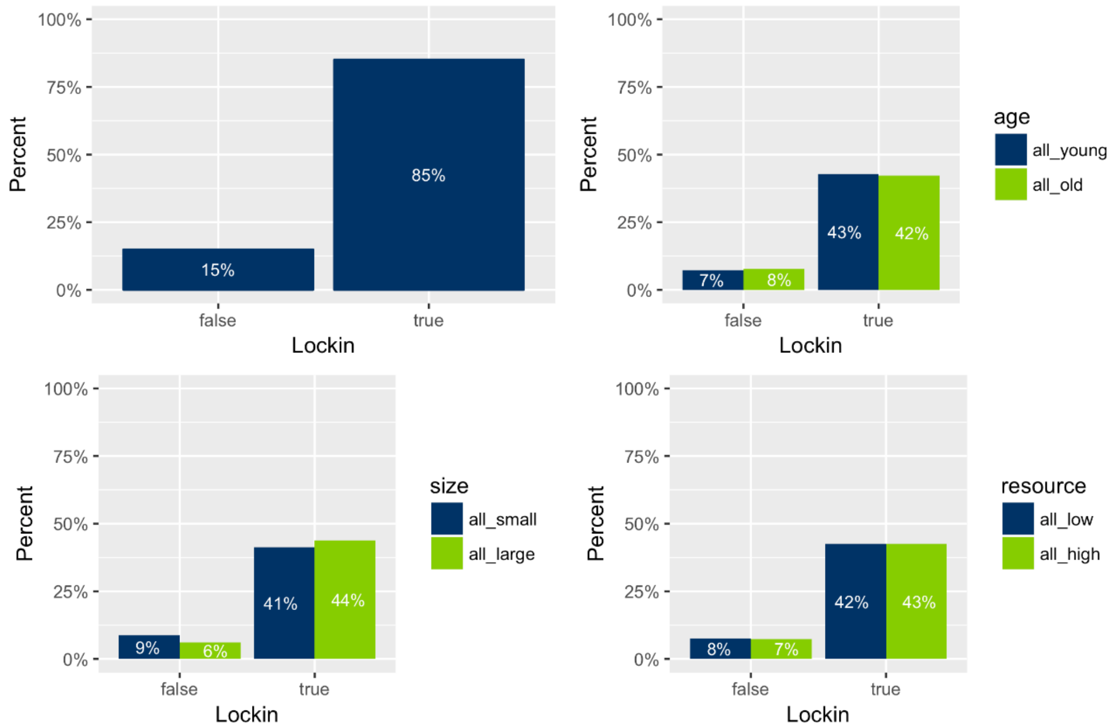

Figure 34: SimPioN, Exp. 2b; lock-in occurrence, frequency statistics

The results in more detailed form can be found in the following Table 30:

Experiment 2b: lock-in occurrence						
	Strategy: Satisfice			Initial-network-scenario: None		
	Firm-Preference: Individual			(All design points, rounded per-centages)		
	Firm-size	Firm-resource	Firm-age	% Lock-in	% non-lock-in	lock-ins % of all runs
1	all_small	all_low	all_young	82.8	17.2	10.3
2	all_small	all_low	all_old	80.8	19.2	10.1
3	all_small	all_high	all_young	84	16	10.5
4	all_small	all_high	all_old	82.4	17.6	10.3
5	all_large	all_low	all_young	87.2	12.8	10.9
6	all_large	all_low	all_old	89.2	10.8	11.2
7	all_large	all_high	all_young	88.4	11.6	11.1
8	all_large	all_high	all_old	85.6	14.4	10.7
	All design points			85	15	85.1

Table 30: SimPioN, Exp. 2b; lock-in occurrence, design point frequencies

Just as for maximisers and satisficers, the despairing firm runs exhibit a difference in the effect of small and big firm-size. `all_large` firm scenarios lock-in 3% more often than those with `all_small` firms. Again, this result is based on the effect of larger firms with more slots having more options for switching once their slots are filled. From the frequency statistics of the factor combinations, we learn that the scores for the highest number of lock-ins have shifted from all_large, all_low, all_young to all_large, all_low, all_old. Also, the 'least' number of lock-ins is now attained by the factor combination all_small, all_low, and all_old rather than all_young. Given that firm-age appeared to have little influence in earlier runs, these results indicate that firm-age seems to matter even less than before with firm-size (and resource) remaining the major (and minor) influence factors for runs' lock-ins. Given that the scenarios' differences for lock-ins are rather low, it is instructive to study the speed of lock-ins and the attained densities of the locked-in alliances.

4. 5. 3. 2. Time-to-lock-in

Since the agents' characteristics play no distinct role when considered individually, it remains important to study if and how they interact to produce lock-ins and, of course, how soon the runs lock-in, also in comparison to the two previous experiments.

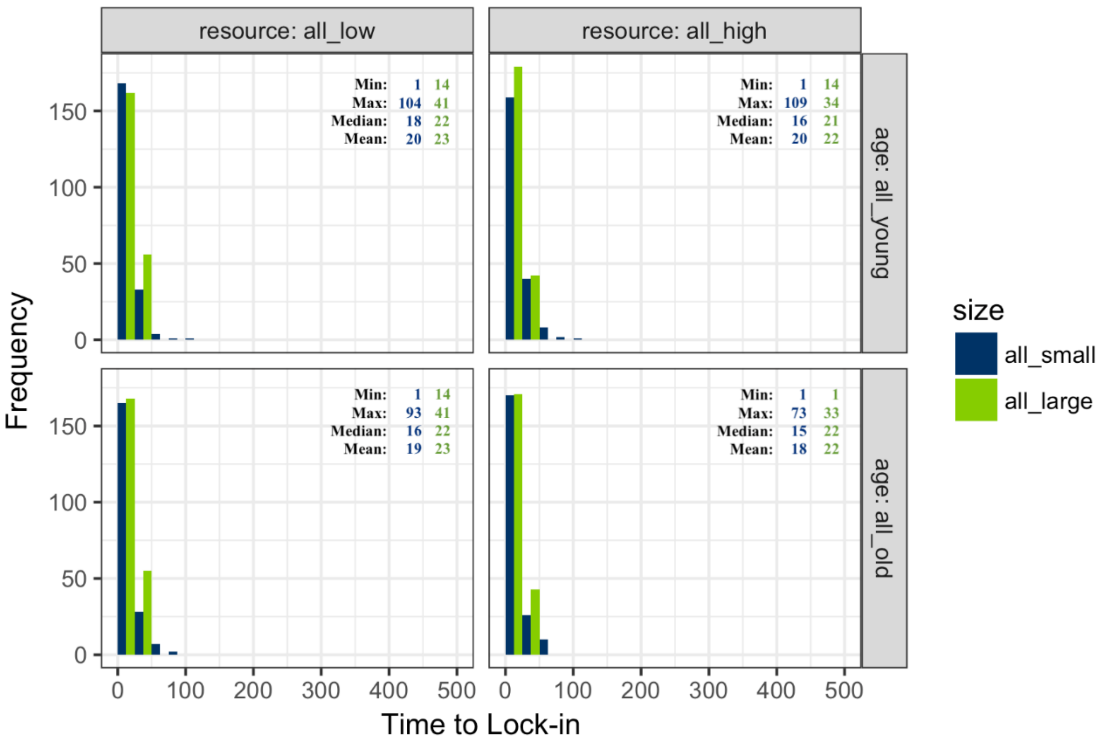

Figure 35: SimPioN, Exp. 2b; time-to-lock-in, bar plots

Like the satisficers, the times to lock-in for the despairing firms are faster compared to maximisers. Compared to the satisficers, however, the all_large firm-size scenarios now lock-in even faster with the main peak similarly high as all_small firms. In the combination with all_high firm-resources and all_young firm-age, large firm runs even noticeably overtake the all_small firms in speed. The combination of all_high resources with all_old age achieves the overall fastest median and mean time-to-lock-in for both all_small and all_large firm scenarios.

The reverse scenario with all_low firm-resource and all_young firm-age locks-in the slowest for both small and large firm runs. all_young scenarios also produce a slightly higher number of later outliers. These differences are minor compared to the bigger picture in which a small influence of firm-size due to slot availability leads to overall faster times-to-lock-in for large firms is the major outcome. The varying combined effects of the two reverse scenarios do show, however, that even in the absence of 'properly' assessing their alters, agents exhibit subtle differences in frequency and speed to lock-in.

Median times-to-lock-in for all_small firms are approx. 15 ticks higher, i.e. runs lock-in slower, than for satisficers and even slower compared to maximisers. all_large scenarios, in contrast, are approx. 10 ticks faster compared to satisficers, and between 20-30 ticks faster compared to maximisers. all_small scenarios, conversely, take slightly longer, indicating more switching between alliances that occurs as a side-effect of fewer available slots, yet also honouring any connection request, which makes over-stability slightly slower to occur. Despairing firm scenario agents do not need to assess which connections should be maintained after a project duration has expired and purely based on slot availability all_small firms will more likely switch relations rather than continue known ones, with all_large firms having more slots to fill, thus taking minimally (approx. 5 ticks) longer to do so. The further decreased time-to-lock-in points out the effect of manipulating the strategy of agent behaviour: the more agents assess their partner's suitability, the longer their lock-ins take.

4. 5. 3. 3. Alliance density and time-to-lock-in

Given the large share of locked-in runs and the even faster times-to-lock-in (except for all_small firms) it remains interesting to ascertain whether the densities in the despairing agents experiment attain similar levels, especially given the shorter duration of runs.

As the diagram shows, the overall densities achieved by the factor combinations are comparable to the satisficer results, with much higher densities attained than in the maximiser runs. A clear difference between satisficers and despairing firms, however, is that all_small scenarios attain much lower density levels at around d=0.20-d=0.25, which is almost comparable to the maximiser result, albeit there for large firms. While satisficing all_small firms attained comparative alliances densities as the all_large agents, when their strategy changes to despairing, only very few of their higher density outliers achieve higher densities than all_large firms. Also noticeable is the difference compared to satisficers is that the majority of all_small runs take much longer to lock-in at the densities attained. While all_small satisficers typically locked-in very early in the run at often just 1 tick, the despairing all_small firms attain their average density at about 15 ticks run duration. all_small continues to exhibit the largest number of late time-to-lock-in outliers (see also the highest maximums in Figure 35) that attain similar densities as earlier locking-in ones.

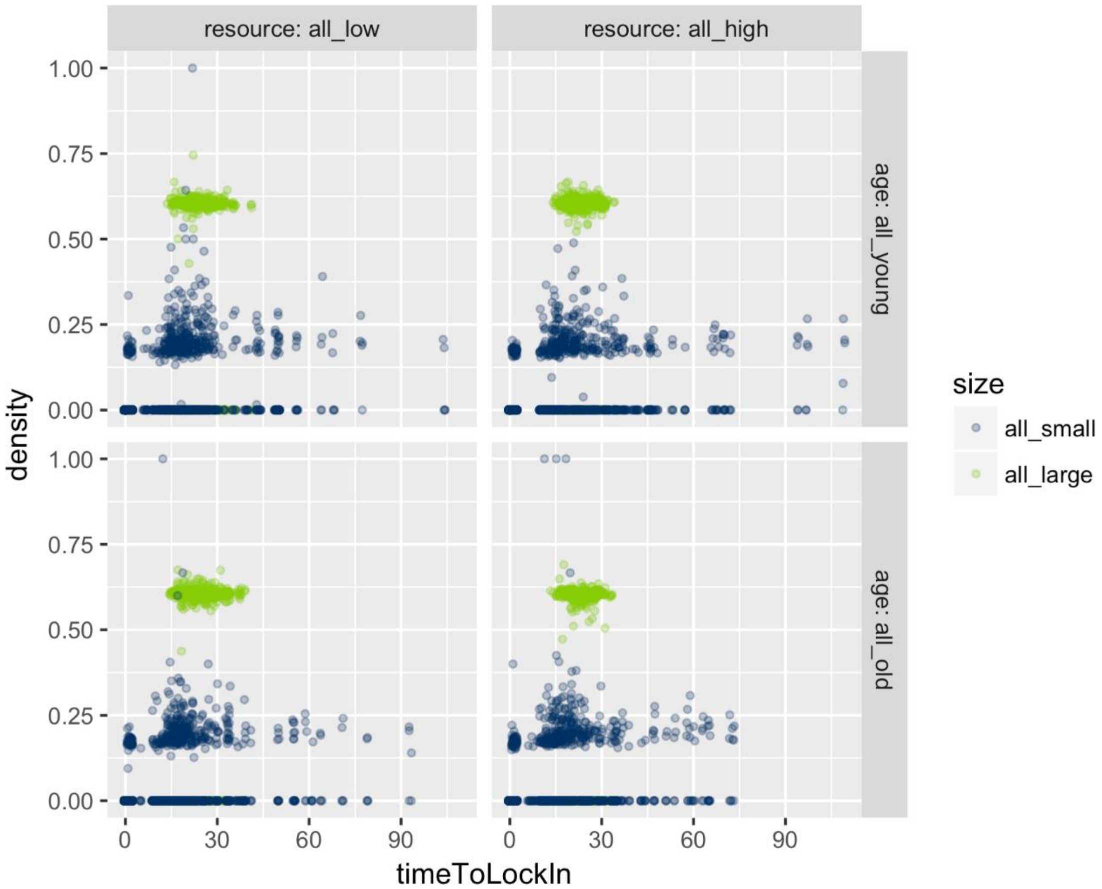

Figure 36: SimPioN, Exp. 2b; density over time, scatterplots

Firm-size thus again appears as the most influential characteristic for emerging alliance densities and `all_large` scenarios again produce the highest densities around the `d=0.6` level, yet with considerably lower spread than for satisficers. The data point clusters are much more concentrated and there seem to be overall fewer data points between the two extreme scenario settings than for satisficers, indicating a kind of concentration effect regarding the effect of firm-size for despairing firms with almost all runs locked-in before 30 ticks.

4. 5. 3. 4. Intra-alliance density

The lock-ins in the despairing scenarios take relatively short times to materialise and produce high densities of around d=0.6 in `all_large firm-size` runs. On the basis of the above findings, it should be expected that the resulting ranked alliances will produce high densities, especially for those with many members.

Non-locking runs of despairing agent scenarios again produce no results with more than two alliances, since only the two first ranks are filled. This means that scenarios either lock-in (as in the 85% of scenarios) or they lead to firms' demise and exit from the world. For those 15% of runs, the first two alliances are also very small, indicating few if any survivors beyond the founding agents. Consistent with the scenario design point, then, for despairing firms, connection is essential to survival even more than it already is for other strategy settings.

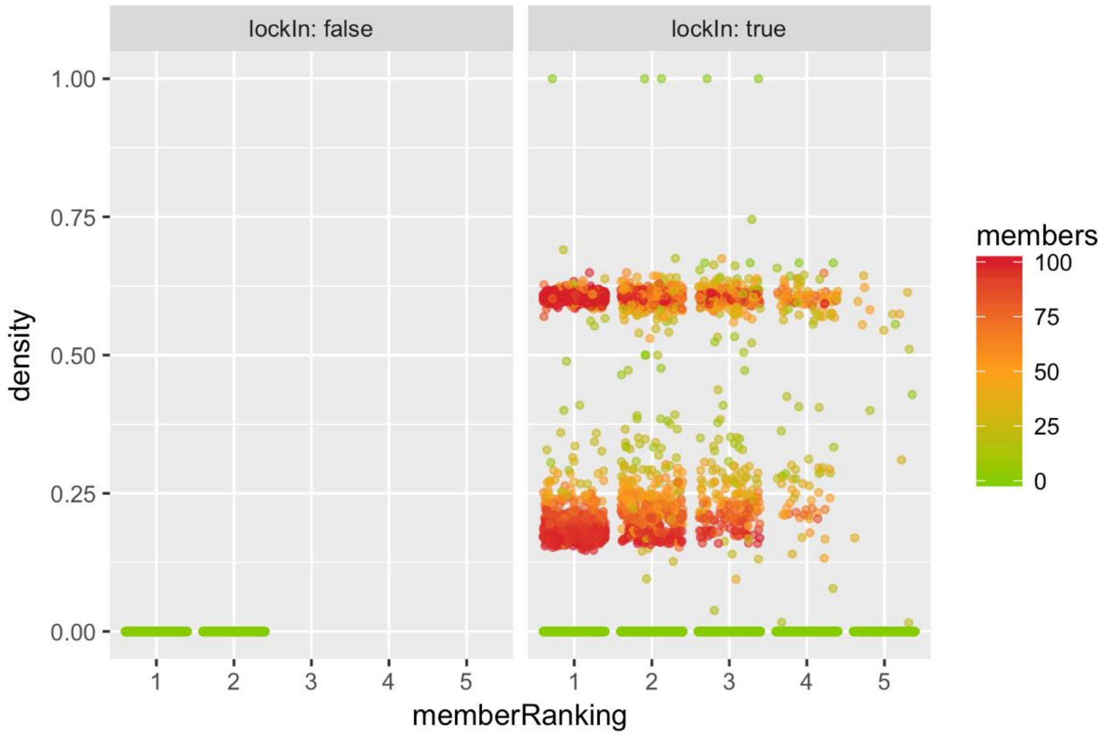

Figure 37: SimPioN, Exp. 2b; intra-alliance densities, ranked scatterplots

For the locked-in runs, the results for the ranked alliances echo the findings from maximisers and satisficers that many alliances in the first, second and third ranking spot are rather large. The colour gradients indicate that with every step down the dominance ranking of alliances, their alliances decrease in density, with the fourth rank containing only few large and dense alliances and the fifth rank containing only the smallest of alliances. The first three ranks being the largest is consistent with model design, according to which agents can become members of a maximum of three alliances through their connections.

Given that the first three often reach member levels of above 75% (darker orange-red dots), we can conclude that, in these cases, many firms appear to be members of all the first three alliances. That appears logical, given that agents will respond positively to any connection request until their slots are filled. The attained alliance densities in most of the runs are either `d=0.60` density or about `d=0.20` density, echoing the finding for the satisficers. However, the second and lower alliance ranks have more spread and outliers. As the diagrams in Figure 38 indicate, this result for the densities is again based on the effect of size on lock-in and densities.

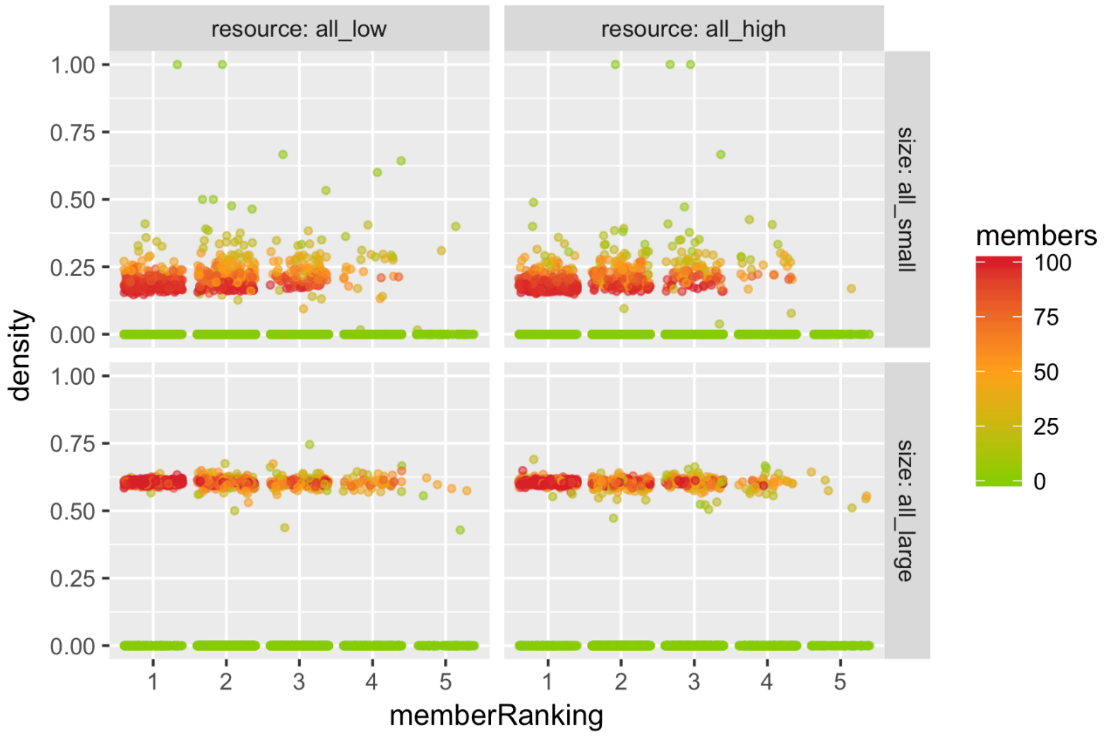

Figure 38: SimPioN, Exp. 2b; intra-alliance densities, ranked scatterplots, by factors

As for the satisficers, the effect of firm-size is that `all_small` scenarios attain a density of approx. `d=0.20`, whereas `all_large` scenarios attain around `d=0.6`, with few smaller alliances in the `all_small` scenarios reaching higher densities, even `d=1.0` in a few instances. Firm-resources appears to play no systematic role in the densities of the ranked alliances. Noticeably, the despairing small firms see more dark red data points in the second and third ranks than the `all_large` firms. This indicates that despairing firms appear to cluster more into one major alliance when firms are `all_large`, likely based on the effect of available slots.

4. 5. 3. 5. Discussion

Given that the only manipulation towards despairing firms occurred for `firm-strategy` in this experiment, it is not surprising that the findings for the other three varied factors in the experiment remain similar. Compared with the maximisers, not only do despairing firms lock-in more often and faster, but they also produce higher densities in their alliances (at least for `all_large` scenarios), and more alliances survive the entire duration of the runs.

Compared to satisficers, despairing firms are relatively similar in both their occurrence of lock-ins and the attained densities. Scenarios with `all_large` firm-size lock-in even faster, in some runs even overtaking `all_small` ones, indicating interaction effects. Scenarios with `all_small` firms, in contrast, were slower to lock-in than in the satisficer experiments. For `all_small` firms with fewer slots to fill, connecting at random means lock-ins take longer than following a satisficing strategy, probably because more indiscriminate switching occurs. Densities of the locked-in runs were comparable to satisficers, echoing the finding that with every step down the dominance ranks, alliances decrease in density. The separation of densities into clusters of approx. `d=0.6` for `all_large` scenarios and `d=0.2` for `all_small` ones was more pronounced than for both satisficers and maximisers, where both small and large firm-size scenarios attain similar densities, albeit in different frequencies and dominance levels. The still decreased time-to-lock-in for `all_large` scenarios compared with Experiments 1-2a indicates that the stricter agents assess their partner's attractiveness, the longer their lock-ins take, but for `all_small` scenarios, more decision logic leads to earlier lock-ins, due to a combined effect of firm-size and strategy.

The reasons for these finding lie, of course, in model and experimental design, but the outcome that for both small and large firms, the partnering decision logic plays an important role for their propensity to find themselves in overly stable network environments, may hold interesting implications for empirical work on firm lock-in. While the literature has identified several causes for connecting to other firms (e.g. needing resource access), future work on the effect of partner selection decision-making rationales appears warranted given the experimental results thus far.

4. 5. 4 Experiment 2c: comparing strategies and preferences

Having already started the process of contrasting the findings across the three different strategies employed by the agents for connecting to their alters, Experiment 2c now takes the comparison to a deeper level. In the above analyses, variations of the variable 'firm-preference' were not made, and it was instead held constant at `fully_individual` while the strategy was varied, along with the three individual characteristics at their respective extremes. In Experiment 2c, I vary both strategy *and* preferences in order to shed light on the relationship between the individual characteristics, firms' strategy, and the variable preferences for connecting. As above, the following table details the (many more) runs derived from the necessary design points for this experiment.

	Factors				Factor levels
Individual	Firm-size-distribution	all_small		all_large	2
	Firm-age-distribution	all_young		all_old	2
	Firm-resource-distribution	all_low		all_high	2
Network	Firm-strategy-distribution	Maximise	Satisfice	Despair	3
	Firm-benefits-preference	Individual	Network	Both	3
	Init-network-scenarios	None			1
Simulation settings	Design points:	72		Total runs:	18,000
	Repetitions:	250		Duration:	520 ticks

Table 31. SimPioN, Exp. 2c; initialisation settings

4. 5. 4. 1. Occurrence of lock-ins

The first overview details the lock-in occurrence frequency, this time, however, classified according to strategy and to preference and not distinguished by the individual characteristics. Such a comparison is more revealing in this case when compared to showing occurrences sorted according to the individual characteristics, because the already subtle differences in influences of the individual characteristics (apart from, perhaps, size) in the above experiments would probably disappear altogether in the aggregated form here. The presentation of findings commences with the strategies first and preferences second. Table 32 further below details the findings for all 72 design points.

Across all design points, runs lock-in 61% of the time and not 39% of the time (not shown in a separate diagram). When studying the outputs sorted by strategic decision-making behaviour, the satisficer scenarios account for almost half of all locked-in runs with 28% being almost as high as the other two strategies taken together. Clearly, the maximising strategy leads to the fewest lock-ins and the satisficing strategy holds the middle rank. Provided that the occurrence of lock-ins is here not clustered according to the influence of the individual characteristics, this output serves as an aggregated overview of the net-effects of the strategy across all scenarios discussed above. The findings are in line with expectations from model design since maximisers assessing more 'carefully' than satisficers. Maximising agents account for more not locked-in runs (19%) than for lock-ins. The despairing agents, meanwhile, are not assessing alters at all, they will respond positively to any of the randomly made requests for connection. The satisficers exhibit the exact reverse picture from the maximisers, and not surprisingly, lock-in slightly more (19%) than not.

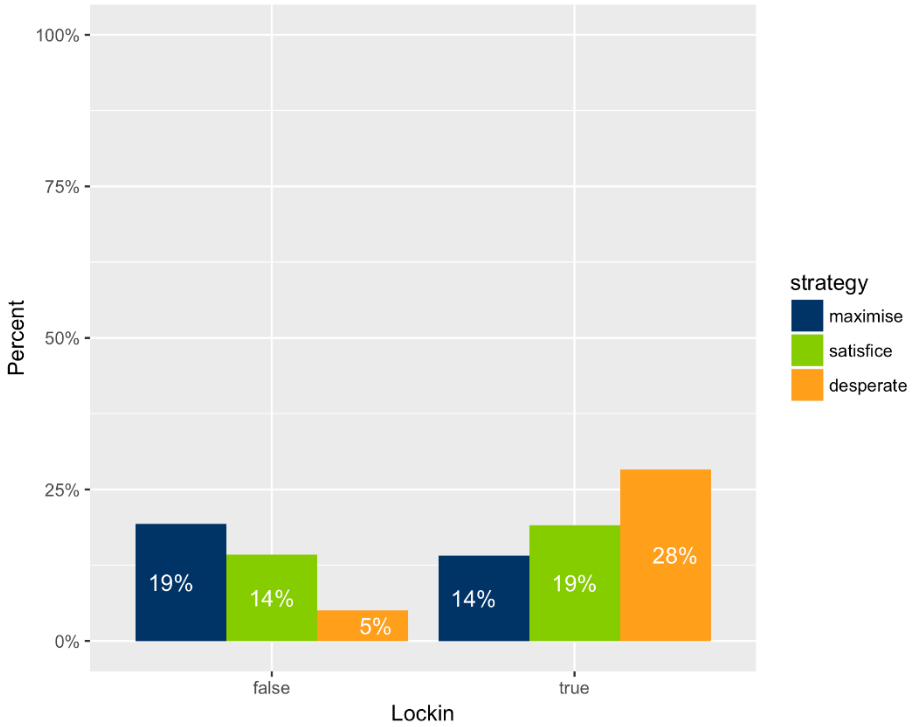

Figure 39: SimPioN, Exp. 2c; lock-in occurrence, frequency statistics: strategies

The variation of a new factor is introduced in Experiment 2c as giving agents different preferences, i.e. looking at individual characteristics, (their) network properties, or both equally, when firms assess their alters' attractiveness for connecting. The following diagram in Figure 40 reveals the isolated effects of varying these preferences across all design points.

The diagram exhibits the 'net-effects' of varying firms' preferences. The findings indicate that the network characteristics (that were disabled in the first three, individual-focused experiments above) are of an overall lesser importance (14%) for producing lock-ins than the individual characteristics. This result is in line with model design choices: preferences for network means that agents focus on their alters' network characteristics for assessing their attractiveness as connections partners. At least initially, they find fewer attractive alters since the network properties take more ticks to develop than the individual characteristics that are available from initialisation for assessing alters' attractiveness. Thus, runs lock-in 24% of the time if only individual characteristics are included in the assessment of alters' attractiveness, whereas the lock-ins of purely network-oriented scenarios lock-in only 14% of the time. When agents consider both sets of characteristics of an alter combined for assessing attractiveness, these scenarios lock-in as often as when only considering individual characteristics.

The more in-depth analysis for the factor combinations of the three strategies with the three preferences is displayed in the next diagram in Figure 41.

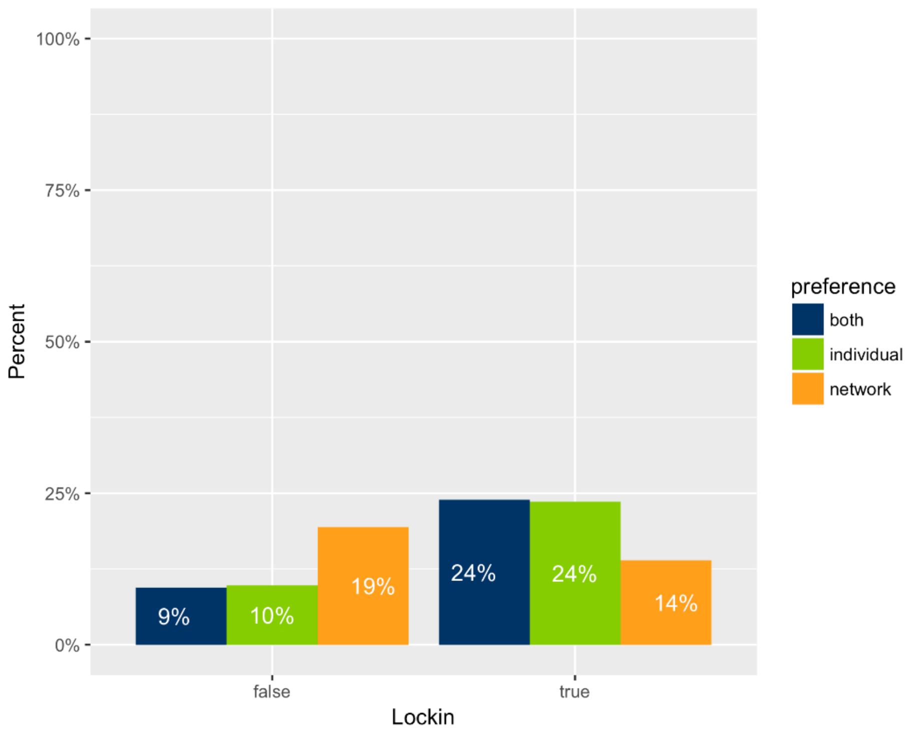

Figure 40: SimPioN, Exp. 2c; lock-in occurrence, frequency statistics: preferences

When detailing the lock-in-occurrence findings according to both strategy and preferences, we gain the following resulting diagram:

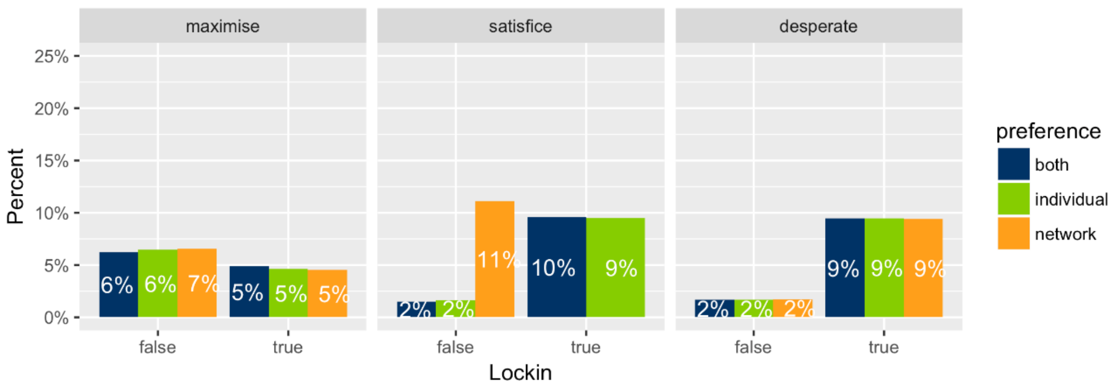

Figure 41: SimPioN, Exp. 2c; lock-in occurrence, frequency statistics: strategies & preferences

As the diagram shows, despairing firms lock-in (and not) at the same frequency for all preference variations with no differences revealed among the scenarios. This makes sense insofar as the despairing strategy essentially deactivates the decision-making logic of the agents and drives them to connect with any asking candidate. Hence, the different preferences account for the same percentage of locked-in runs and non-locked-in runs, respectively. Maximising agents, at the other behavioural extreme lock-in with same frequency across preference scenarios, too. Only the not-locked-in runs where maximising agents focused on network characteristics when assessing the attractiveness of alters are slightly more frequent at 7%. They are thus more frequent than the locking-in and not-locking-in runs of both other preference manipulations.

For the satisficers this finding is similar. Runs not-locking-in are evenly distributed except for the purely network-oriented scenarios that are rather conspicuous at 11% of all runs not-locking-in. Even more notable, scenarios with satisficing agents do not lock-in at all when focusing exclusively on the emergent network characteristics of their alters. This result is due to the effect of the network characteristics taking time to develop. Satisficing agents require their alters to meet at least `attractivenessScore≥0.5` for entering in to ties and without any characteristics to go by, these agents remain unconnected before their eventual demise. In that sense, the absolute point of reference is stricter than for the maximisers that will (seek to) connect to the best agents on their wish list of connection partners. For the `both` preference setting, satisficing agents are able to first use individual characteristics to forge connections, and then to become influenced by the emerging network characteristics afterwards. That way, `both`-oriented satisficer agents lock-in in the most, accounting for 10% of all runs vs. 10% for individual characteristics-oriented agents.

Table 32 details the lock-in frequency findings for each design point. For the sake of brevity, I have shortened the factor level designators as follows: all_small = small; all_large = large; all_high = high; all_low = low, all_young = young; all_old = old, firm-strategy = Strat.; maximise = max.; satisfice = sat., despairing = desp.; benefits-preference = Pref.; individual = ind.; network = net.; both = both. The table is sorted first by firm-strategy and second by firm-preference, and then by the individual characteristics columns.

The satisficers exhibit the strongest differences due to the influence of the preferences. Their lock-in results show that 0% of runs lock-in for the purely network-oriented preferences and this holds across all other factor variations – a consistent finding, given that e.g. `firm-age` cannot influence attractiveness assessments when agents do not consider individual characteristics. When satisficers do, however, between 85-90% of the purely `individual`-oriented runs lock-in, accounting for 9% of total runs. The highest number of lock-ins produced by these runs are, unsurprisingly, the runs with `firm-size all_large` (rows 61, 64), echoing the results of Experiment 2a. When satisficers weigh preferences equally as `both`, the result is 10% of total runs and thus slightly increased compared to purely `individual`-oriented agents, indicating a combined effect of the attractiveness of network and individual characteristics. In this case (rows 53, 54), the share of locking-in runs even exceeds 91% when `all_large`. These findings even exceed the despairing agents' runs with just under 90% of runs locking-in.

Experiment 2c: lock-in occurrence								
	Strategy: maximise, satisfice, despairing			Initial-network-scenario: None				
	Firm-Preference: Individual, network, both			(All design points, rounded percentages)				
	Firm-size	Firm-resource	Firm-age	Pref.	Strat.	% Lock-in	% non-lock-in	lock-ins % of all runs
1	small	low	young	both	desp.	83.6	16.4	1.2
2	small	low	old	both	desp.	81.2	18.8	1.1
3	small	high	young	both	desp.	78	22	1.1
4	small	high	old	both	desp.	84.8	15.2	1.2
5	large	low	young	both	desp.	88.8	11.2	1.2
6	large	low	old	both	desp.	86.4	13.6	1.2
7	large	high	young	both	desp.	89.2	10.8	1.2
8	large	high	old	both	desp.	87.6	12.4	1.2
9	small	low	young	ind.	desp.	82.8	17.2	1.1
10	small	low	old	ind.	desp.	80.8	19.2	1.1
11	small	high	young	ind.	desp.	84	16	1.2
12	small	high	old	ind.	desp.	82.4	17.6	1.1
13	large	low	young	ind.	desp.	87.2	12.8	1.2
14	large	low	old	ind.	desp.	89.2	10.8	1.2
15	large	high	young	ind.	desp.	88.4	11.6	1.2
16	large	high	old	ind.	desp.	85.6	14.4	1.2
17	small	low	young	net.	desp.	80.8	19.2	1.1
18	small	low	old	net.	desp.	83.6	16.4	1.2
19	small	high	young	net.	desp.	82.8	17.2	1.1
20	small	high	old	net.	desp.	80.8	19.2	1.1
21	large	low	young	net.	desp.	86.8	13.2	1.2
22	large	low	old	net.	desp.	88	12	1.2
23	large	high	young	net.	desp.	88	12	1.2
24	large	high	old	net.	desp.	85.6	14.4	1.2
25	small	low	young	both	max.	36.8	63.2	0.5
26	small	low	old	both	max.	32	68	0.4
27	small	high	young	both	max.	35.2	64.8	0.5
28	small	high	old	both	max.	34	66	0.5
29	large	low	young	both	max.	52	48	0.7
30	large	low	old	both	max.	51.6	48.4	0.7
31	large	high	young	both	max.	52.4	47.6	0.7
32	large	high	old	both	max.	57.2	42.8	0.8
33	small	low	young	ind.	max.	38	62	0.5
34	small	low	old	ind.	max.	32	68	0.4

35	small	high	young	ind.	max.	36.4	63.6	0.5
36	small	high	old	ind.	max.	35.2	64.8	0.5
37	large	low	young	ind.	max.	51.6	48.4	0.7
38	large	low	old	ind.	max.	44.8	55.2	0.6
39	large	high	young	ind.	max.	46.8	53.2	0.6
40	large	high	old	ind.	max.	48.8	51.2	0.7
41	small	low	young	net.	max.	32	68	0.4
42	small	low	old	net.	max.	42	58	0.6
43	small	high	young	net.	max.	37.6	62.4	0.5
44	small	high	old	net.	max.	39.2	60.8	0.5
45	large	low	young	net.	max.	45.6	54.4	0.6
46	large	low	old	net.	max.	42	58	0.6
47	large	high	young	net.	max.	47.6	52.4	0.7
48	large	high	old	net.	max.	40.8	59.2	0.6
49	small	low	young	both	sat.	86.4	13.6	1.2
50	small	low	old	both	sat.	81.2	18.8	1.1
51	small	high	young	both	sat.	81.2	18.8	1.1
52	small	high	old	both	sat.	83.2	16.8	1.2
53	large	low	young	both	sat.	91.6	8.4	1.3
54	large	low	old	both	sat.	92	8	1.3
55	large	high	young	both	sat.	86.8	13.2	1.2
56	large	high	old	both	sat.	89.2	10.8	1.2
57	small	low	young	ind.	sat.	86	14	1.2
58	small	low	old	ind.	sat.	83.2	16.8	1.2
59	small	high	young	ind.	sat.	82.4	17.6	1.1
60	small	high	old	ind.	sat.	83.2	16.8	1.2
61	large	low	young	ind.	sat.	89.2	10.8	1.2
62	large	low	old	ind.	sat.	84.8	15.2	1.2
63	large	high	young	ind.	sat.	86.4	13.6	1.2
64	large	high	old	ind.	sat.	88	12	1.2
65	small	low	young	net.	sat.	0	100	0
66	small	low	old	net.	sat.	0	100	0
67	small	high	young	net.	sat.	0	100	0
68	small	high	old	net.	sat.	0	100	0
69	large	low	young	net.	sat.	0	100	0
70	large	low	old	net.	sat.	0	100	0
71	large	high	young	net.	sat.	0	100	0
72	large	high	old	net.	sat.	0	100	0
Σ	All runs					61	39	100

Table 32: SimPioN, Exp. 2c; lock-in occurrence, design point frequencies

The maximisers consistently lock-in the least (except for the not-locking-in `network`-oriented satisficers), and the outputs show that those assessing alters purely on `network` characteristics lock-in the least (maximum 47.6%, row 47; minimum 32%, row 41), and those assessing `both` lock-in the most (maximum 57.2%, row 32; minimum 32%, row 26). Interestingly, the scenarios differ with regard to the factor combinations for the individual characteristics, but the maximum numbers are in `all_large` scenarios and the minimums in `all_small` scenarios. Overall, `network`-oriented agents score most often in the no-lock-in category and lock-in the most when considering `both` types of characteristics of their alters. Like in the above experiments, maximisers lock-in less often than despairing firms, but less often than satisficing firms, except when having `network`-preferences when they lock-in more, or rather, at all and even exceed 50% lock-ins in scenarios with `all_large` firms.

Overall, the satisficer and despairing scenario runs hold more lock-ins, which is to be expected from the above findings and from the setup of the decision-making logic. From these, it is clear that the despairing agent runs exhibit a low level of influence of the three preferences, since their decision-making is reduced to a randomly filling their 'wish list' and thus connecting largely to unassessed partners. They do, however, lock-in less often than the satisficing agents, as opposed to Experiments 2a and 2b. For the satisficers, a systematic influence is visible where focusing on the `individual` characteristics leads to lock-ins, while focusing only on the `network` characteristics does not. Satisficers assessing `both` characteristics, however, leads to the highest number of lock-ins of any other experimental setup. The influence of the `network` characteristics of agents also plays a pronounced role for the maximisers when they focus on these `network` characteristics of their alters, but especially when they also consider `both`.

The findings are thus clear indications for strategy and preferences interacting, with `network`-oriented preferences of agents becoming much more relevant when agents use the strategy of `maximising`. Especially in the case of runs with preferences for `both` characteristics, lock-in shares increase considerably. This finding also points towards the lock-ins in the `both` scenarios taking some time to develop with agents' decision-making *first* more influenced by `individual` characteristics and *later* increasingly by `network` characteristics, since network characteristics take some time to develop, while individual characteristics are set in initialisation.

One of the crucial differences in the results for experiments 1-2b was that the times-to-lock-in were substantially longer for the maximisers. The vast majority of the despairing agents and satisficing agents locked-in before even 5% (despairing) or 10% (satisficing) of the duration of the runs has expired, especially when firms were `all_small`. Agents' network properties develop over time in consequence of their networking activities compared to the individual characteristics that are attractive (or not) immediately at the initialisation of the run. For the network characteristics to become attractive (enough) to lead agents to lock-in their networks based on alters' attractiveness in these characteristics, the runs need to run longer before stabilising, i.e. giving agents' network characteristics the time to develop so that a substantial impact on the likeliness of runs locking-in could unfold. The next section, discussing the times-to-lock-in, will elucidate this aspect

4. 5. 4. 2. Time-to-lock-in

Results on times-to-lock-in are shown in Figure 42 grouped according to strategy and preferences but aggregated across all of the runs where individual characteristics were varied. While the diagram is an aggregation of the findings for the three strategies from above, it serves to contrast the different combinations of strategies and preferences. It does, however, not simply summarise the data (i.e. reiterating the values from the runs in Experiments 1-2b) but shows entirely newly-calculated bar plots with median values and outliers based on the new (aggregated) factors of Experiment 2c, revealing the aggregated interaction effects of preferences and strategies.

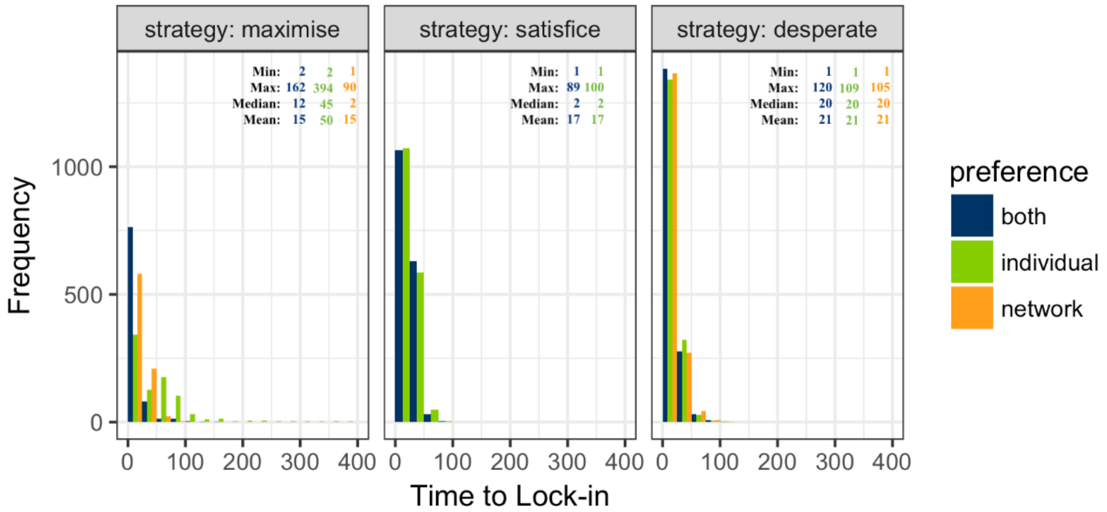

Figure 42: SimPioN, Exp. 2c; time-to-lock-in, box plots: strategy & preferences

At first glance, the despairing agents unsurprisingly lock-in the fastest, repeating the findings from Experiment 2b. However, the maximums are higher for the preference for `both` and thus can take longer than when assessing either purely `individual` or `network` characteristics. This underlines the suspected interaction effect with regard to time, but still the despairing runs that lock-in do so at a median of 20 ticks (mean 21) no matter what preferences they follow. The findings thus highlight the implementation of the despairing strategy mode, where agents essentially do not consider options and preferences to make decisions but rather do so at random. However, they appear to be influenced regarding maximum run duration until lock-in when `both` characteristics are assessed, albeit not considerably.

Given that for times-to-lock-in only locked-in runs were selected, there are no network-oriented satisficers lock represented, since these design points did not lock-in as indicated by the absence of orange bars in the centre segment of the diagram. Half of `individual` and `both`-oriented satisficer runs lock-in before 2 ticks (median 2), of course identified post-hoc, and the lock-in maximum is faster when agents assess both network and individual characteristics rather than only individual ones. The mean times-to-lock-in are the same, however, indicating that there are only few outliers that push the maximum value for `individual`-oriented runs.

Maximising agent runs lock-in after a median of 2 ticks when these agents consider the network characteristics of their alters, after 45 ticks when considering only individual characteristics and after a median of 12 ticks, when assessing `both`.[34] Notably, the maximising agents also produce the largest amount and longest outliers in time-to-lock-in across all preferences, with `individual` running the longest before locking-in, `both` medium-long, and `network` the shortest. In particular, runs in which `network` characteristics are considered by the agents in their assessment of alters' attractiveness, are faster to lock-in.

The interactions of strategies and preferences are quite revealing for time-to-lock-in: `network`-oriented preferences lead to faster lock-ins for maximisers and `individual`-oriented runs last the longest before locking-in for all but despairing scenarios. Agents assessing `both`, are still faster than `individual`-oriented ones to lock-in, and have less outliers (except for despairing agents), indicating a speed-increasing effect of the network characteristics developing attraction forces over time.

The findings appear consistent with the occurrence data above and the time-to-lock-in findings for previous experiments. While `network`-oriented agent runs overall lock-in rarely in general (except for maximisers, and the indiscriminate despairing agents), when they do so, they lock-in quickly. This can be attributed to the effect of the duration of run before lock-in as discussed above with the network characteristics not getting enough time to develop an attraction force, and also given that the experiments so far only varied the individual characteristics systematically and only let the network characteristics emerge from the connections based on the attractiveness of the individual characteristics. This will be changed in Experiment 3 where network structures will be initialised to test for the influence of historical structures on propensity, time-to-lock-in and attained densities.

4. 5. 4. 3. Alliance density and time-to-lock-in

The next step, just as above, is to compare the densities produced by the networking activities of agents for the runs that do lock-in. The diagram in Figure 43 displays the densities of alliances at the end runs on the ordinate and time-to-lock-in on the abscissa. The data is grouped by combinations

[34] Note that results for the firm-preference "both" stem from individually-performed actual experiments for all strategies and not from artificially produced "averaged median" calculation only drawn from previous results on "network" and "individual" for illustration purposes. This much improves the quality and reliability of the data.

of different settings for strategy and preferences, as above. Since purely `network`-oriented satisficer runs are not locking-in at all, the respective data field in the diagram is not populated. All other combinations of preferences and strategies produced experimental data for alliance densities. As before, colour of the data points indicates alliance size.

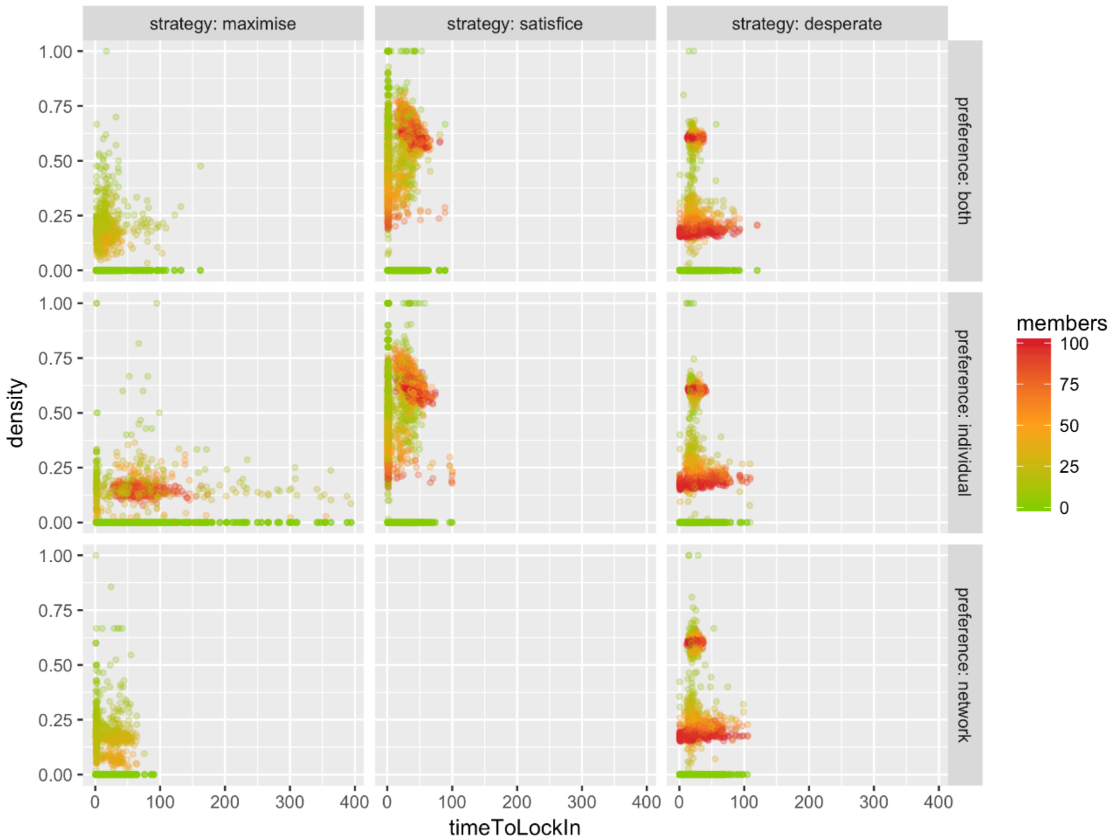

Figure 43: SimPioN, Exp. 2c; density over time, scatterplots: strategies & preferences

The first notable finding concerns the despairing agents' scenarios. They reveal a similar pattern of densities and time-to-lock-in across all preference settings. They produce alliance groups with densities clustering around the `d=0.6` and the `d=0.2` levels. These findings echo those from above where they have largely been attributed to the influence of `firm-size` on the `individual`-focused despairing agents. It appears that this finding also holds for the other preferences. Sizeable agent scenarios lead agents to link extensively when being indiscriminate with their choices and thus produce relatively high densities in their runs. Also, these two density levels account for predominantly large alliance groups with members in the colour shade of above 75 members per alliance. Notably, more alliances and bigger alliances are to be found in the lower density cluster, while the higher density cluster contains few large alliances with several data points connecting the two clusters.

For the satisficing agents the findings show a stark contrast between the preference variations. The runs incorporating the attractiveness of firms' individual characteristics, and of `both`, show high levels of density with some large alliances clustering, again, around the `d=0.6` and `d=0.2` mark and some smaller alliances occasionally even reaching the fully-connected `d=1.0` mark. Differences between the `individual`- and `both`-oriented scenarios are not markedly large. A minor difference between the plots are the `both`-oriented scenarios where more orange dots between the two main clusters point towards an increased number of medium-sized, relatively dense (around `d=0.45`) alliances. This indicates a small added effect with higher attained densities of agents orienting their attractiveness assessment of alters also towards their network characteristics. Compared to the despairing strategy runs, however, the differences are stronger in that many more of the larger alliances reach the higher density level. In that sense, the data point plot appears to almost be an inverse-image. Again, the clustering around the two data points is contributable to the effect of `firm-size` with `all_large` scenarios allowing for higher densities based on more available slots. Furthermore, as pointed out above, more alliances lock-in early on for the satisficers than for the despairing agents and their attained densities vary across the entire density and size spectrums while the few fast despairing ones have only large alliances with density at `d=0.2`.

The maximisers reveal lower densities overall. While some maximiser alliances do reach `d=0.5` with some outliers beyond that, the majority of alliances exhibits lower densities, clustering mainly around `d=0.2`. Unlike in the despairing and satisficing runs, `all_large firm-size` scenarios do not lead to the higher densities of around `d=0.6`. The plots for the three preferences are also remarkably different with regard to alliances sizes. For the purely `network`-oriented runs, only few alliances attract many members, and the lack of red dots indicates that no alliance manages to attract all agents. Given that agents can be member of up to three alliances, this is somewhat remarkable and points towards the attractiveness levels taking longer to develop when based purely on network characteristics.

For maximisers focusing only on individual characteristics, the plot looks similar to Experiment 1. The runs have considerably more outliers for time-to-lock-in than any other scenario, reflecting the more intense deliberation of agents before committing to alliances in the long-term. Furthermore, these runs exhibit many more alliances with high member counts, with many dark orange to red dots indicating memberships reaching close to 100%. When focusing on `both` characteristics, runs are faster to lock-in again and attain higher densities than the separate assessments with many alliances reaching densities between `d=0.25` and `d=0.5`. These alliances are, however, also smaller and hardly show any orange data points. The maximisers are the overall most interesting settings since the findings indicate the clearest output differences between the preferences. It will be interesting to study below how these density and membership differences translate into alliance ranks.

4. 5. 4. 4. *Intra-alliance density*

Having studied the densities of alliances in individual runs that have locked-in, there are certain questions with regard to the patterns of surviving alliances raised not least by the distinct findings on the maximiser scenarios and the differences to both despairing and satisficing ones. Runs with agents satisficing purely based on `network` characteristics did not lock-in and the respective data field is again not populated, although all other fields are filled with data points.

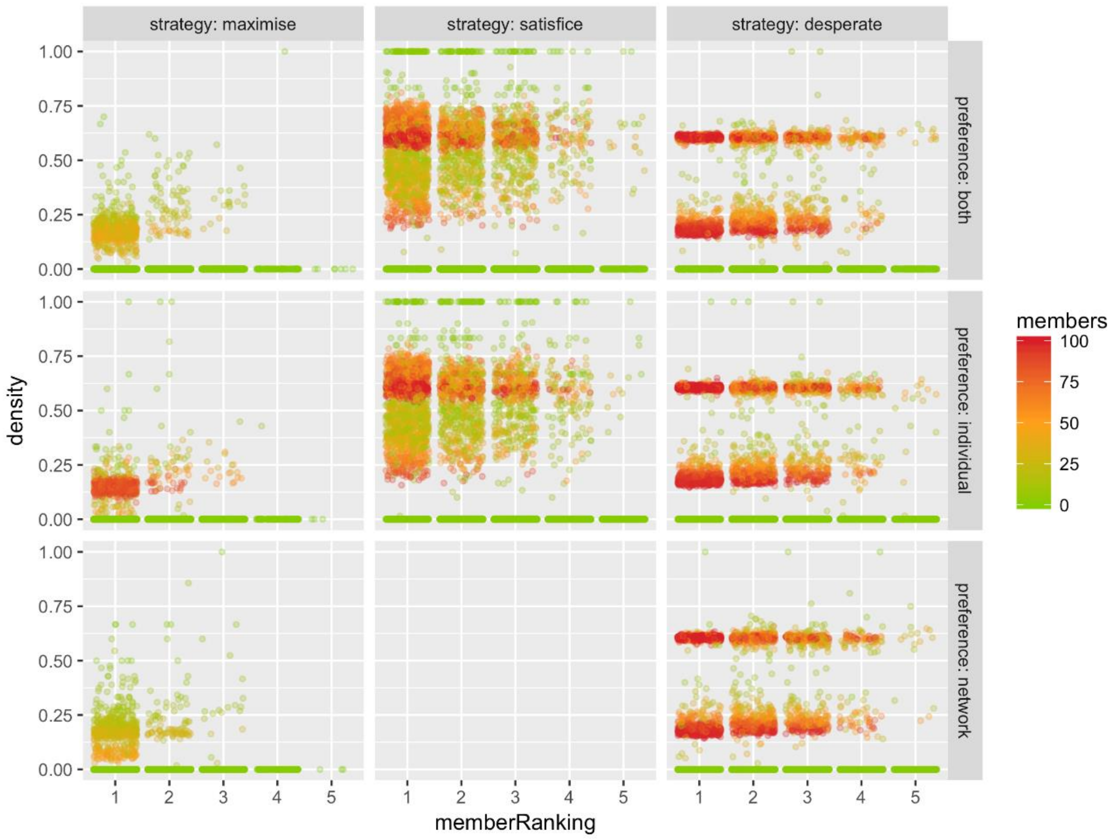

Figure 44: SimPioN, Exp. 2c; intra-alliance densities, ranked scatterplots: strategies & preferences

The intra-alliance densities are similarly revealing as the densities over time. The despairing firm runs lock-in most of the time and are equally indiscriminate with regard to the preference employed in the run. All four surviving alliances attain densities clustering around `d=0.6` and `d=0.2` levels (driven by firm -size as the distinguishing variable). The first alliance rank shows many alliances with 100% membership, while second through fourth ranks also cluster around these density values, but with more spread and smaller alliances after rank three. The fifth largest alliance rank hold fewer alliances and no large alliances with only few runs actually resulting in a fifth alliance producing any density.

For the satisficer agent runs, the situation is a similarly stark contrast as for the above diagram. When agents have a preference for the `individual` or `both` characteristics of their alters, lock-ins within the largest alliances spread between `d=0.2` and `d=0.8`, indicating a large share of realised relationships within the alliances, with some runs even reaching `d=1.0` fully connected densities.

High density runs have alliances sizes reaching red levels of high double-digit memberships counts and less members at lower densities. The satisficers additionally produce many more small alliance data points between the two main density clusters, meaning that many scenarios reach relatively high densities for both small and large alliances. This outcome applies also to alliance ranks two and three, but alliance rank four is filled with fewer data points with a similar distribution. Only alliance rank five, like for the despairing firms, is occupied with only few alliances. The relatively high survival rates of the present satisficer scenarios, echo findings of Experiment 2a, again pointing towards the lock-in vs. survival trade-off. Moreover, the satisficer scenarios outcomes regarding density and alliance rank exhibit a rather low (if any) combined effect of `individual` and network `characteristics` being assessed for attractiveness. This is partly due to the duration-of-run effect for network characteristics to develop as outlined above, but also partly to the fact that once agents reach the `0.5` attractiveness for alters to find them interesting enough to connect, these agents are past the threshold and while their attractiveness may increase beyond 0.5, satisficers will not actually consider this, since these agents are already 'good enough' to connect to.

In this sense, the threshold assessment appears to be a stricter decision-making behaviour than the strategy employed by the maximising agents who use a relative score assessment, but do not have a minimum level of attractiveness for connecting to alters. The maximising strategy, in contrast, makes agents more likely to connect to alters that achieve attractiveness scores below `0.5` since the maximising strategy employs no minimum threshold but ranks alters strictly according to their scores. These agents are thus more flexible and can detect developing nuances between agents better and connect to those with subtle but slowly-developing `network` characteristics. This also shows in the results, where the maximisers develop similarly dense alliances when focusing on `network` characteristics only as when they focus on individual characteristics, or both with the majority of data points clustering around `d=0.2`. Also, the distribution of alliances in their membership size ranking appears to be similar. Notable differences are that maximisers only focusing on `individual` characteristics appear to create larger alliances in the first and second ranks than when they focus on only `network` characteristics or `both`. The fifth alliance rank is never filled with alliances that report densities, i.e. only founding members survive until end-of-run, and the fourth alliance rank is similar safe for some outliers. As a general tendency, the maximiser runs focusing on `network` or `both` attain slightly more outliers with higher densities than those assessing only alters' `individual` characteristics. This indicates a density-increasing effect of the emerging network attributes. Interestingly, maximisers with pure `network`-preferences produce outliers with higher density levels for the secondary alliance-size ranks than for the first, largely attributable to smaller alliances being in the second rank.

4. 5. 4. 5. Discussion

Occurrence frequencies demonstrate that the most lock-ins occur for despairing and then for satisficing agents. Maximisers lock-in comparatively less often, and almost evenly across the preference scenarios, but slightly more often when assessing `both` characteristics of alters. `Both` is also the preference variation that locks-in the most overall, but not much before `individual` preferences. Purely `network`-oriented runs, overall, lock-in the least, based on the lack of time to develop these characteristics meaningfully, especially in the 'stricter' satisficer decision-making scenarios.

The despairing agents lock-in entirely at random and thus with the same frequency and time-to-lock-in irrespective of their behavioural setting regarding preferences with only slightly more outliers for the `both` scenarios. Satisficer runs lock-in faster than despairing agents, but also create considerably higher densities in their alliances than both maximisers and despairing firms. For the design points with preferences purely for alters' `network` characteristics, no lock-ins occur for satisficers, since these characteristics cannot develop (fast enough) for any agent to survive until an alter has reached the `min-attraction = 0.5` threshold, given that no individual characteristic can compensate for this lack of attractiveness – a duration-of-run effect.

Despairing and satisficing scenarios result in the highest memberships numbers in their alliances in the first and second ranks, maximisers only match the membership numbers when focusing purely on `individual` characteristics, but at much lower densities. Satisficers achieve the overall highest average densities, but only when focusing on `individual` characteristics, or `both`, since they do not lock-in when focusing only on the `network` characteristics due to the duration-of-run effect, as described above. The maximising strategy – according to which agents rank their alters relatively rather than absolutely against a threshold – do produce runs with lock-ins based purely on `network` criteria. If these do lock-in, they do so rather quickly and at density levels comparable or slightly lower to those runs with `individual` preferences, albeit with fewer large membership alliances and more density outliers. Maximiser runs produce alliances in the first three ranks (and a negligible number of outliers in rank four), unlike despairing and satisficing runs with data points in all five ranks.

The speed of maximisers locking-in for purely `network`-based decision-making is faster than any of the other factor combination. This finding points towards a positive feedback loop in the network characteristics, as intended in model design: while initially connections appear essentially at random (all agents start with attractiveness = 0), central actors are then recognised as desirable partners and experience from previous connections and membership of the same alliance contribute to a system-wide visible increasing level of attractiveness through the new connections gained, which then indirectly leading to a lock-in very early on in the runs.

The results for the `network`-oriented satisficers are an artefact of the decision-making model implementation. Nonetheless, they reveal a certain pitfall for agents: if firms are satisficing, i.e. deciding more readily on connections than maximisers, but simultaneously have rigid criteria for identifying suitable partners without factoring-in the time for allowing these criteria to develop, they may pay a worse price for their behaviour than lock-in, namely that of firm death. Combined with the findings from the maximisers' occurrence frequencies above, network runs lock-in the least often overall, but if they do, they lock-in the fastest. Maximiser runs with agents assessing `both` behave similarly as those assessing only `network` characteristics, but the experiment produces more medium-density outliers, also in terms of time-to-lock-in. This slight increase in time-to-lock-in indicates a slowing-down based upon the effect of more characteristics playing a role for decision-making and them taking more ticks to develop.

The findings and intriguing results for the influence of the `network` characteristics on lock-in occurrence, time-to-lock-in and density, and warrant further attention. As revealed by the results from this experiment comparing the behavioural assumptions, it is of high importance to allow the network characteristics of agents to develop over time in order for them to (be able to) play a role in the decision-making of `network`-oriented agents. Historically-existing relations that are quite likely to exist in the real-world would obviously contribute to such attractiveness scores.

The subsequent Experiment 3 is thus a more in-depth study of such scenarios with existing historical relations and explores the existence of network history, i.e. relations between agents that already exist at the initialisation of the experimental run, thus allowing for these emergent properties to potentially exert their influence on the agents. In this experiment, I decided to focus only on the maximising strategy agents for two reasons: the despairing agents are too indiscriminate (by design) to uncover systematic influences of the developing `network` characteristics. Further, the maximising agent is designed to be the most 'rational', i.e. they are less biased in their decision-making and their strategy allows for more nuanced results than the indiscriminate pairing of despairing firms or the rigidly threshold-driven satisficers.

4. 5. 5 Experiment 3: maximising on network characteristics

Experimenting with agents' individual characteristics, above, involved the variation of the three variables `firm-size`, `firm-resource` and `firm-age`, in order to study their influence on the attractiveness of firms' alters and the consecutive influence on the occurrence and conditions of system lock-ins created by the interlinking agents. The recent step involved a comparison of the three strategies (`despairing`, `satisficing` and `maximising`) and a comparison of the workings of the three preferences (`individual`-oriented, `network`-oriented, and `both`).

One central finding of this comparison was that the impact of agents' `network` characteristics was overall rather limited. In the runs that had agents focus only on these `network` characteristics, the agents behaved in patterns that indicated they found the network characteristics of low relevance for alters' attractiveness compared to individual characteristics, and they were thus also of limited systematic consequence for lock-ins and measures such as density. Agents locked-in mainly based upon random influences (`despairing`, `satisficing` strategies), `individual` characteristics, or considered `network` characteristics only after they had the opportunity to develop over time, e.g. when their strategy reduced their readiness to commit to relationships and thus kept them evaluating their alters for longer durations of ticks before locking-in – as was the case for the maximisers considering `both`.

Apart from firms' `individual` characteristics driving their attractiveness, one important argument made in both the literature and the explanatory framework developed above is that agents find alters worthy of linking with based on their assessment of those alters' `network` position and characteristics. In order for these characteristics to be able to influence the lock-in occurrence, time-to-lock-in and densities, an experimental condition is required that enables agent decision-making to adequately appreciate alters' `network` characteristics, i.e. for these to develop over time to become appreciable by assessing agents beyond the `individual` characteristics.

The setup of Experiment 3 explicitly creates situations where agents do not begin the development of their `network` characteristics with the commencement of the experimental run, but rather already before the runs commence, i.e. in the runs' 'past.' Creating such a history of relationships appears adequate both because it has been argued in network literature that network history plays an important role in future developments (e.g. Walker, Kogut & Shan 1997), and also because in path dependence literature, the element of "historicity" (e.g. Sydow, Schreyögg & Koch 2009: 704) plays a central role in the process dynamics underpinning the theory. Experiment 3 builds three different alliance constellation scenarios where the agents are already embedded into a network structure at the initialisation of the run. Agents can then draw on the resulting `network` characteristics to assess alters' attractiveness from the very beginning of the experimental run. The findings on lock-in occurrence and conditions from these runs can then provide more insights into what role these characteristics play as far as becoming locked-in.

For these three embedded experiments, I selected agents' strategy to follow the maximising rationale. This decision is based on the maximiser being the most-used decision model in OMS and having been the strategy that produced the most purposeful results when interacting with agents' preferences set to fully `network`-oriented. The main goal of the settings in Experiment 3 is to provide agents in the scenarios with a history in their network relations and structure so that its influence on network lock-ins can be examined. One result of the above experiments was that many runs locked-in with rather large alliance groups, leaving many agents as members of a single, dominant alliance towards the end of the run. In order to study variations of this tendency, the agents receive not only random connections, but these are grouped into variations of alliance constellations around the initialised alliance 'founders' (similar to the above, `individual` -oriented scenarios).

I set up the network experiments with historical network relationships at the point of initialisation by randomly creating links between several agents with `link-age = 1`. The connections themselves are selected fully at random, except for those of the 'alliance founders' which are – for simplification reasons – the largest agents in the environment. Each of the involved agents receives only one connection as historical relations to not inscribe their embeddedness *ex ante*. For testing several variations of alliance sizes and effects on the whole network system, I create three different alliance constellation scenarios which I subsequently compare regarding their effects on system level lock-in:

- The first scenario `oneAlliance` is derived from the findings on alliance dominance and density from Experiments 1-2c above where one consistent finding was one large alliance at the end of a locked-in run. The scenario seeks to study the influence of already starting the run with one dominant alliance and initialises one group of 20 agents (i.e. 20% of the agents in the environment) which are connected to each other by a single link for each agent. Thus, they connect to their initial alliance founder (the largest firm-size agent in the environment) at varying network path lengths (and implemented restrictions on path-length perception). All other 80 agents in the environment remain unconnected at initialisation.

- The second scenario `twoAlliancesEqual` draws on the situation in the case study where two, in many ways similar, alliances compete for the dominance in an industry. The scenario seeks to study the effect of such a situation on system-level lock-in and creates two equally-sized initial alliance groups with 10 members each. Members are selected at random, except for the founding agents, which are the two agents with the highest firm-size in the environment. All other agents remain unconnected at initialisation. Each alliance members only holds one network relation to one other agent, all of which are thus connected to the alliance founder at varying network path lengths (and implemented restrictions on path-length perception). This scenario allows for tracing the effect of alliance competition of two initially equally large alliance groups.

- The third scenario `twoAlliancesUnequal` is a variation on the second but introduces heterogeneity into the alliance group size by making them unequal and thus allocating the first alliance 15 initial members, and the second alliance only 5 initial members. All other aspects of the initialisation are kept the same as in `twoAlliancesEqual`. This variation changes the values attainable for agents' network characteristics, e.g. centrality assumes lower values for agents in a smaller alliance than for those in a bigger one, and thus affects the perceived attractiveness of agents.

Table 33 offers an overview of the 72 design points derived from the three network scenarios and other factor variations.

	Factors				Factor levels
Individual	Firm-size-distribution	all_small	all_large		2
	Firm-age-distribution	all_young	all_old		2
	Firm-resource-distribution	all_low	all_high		2
Network	Firm-strategy-distribution	Maximise			1
	Firm-benefits-preference	Individual	Network	Both	3
	Init-network-scenarios	oneAlliance	twoEqual	twoUnequal	3
Simulation settings	Design points:	72	Total runs:		18,000
	Repetitions:	250	Duration:		520 ticks

Table 33: SimPioN, Exp. 3; initialisation settings

4. 5. 5. 1. Occurrence of lock-ins

In Experiment 3, I study the lock-in behaviour of maximiser agents in three different initial network scenarios. The analysis logic of these three scenarios slightly differs from the above experiments, since they do not compare as factor variations that are part of the overall same setup, but rather they are three different experiments that are contrasted for highlighting key differences and similarities. Since they are not the same experiment, using a table rather than the above lock-in percentage diagrams appears more adequate. Table 34 details the lock-in frequency findings for each design point. The column "lock-ins % of all runs" has been removed for the same reason. For brevity reasons, I have shortened the factor level designators as follows: all_small = small; all_large = large; all_high = high; all_low = low, all_young = young; all_old = old, benefits-preference = Pref.; individual = ind.; network = net.; both = both; Init-Network-scenarios = Net.-Scen.; oneAlliance = one; twoEqual = twoE; twoUnequal = twoU. Statistics on the occurrence of lock-ins is grouped according to the three experimental scenarios rather than the individual characteristics of the agents. The table is sorted first by the network-scenarios, second by firm-preference, and then by the individual-characteristics columns, starting with size which thus far exhibited the greatest influence on lock-in outcomes.

Experiment 3: lock-in occurrence							
	Strategy: maximise			**Initial-network-scenario:** oneAlliance, twoEqual, twoUnequal			
	Firm-Preference: Individual, network, both			(All design points, rounded percentages)			
	Firm-size	Firm-resource	Firm-age	Pref.	Net.-Scen.	% Lock-in	% non-lock-in
1	large	low	young	both	one	100	0
2	large	low	old	both	one	100	0
3	large	high	young	both	one	100	0
4	large	high	old	both	one	100	0
5	small	low	young	both	one	100	0
6	small	low	old	both	one	100	0
7	small	high	young	both	one	100	0
8	small	high	old	both	one	100	0
9	large	low	young	ind.	one	100	0
10	large	low	old	ind.	one	100	0
11	large	high	young	ind.	one	100	0
12	large	high	old	ind.	one	99.9	0.1
13	small	low	young	ind.	one	95.1	4.9
14	small	low	old	ind.	one	94.3	5.7
15	small	high	young	ind.	one	96.4	3.6
16	small	high	old	ind.	one	94.9	5.1
17	large	low	young	net.	one	100	0
18	large	low	old	net.	one	100	0
19	large	high	young	net.	one	100	0
20	large	high	old	net.	one	100	0
21	small	low	young	net.	one	100	0
22	small	low	old	net.	one	100	0
23	small	high	young	net.	one	100	0
24	small	high	old	net.	one	100	0
25	large	low	young	both	twoE	100	0
26	large	low	old	both	twoE	100	0
27	large	high	young	both	twoE	100	0
28	large	high	old	both	twoE	100	0
29	small	low	young	both	twoE	100	0
30	small	low	old	both	twoE	100	0
31	small	high	young	both	twoE	100	0
32	small	high	old	both	twoE	100	0
33	large	low	young	ind.	twoE	99.8	0.2
34	large	low	old	ind.	twoE	100	0

35	large	high	young	ind.	twoE	99.9	0.1
36	large	high	old	ind.	twoE	100	0
37	small	low	young	ind.	twoE	95.4	4.6
38	small	low	old	ind.	twoE	94.3	5.7
39	small	high	young	ind.	twoE	95.6	4.4
40	small	high	old	ind.	twoE	95	5
41	large	low	young	net.	twoE	100	0
42	large	low	old	net.	twoE	100	0
43	large	high	young	net.	twoE	100	0
44	large	high	old	net.	twoE	100	0
45	small	low	young	net.	twoE	100	0
46	small	low	old	net.	twoE	100	0
47	small	high	young	net.	twoE	100	0
48	small	high	old	net.	twoE	100	0
49	large	low	young	both	twoU	100	0
50	large	low	old	both	twoU	100	0
51	large	high	young	both	twoU	100	0
52	large	high	old	both	twoU	100	0
53	small	low	young	both	twoU	100	0
54	small	low	old	both	twoU	100	0
55	small	high	young	both	twoU	100	0
56	small	high	old	both	twoU	100	0
57	large	low	young	ind.	twoU	99.9	0.1
58	large	low	old	ind.	twoU	100	0
59	large	high	young	ind.	twoU	100	0
60	large	high	old	ind.	twoU	100	0
61	small	low	young	ind.	twoU	95.4	4.6
62	small	low	old	ind.	twoU	95.1	4.9
63	small	high	young	ind.	twoU	95.6	4.4
64	small	high	old	ind.	twoU	95	5
65	large	low	young	net.	twoU	100	0
66	large	low	old	net.	twoU	100	0
67	large	high	young	net.	twoU	100	0
68	large	high	old	net.	twoU	100	0
69	small	low	young	net.	twoU	100	0
70	small	low	old	net.	twoU	100	0
71	small	high	young	net.	twoU	100	0
72	small	high	old	net.	twoU	100	0
Σ	All runs					99	1

Table 34: SimPioN, Exp. 3; lock-in occurrence, frequency statistics

When considering the overall effect of each individual initial network scenarios on the agents seeking to maximise partner attractiveness by focusing on their network characteristics, the results reveal that almost all runs lock-in. 99% of overall runs exhibit lock-ins, and also for each scenario individually, irrespective of their specific initial network setup, each design point (combination of preference, variation of individual characteristics and the network scenarios) lock-in at least in 94% of the cases. Closer inspection of Table 34 reveals that certain scenarios lock in less than the 99-100% typical for these experimental runs. These runs are the factor combinations where firms are all_small and individual-oriented across all three network scenarios.

This finding of lower lock-ins in individual-oriented maximiser scenarios point towards that, unsurprisingly, the network characteristics, however salient, do not influence the attractiveness of agents' alters when they are fully oriented towards individual characteristics. It remains surprising, however, at least at first glance, that these runs still lock-in at far higher rates than the individual-oriented maximisers from Experiment 1 that locked-in 'only' 42% of the time in total and 17.7% of the time when agents were initialised as all_small.

The explanation for this difference and the strength of this effect lies in the perception of firms' alters, rather than in their assessment of them. Firms' perception of alters is influenced and informed by their network (and alliance) members during the performance of perceiveFirms(). There, agents perceive alters and also their alters' alters at network path length reach=2. The existence of historical ties means that agents' perception of alters is influenced by this existing network. Individual-oriented agents do not change their assessment of alters based on the network characteristics, but they are influenced concerning which alters they *do* assess. As the scenarios are designed, agents are already embedded in relations at the initialisation of the runs and the results show they are driven to lock-in even when not considering network characteristics. This means that agents cannot "free" themselves of the influence of their network-driven *perception* of their alters. It is further consistent with previous findings that scenarios with all_small agents lock-in less often than those with all_large, based on their fewer available free slots that affect smaller firms and also made them slower to lock-in for the runs that did lock-in. Runs with the same initialisation but with all_large firms exhibit some runs with just under 100% lock-in but overall fit their above pattern of filling all available slots and by doing so creating an overly stable system at the whole network level, no matter which network setup they find themselves in.

For all other scenarios that exhibit 99% or more of locking-in runs, the network scenarios appear to matter in the same way as described above and additionally, for all runs where firms' preferences included both or were network-oriented, the network played a direct role for firm lock-in by signalling attractiveness to their alters. For the subsequent analyses, in addition to the network scenarios, I focus on the two factors of preferences and firm-size since they are the two factors exhibiting sufficient interesting variation.

4. 5. 5. 2. Time-to-lock-in

As in the individual-focused experiments above, the occurrence statistics alone often do not reveal the entire causation effects in the data. Time-to-lock-in analyses the extent to which certain scenarios appear to be faster to lock-in as an indication of the sensitivity to the starting conditions of a runs or to the over-time dynamics instead. Since the previous Experiments 1, 2a-c indicated that `firm-size` and firms' `preferences` have generally the strongest influence on lock-in, the results will immediately be shown at that level of detail in Figure 45 to reveal the most insightful differences and similarities between the experimental runs.

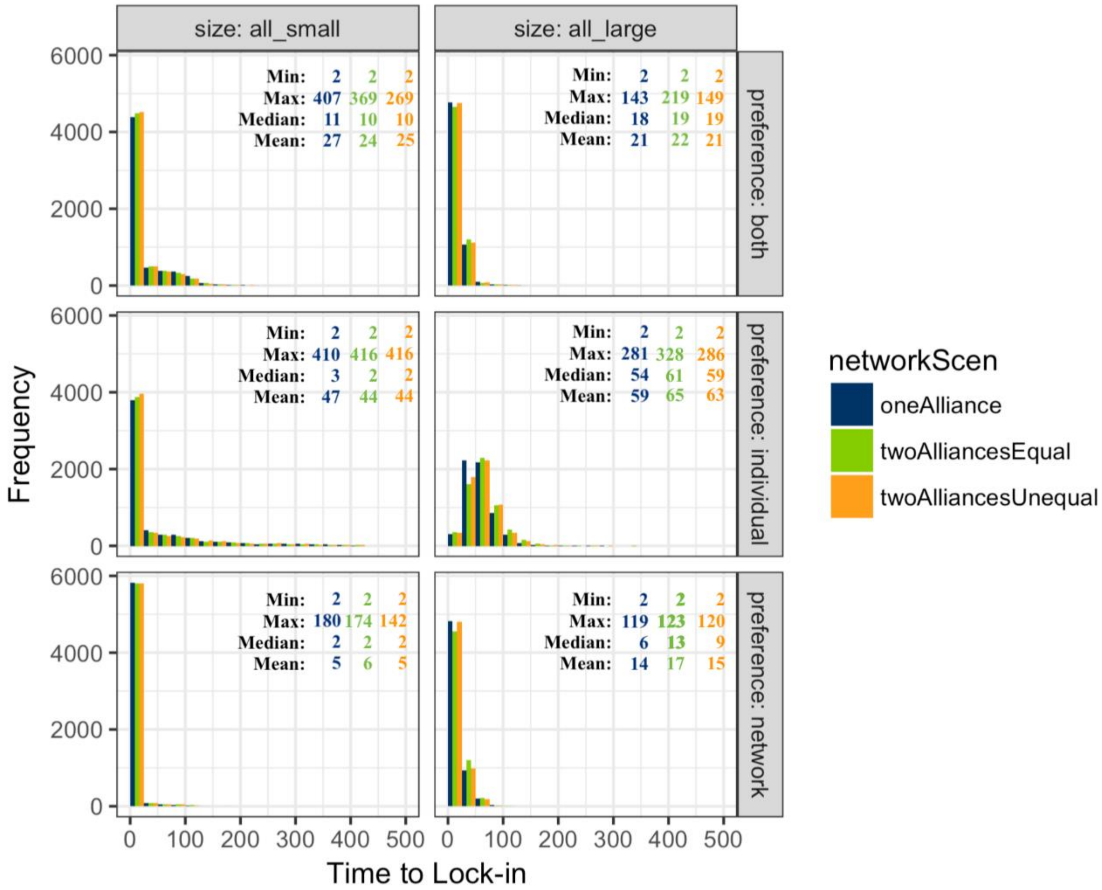

Figure 45: SimPioN, Exp. 3; time-to-lock-in, bar plots: scenarios

The diagram in Figure 45 reveals the overall impression that all experimental scenarios of Experiment 3 lock-in rather quickly. The network-oriented runs where agents are caused to assess their alters based upon their `network` characteristics are the fastest to lock-in, while the runs where agents are fully `individual`-oriented are the slowest across all network scenarios. Apart from the overall fast times-to-lock-in, one result in the diagram stands out particularly: the distribution of the `individual`-oriented `all_large` firms scenario.

While the individual-oriented `all_small` scenario exhibited the 'lowest' number of lock-in occurrences (see Table 34), they are quite fast to lock-in at a median of 2 ticks (3 for the `oneAlliance` case) and a mean of around 44 ticks, but also have the highest outliers at above 410 ticks of all scenarios, visually represented by a long-tailed distribution. The `all_large` firm scenarios with median lock-ins at 54, 61 and 59 ticks and also higher mean times-to-lock-in are slower to lock-in (even though they do so more often) than the `all_small` scenarios with median lock-ins at 3, 2 and 2 ticks for `oneAlliance`, `twoAlliancesEqual` and `twoAlliancesUnequal`, respectively.

These findings are in keeping with those for the `individual`-oriented maximisers in the base case Experiment 1 where `firm-size` produced similar runs with `all_small` locking-in faster than `all_large` ones. A key difference to Experiment 1, however, is that through the initialised network scenarios, outliers for both `all_small` and `all_large` are taking considerably longer time-to-lock-in. This effect is attributable to the maximising agents searching for the 'right' partners within their pre-defined network structure. This takes longer than without prescribed historical connections because agents might already be connected to potential candidates but have slots left to fill, or because they might have their slots filled with suboptimum partners (based on their individual characteristics), needing to wait for these ties to end and switch more often.

Figure 45 also reveals that agents in `both`-oriented scenarios are slower to lock-in than the purely `network`-oriented runs. Like the `individual`-oriented ones, the `both`-oriented agents are affected by the network in their perception of `individual` characteristics. They do, however, also take their alters' `network` characteristics into consideration which means that agents need to additionally assess their alters' heterogeneity and adjust attractiveness scores. While this leads 100% of all runs to lock-in, it slows down the times-to-lock-in somewhat compared to purely-`network`-oriented runs but `both`-oriented agents still lock-in faster than in `individual`-oriented runs. While `all_small` firm scenarios exhibit longer outliers and shorter median times-to-lock-in as above, their mean values are slightly above the `all_large` runs, indicating lesser outliers for the latter. Again, `all_large` firms need longer time to fill their more numerous slots, but the existence of a historical network appears to slightly reduce the outliers which appears logical given that some of these agents' slots are already pre-filled at initialisation.

The purely `network`-oriented agents are not only locking-in at 100% in all experimental conditions, but they also do so the quickest compared to the other scenarios, exhibiting medians of 2 ticks for `all_small` firms and below 13 ticks for `all_large` ones, with similarly low mean values, and much lower outliers. Compared to the `network`-oriented maximisers in Experiment 2c that had no existing network structures initialised, the present runs' outliers take longer to lock-in. Small firms' inability to entertain many simultaneous connections means they become more quickly reliant on the pre-established connections due to having their slots already pre-filled and due to primarily perceiving their existing partners, and are thus less likely than `all_large` firms to have free slots available for more connections, which decreases their overall time-to-lock-in.

Comparisons across network-scenarios show little systematic influence of any of the three network scenarios on time-to-lock-in. The longest run durations before lock-in appear in `oneAlliance` or `twoAlliancesEqual` setups, but this is mainly expressed in the outliers, with means and medians not being systematically different across other factors. Furthermore, for `all_large` scenarios, `twoAlliancesEqual` generates the longest times-to-lock-in which is consistent with large agents' ability to connect to more partners but being confronted with alters having quite similar `network` characteristics-derived attractiveness. The longer duration before lock-in of these runs also suggests an effect of the competition between the agents belonging to the two initialised alliance groups, although this difference is not very pronounced. Overall, though, the runs take longer (if not by much in some instances) to lock-in than the comparable maximising agents without initial network scenarios (compare Figure 44). This effect can be attributed to the need for information regarding agents' attractiveness to filter through the initialised, historical network structure, and the additional assessment of network characteristics in the `both` scenarios where `network` characteristics add to the attractiveness of `individual` characteristics. The fact that the times-to-lock-in are shorter in `network`-oriented than for `individual` or `both` runs reveals that the agents within the initialised networks tend to continue their membership based on remaining connected to their members.

The evaluation of the densities below can shed further light on the influence of the network scenarios on the conditions of lock-in also on how the initially unconnected agents react to the presence of the initialised alliances.

4. 5. 5. 3. Alliance density and time-to-lock-in

Times-to-lock-in are not the only characteristic where the three network scenarios play a role. The resulting densities created in the process are of high interest, not least for a comparison with the effects of the individual characteristics from the experiments above.

The density plots across time-to-lock-in reveal no systematic differences between the three scenarios. The two scenarios with `twoAlliances` exhibit more orange dots between 75 and 200 ticks' duration, indicating alliances with more members emerging later in the run than in the `oneAlliance` scenario where the orange data points already appear around 50 ticks. Outliers in both time and density appear similar and for the scenarios with two alliances and the data, again, appears to cluster around the two values of `d=0.2` to `d=0.6`, a potential effect of `firm-size` (to be explored below). Interestingly, there appear few data points with dark red colour unlike above, indicating an absence of very large alliances, and the data points show a higher degree of spread than in the more clustered diagrams above (e.g. Figure 26 and Figure 41), with `twoAlliancesEqual` exhibiting the strongest spread of all.

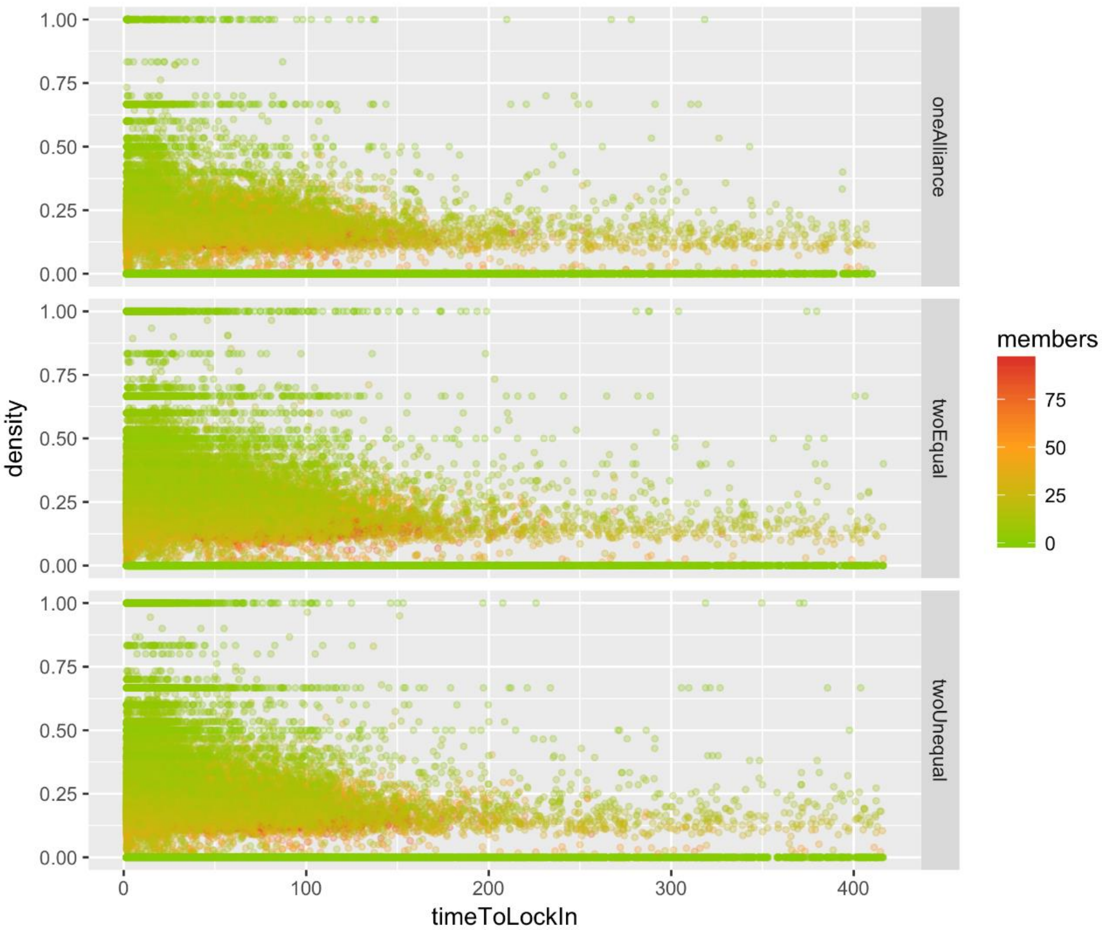

Figure 46: SimPioN, Exp. 3; density over time, scatterplots: net. -scenarios

Plotting the above result according to `firm-size`, the diagram below reveals that `all_large` `firm-size` scenarios lock-in much more quickly than `all_small` scenarios. Note that this is not due to large `firm-size` being perceived as attractive (this effect is disenabled in this experiment being weighted `0` in the attractiveness equation), but because firms derive their available number of slots from their size. Thus, large firms hold the potential to forge more simultaneous links than small firms which lock-in more slowly, given they have more ability to switch and/or search for more optimum alters than those they were initially connected with. The results essentially echo those in the previous figure but add detail by showing that runs with `all_large` create larger alliances with alliance sizes reaching 75-100 members while the `all_small` runs exhibit many more green and light orange dots with alliances sizes attaining around 25 members. Based on large firms' ability to entertain more links with alters, they can also sustain more alliance memberships, and this can lead to overall larger alliances with faster lock-ins – a finding which should be reflected in the alliance rank analysis further below. `Firm-size` variation thus accounts for both the alliance size and the times-to-lock-in differences. Furthermore, the densities attained by these very large alliances of `all_large` firms are expectedly lower than those of the smaller alliances with few members, and this result holds across network scenarios.

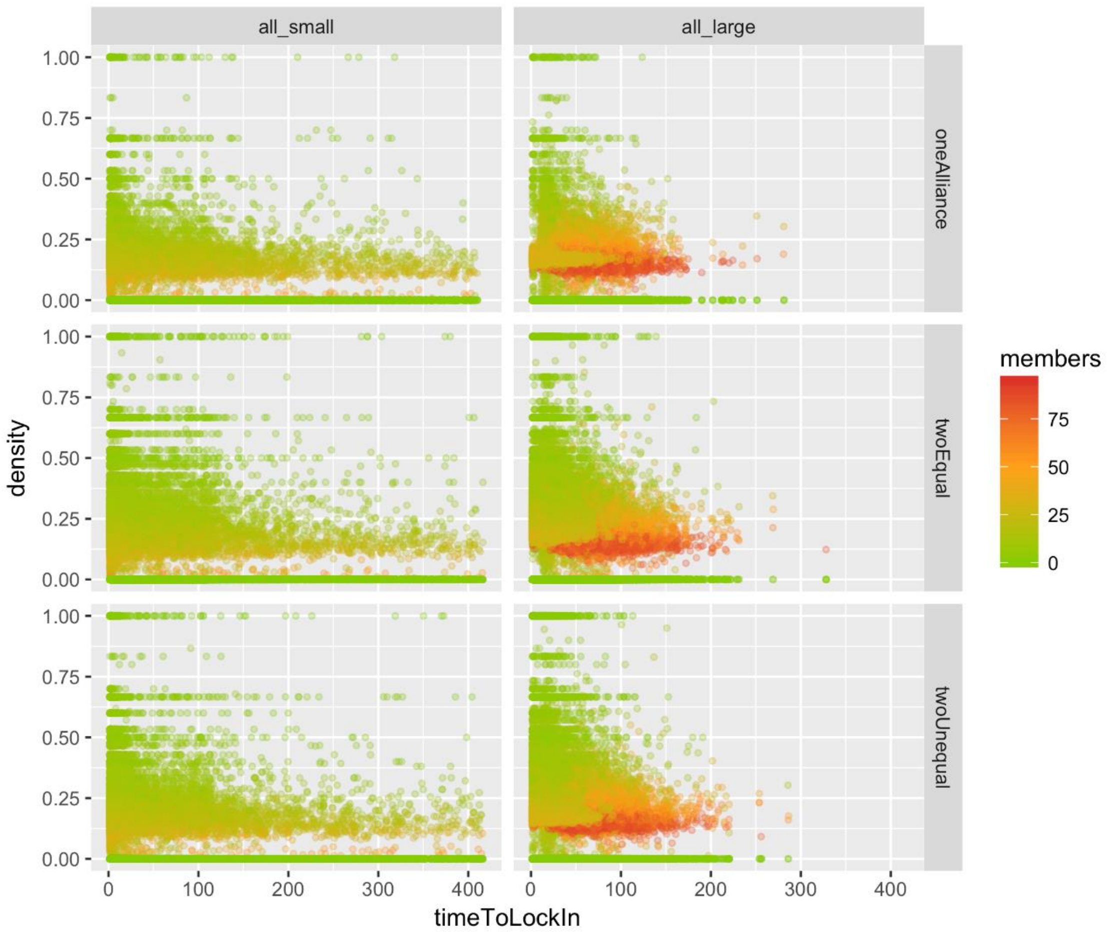

Figure 47: SimPioN, Exp. 3; density over time, scatterplots: net. -scenarios & firm-size

When differentiating runs according to preferences and the initialised network scenarios, a more refined picture emerges and exhibits differences and similarities between both preferences and network scenarios. The analytical diagram below again shows that the majority of the outlier runs with regard to time-to-lock-in are attributable to those with preferences for `individual` characteristics, and across all three network scenarios. These most outlying runs achieve largely densities of around `d=0.2`, but with considerable spread and data points covering almost all segments of the plot. This makes sense since they are also the alliances with the most members, i.e. the `all_large` ones, where the high number of members makes high density relatively unlikely given limited `firm-slots`, even if firms are large and thus have more slots available.

Furthermore, the runs with agents embracing `both` characteristics for attractiveness assessment take the second-longest to lock-in, which is consistent with their increased need to perceive their alters through the prescribed network structure and their assessment of `both` the fixed `individual` characteristics and the changing `network` characteristics. The purely `network`-oriented firm runs are the shortest with regard to time-to-lock-in, as was described in the previous analysis. Their densities are not fundamentally different from the other preferences, though, except for fewer data points at higher density levels such as `d=0.6` and above.

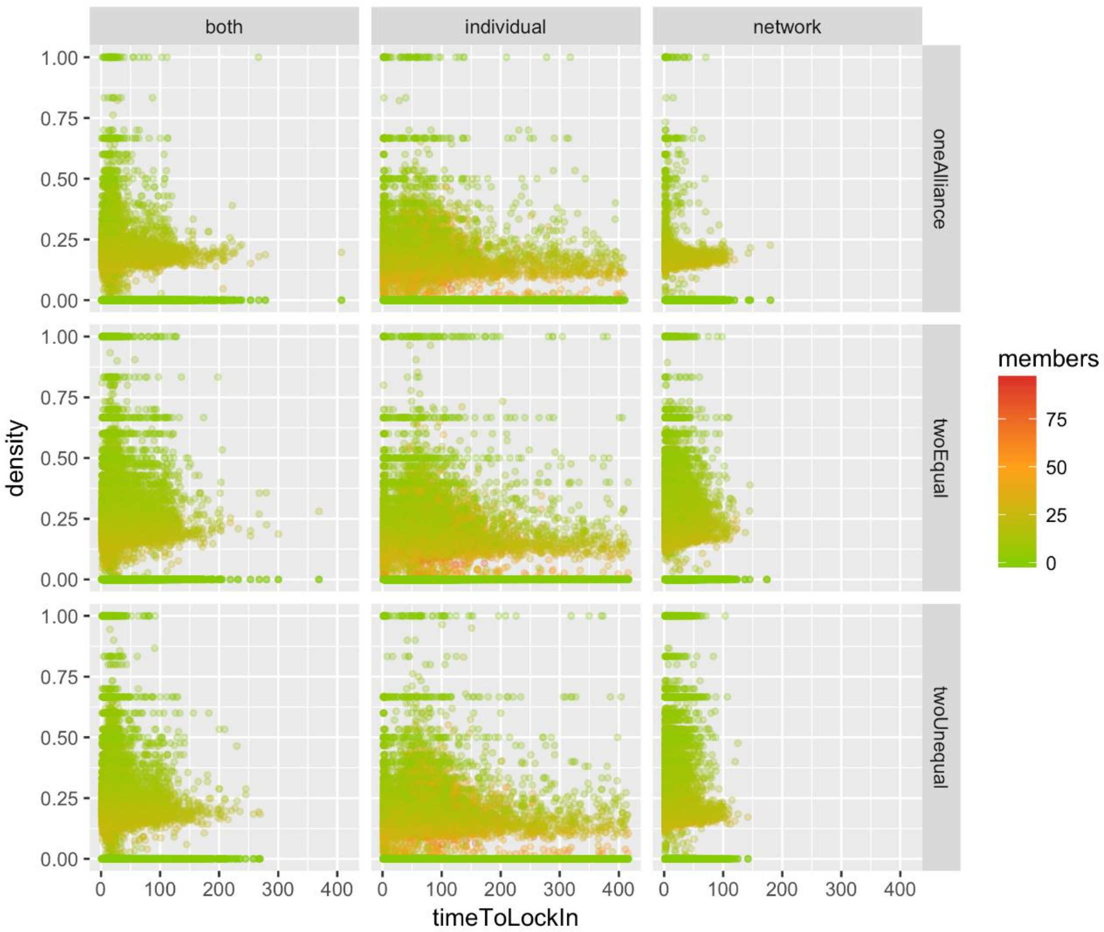

Figure 48: SimPioN, Exp. 3; density over time, scatterplots: scenarios & preferences

What can further be derived from the diagram is the much lower density spread of the data points in the `oneAlliance` scenario where the vast majority of the runs stay at a lower density level around `d=0.2`. The scenarios with two initialised alliances attain not only many more runs with higher densities, but these higher density alliances also appear to take longer to lock-in than the higher density ones in the `oneAlliance` setup. While the `twoAlliance` scenarios appear relatively similar overall, the orange shades of the data points indicating larger alliances are slightly more concentrated in the `twoAlliancesUnequal` which runs at minimally higher density levels. This could indicate an imbalance effected by the one initialised larger alliance with more members attaining slightly higher density levels than the `twoAlliancesEqual` scenario with more spread towards the lower density levels. While this result is (at least initially) attributable to the unequal initialisation, a subsequent attraction effect leads more agents to be primarily attracted to the larger alliance than to the smaller, but with lower resulting densities. This result echoes the trade-off between alliance size and alliance density, which was already noted in other experiments above, and also the influences of `firm-size` on lock-in. With the distribution of alliances reaching relatively high density levels overall, it is interesting which of the alliance ranks exhibits these values, given that the initialisations of the network scenarios are rather different with regard to that distribution.

4. 5. 5. 4. Intra-alliance density

The intra-alliance densities and the rankings according to alliance size are the result of the share of realised versus possible connections forged within the alliances and plotted against attained membership sizes. These statistics can be expected to be influenced by the initialisation of the network scenario, since these provide the conditions upon which alliances develop their future states until the end of the run.

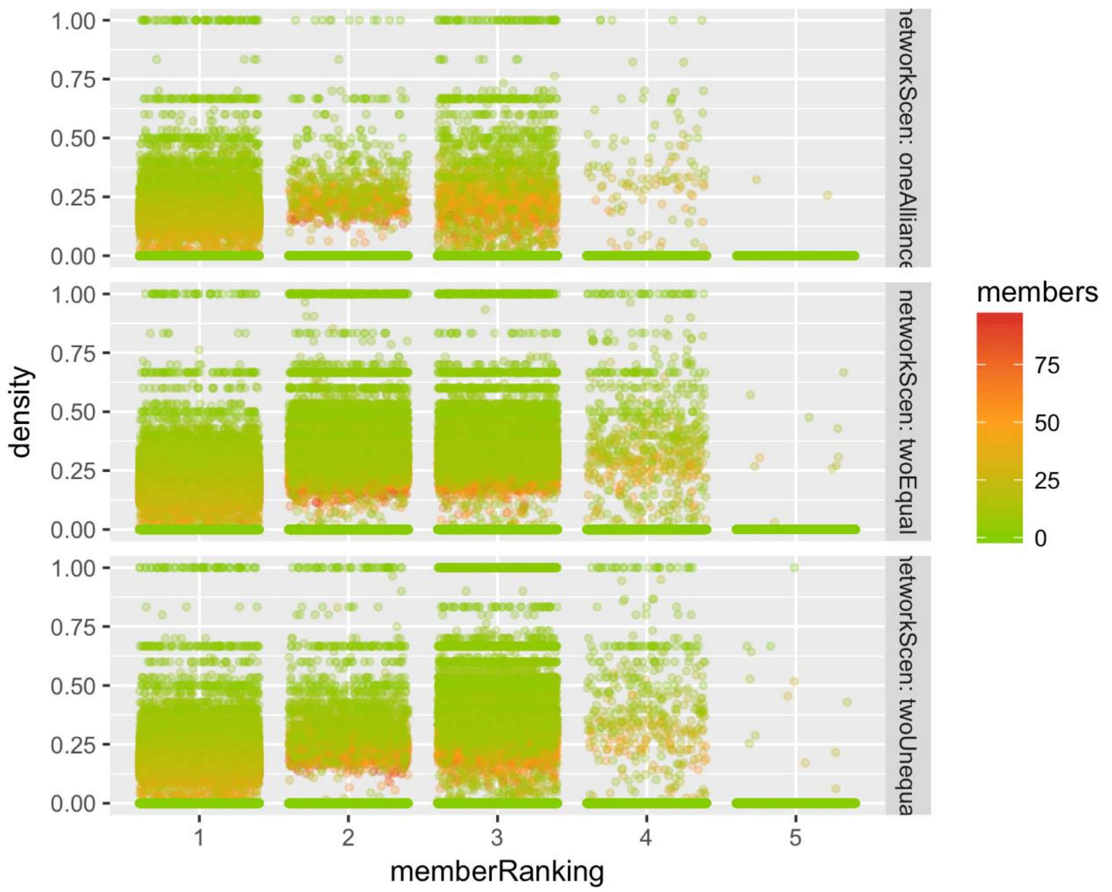

Figure 49: SimPioN, Exp. 3; intra-alliance densities, ranked scatterplots: scenarios

Notable for the results is the near-absence of a fifth alliance rank which indicates that the chance of smaller alliances to survive is reduced, since mainly their founders remain towards the end of the run. Additionally, the fourth alliances rank is mainly filled with comparatively small alliances, as indicated by few light orange data points, with densities in most runs achieving between d=0.25 and d=0.75.

The results for the `oneAlliance` scenario where 20 agents form one initial alliance with random internal links demonstrates the existence of one dominant alliance towards the final state of the run with densities of larger alliances around the `d=0.2` level but with considerable spread for smaller alliance sizes. These largest alliances attract memberships ranging between 20-30 members. The second largest alliances are fewer and, of course, smaller, but generate higher densities. The third rank interestingly exhibits a considerable amount of medium-sized alliances with similar spread as the first rank.

The twoAlliancesEqual scenario produces three fairly dominant alliances that attain noteworthy density levels. The first-ranked alliances achieve densities at the d=0.2 level for larger alliances while the second-ranked alliances attain higher densities with much smaller alliance sizes around d=0.35. The third-ranked alliances follow the pattern of the second alliance rank. Interestingly, this result holds similarly for the twoAlliancesUnequal scenario, except with slightly less spread in the densities for the second and third alliance ranks.

Given that firms are able to connect to a maximum of three alliances, the finding regarding the three dominant alliances appears not very surprising. The network characteristics attained in the first and second alliance ranks make firms also attractive to members of the third rank alliances. If these see fit, connecting with members of the third alliance makes sense and indicates the existence of brokers that bridge the network-structural holes between the alliances of the first three alliance ranks. Plotting the results divided by firm-size shows an influence of firm-size via the firms' free available firm-slots for connecting.

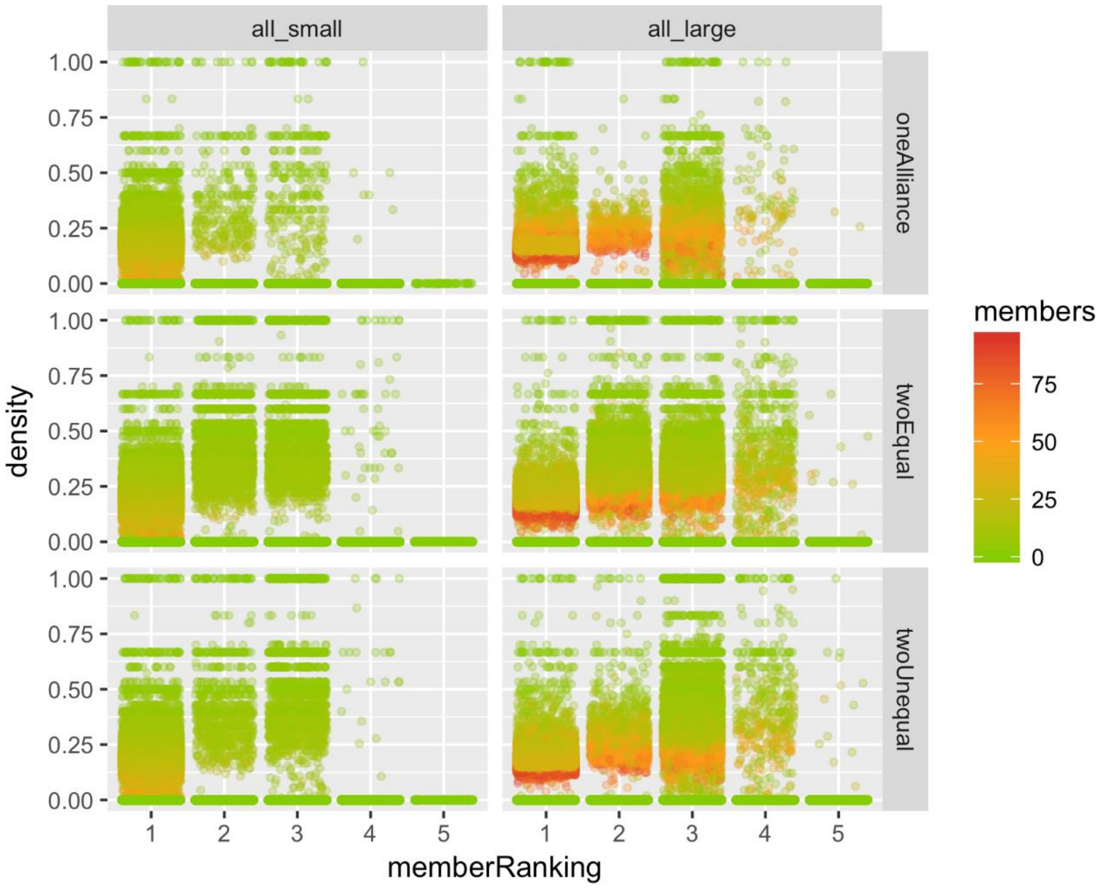

Figure 50: SimPioN, Exp. 3; intra-alliance densities, ranked scatterplots: net. -scenarios & firm-size

The findings for all_small reveal an almost complete absence of data points in the fourth alliance rank which indicates that the above fourth rank in (Figure 49) must be populated mainly by all_large firm alliances. In the oneAlliance scenario, all_small firms attain densities of approx. d=0.2 for their larger alliances, that attract clearly far fewer members per alliance than in the all_large setting runs which have a similar spread of the resulting alliance densities but larger sizes across all ranks. This finding also holds across the network scenarios which indicates that the more numerous available firm-slots of all_large firms enable firms to sustain bridging connections across alliances (or as shown here: alliance ranks). Furthermore, results for all_large are rather clustered around d=0.25 for the second alliance rank in oneAlliance while the twoAlliance scenarios exhibit even more spread than in the first alliance rank but obviously with smaller alliances. The all_large firm runs with oneAlliance indeed retain four of the five alliance ranks, again indicating the trade-off between higher densities and more surviving alliances.

The attained densities in the twoAlliancesEqual scenarios are higher for the second rank for both all_small and all_large than for the oneAlliance scenarios, and also exhibit more spread and more data points in that rank (and the third and fourth rank, too). The third ranks again exhibit a considerable amount of medium to smaller-sized alliances with similar spread as the first rank. This effect is especially pronounced in the twoAlliancesUnequal scenario, indicating that the maximally three 'allowed' alliance memberships are realised for these scenarios despite the initialisation of 'only' two alliances to begin with. The effect is bigger for all_large firms that have more slots available and achieve larger alliances. The effect warrants more careful examination below. Otherwise, the twoAlliancesUnequal scenario essentially echo the results for twoAliancesEqual, except that the alliances in the second rank the data points spread less within the rank and exhibit slightly lower densities with only few runs exceeding d=0.5 density. This indicates that there is competition of two unequal alliances that leads to an attraction effect for the larger but less dense alliances, and higher densities with fewer alliances in rank two.

Finally, Figure 51 plots the result data by preferences and the network scenarios reveals further interesting patterns. Individual-oriented scenarios produce the overall densest alliances which can mostly be attributed to the all_large scenarios, as indicated above. Secondly, the both-oriented runs behave like individual-oriented runs with regard to density spread but behave like network-oriented runs with regard to their overall smaller alliances sizes and thus echo the network-oriented scenarios more closely. Taken together, both-oriented runs exhibit combined effects of individual-oriented runs where the information on alters transpires through the initialised network structures and the network-oriented runs where attractiveness calculations do include the alters' network characteristics.

Network-oriented runs with oneAlliance exhibit hardly any alliances in the second rank, but some in the third rank – an attraction effect of the higher attractiveness of the members of one initialised alliance. Meanwhile, the `twoAlliance` scenarios again show the first three ranks filled, albeit fewer alliances in the second rank for `twoAlliancesUnequal` where the attractiveness of members of the larger first alliance leads to less dense, but larger alliances over the denser but less populated alliance in the second rank.

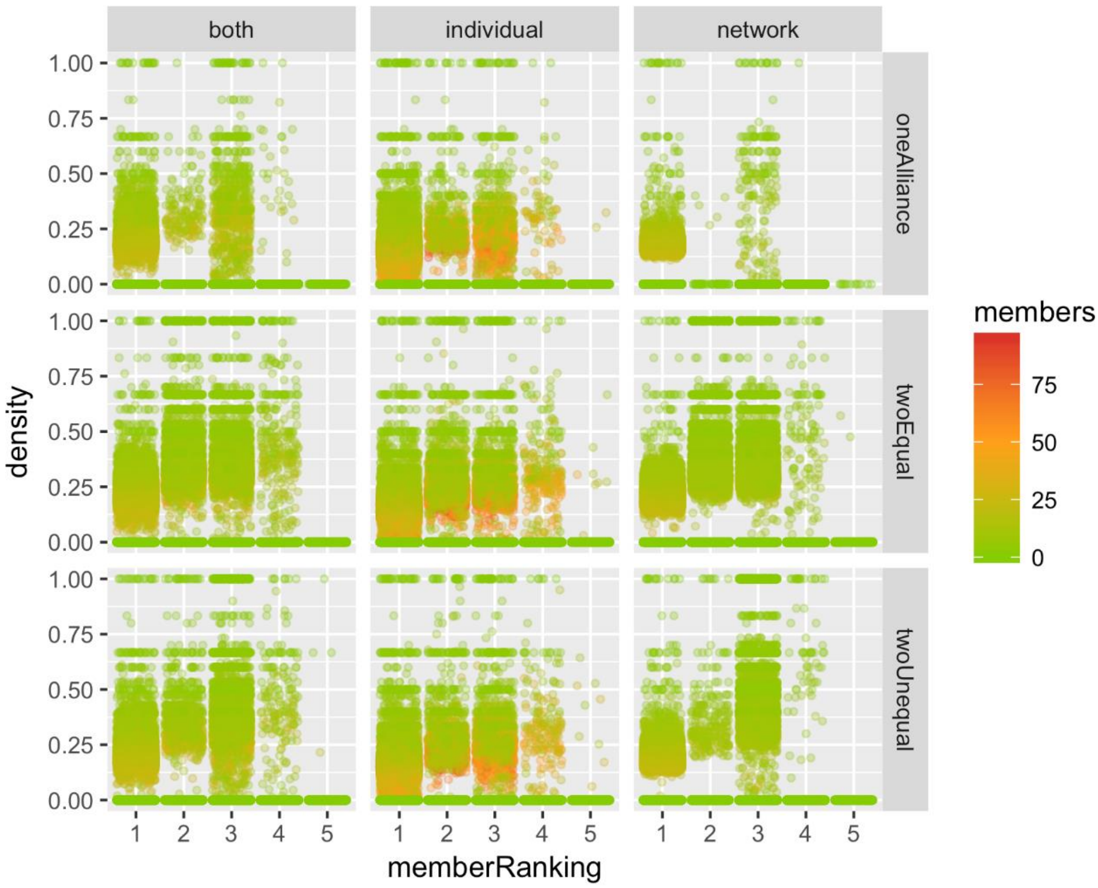

Figure 51: SimPioN, Exp. 3; intra-alliance densities, ranked scatterplots: net. -scenarios & preferences

Overall, both the network scenarios and the preferences exhibit systematic influences on lock-in conditions such as density and dominance, i.e. size of the alliances. The network-oriented runs are clearly different from individual-oriented runs due to the different effects of the existence of the initialised network structure. `Both`-oriented runs exhibit combined effects and thus results similar to both `individual` and `network`-oriented runs. Scenarios with `twoAlliances` strongly increase the presence of data points for the second alliance rank over `oneAlliance`, with the `twoAlliancesEqual` runs revealing more spread in the attained densities. Initialising the network scenarios causes the outcomes of locked-in runs to be overall much denser, more numerous and to occupy more ranking spots than the maximising agents of previous experiments (compare e.g. Figure 27 with hardly any lock-ins and lower levels of density, and Figure 42 with results echoing those of Experiment 1).

4. 5. 5. 5. Discussion

The findings for the three network scenarios differ strongly from those for the runs with individual-oriented agents, above. Almost all factor combinations lock-in at (nearly) 100%, and only all_small runs with individual preferences remain systematically 'lower' at around 94% of runs locking-in, indicating network scenarios' overall strong influence on runs' likeliness to lock-in. Not only do the network scenarios lead to overall more lock-ins, but they also lock-in more quickly compared to the maximisers focusing on alters' individual characteristics in previous Experiments 1 and 2c. This shows that the historical ties inform the continuation/ formation of new ones and make lock-ins fast overall, based on the already established relations.

The individual-oriented agents remain the slowest to lock-in while network-oriented runs are the fastest across all initialised network scenarios. However, both also generate outliers for all_small and all_large setups which take considerably longer time-to-lock-in. Agents' searches for optimum connection partners are here slowed down by the pre-defined network structure through which information on attractiveness needs to transpire for assessment. This may also take longer than without prescribed historical connections because agents are already connected to partners but have slots left to fill (for all_large firms), or their slots may be filled with suboptimum partners and need to wait for these ties to end and then switch (for all_small scenarios).

The both-oriented agents are also affected by their network in their perception of individual characteristics and need to take alters' network characteristics into consideration to assess their attractiveness. While all these runs lock-in, this double consideration slows down the times-to-lock-in somewhat compared to purely network-oriented firms. both-oriented runs behave like individual-oriented runs with regard to density and its distribution but behave like network-oriented runs with regard to their overall smaller alliance sizes and lock-in speed. The differences in alliances sizes are accounted for mainly by the variations of firm-size with all_large firm runs generating larger but less dense alliances than all_small ones which exhibit more spread in density and attain higher levels more frequently.

Findings regarding the influence of the network scenarios show that a majority of oneAlliance runs stay at a lower density than the twoAlliance initialisations which also exhibit more spread in density. Notable for all results is the near-absence of a fifth alliance rank but presence of alliances in all other four ranks for all_large firms and in the first three ranks for all_small runs. Both is considerably more than for previous maximiser experiments and indicates that initialised alliances tend to survive, plus some emergent ones. These exist because agents are able to connect to three alliances in total. Initialising twoAlliances with three ranks filled thus points towards the existence of brokers that bridge the network-structural hole between the alliances of the first three ranked alliances. The slightly longer duration of these runs also suggests a small effect of the competition between the agents belonging to the two initialised alliance groups. This competition effect is underlined by the near-absence of data points in the second alliance rank in the network-oriented oneAlliance scenario where most data points are found in the first alliance rank, showing that the initialised alliance prevails over others. This effect, albeit to a lesser degree, is also revealed in the twoAlliancesUnequal runs with network-oriented agents where alliances in the second rank the data points spread less within the rank and exhibit slightly lower densities due to an attraction effect for the larger but less dense alliances.

Comparing the effects of the three initialised network setups among themselves reveals that the lock-in occurrence is not systematically different for the three setups, but times-to-lock-in are different, especially for the all_large runs with shorter run durations before locking-in. Densities were slightly higher in the twoAlliancesEqual scenarios, but with more spread, especially for the second-ranked alliances. Furthermore, network scenarios and preference settings interact and reveal systematic influences on lock-in conditions density and dominance, but not on the occurrence of lock-ins. The both-oriented runs with their combined attractiveness effects and result similarity to both individual- and network-oriented preferences probably mimic real-world firms most accurately, since they are interested in both alters' individual characteristics such as resources and in their network characteristics. A pure strategy of either type, as also modelled, appears possible in the empirical reality. At least with regard to cooperation in competing interorganisational alliances, such as in the case study, such a both-preference does appear most consistent. The implication for these preferences, assuming maximising strategy etc., is that they lock-in 100% of the time, albeit slightly more slowly than if they were purely looking for network-related benefits, but faster than those preferring only agents' individual characteristics. Additionally, when these agents are in a twoAlliances scenario, this causes more data points for the second alliance rank over oneAlliance, with the twoAlliancesEqual runs exhibiting more spread in the attained densities.

Overall, initialising the network scenarios causes the outcomes of locked-in runs to be much denser, more numerous and occupy more ranking spots than the maximising agents of previous experiments. The notable difference is the survival of more alliances until the end of the run and the higher densities attained, especially in the case of twoAlliancesEqual, which is probably the closest representation of the case study scenario at the beginning of data gathering. The interesting finding for the scenarios with twoAlliancesUnequal and oneAlliance is that there appears to an attraction effect of agents to the larger alliance, whose members they perceive as more attractive. Two types of alliances emerge (more pronounced in the all_large firm-size scenarios), but with a clear trade-off: alliances either attract a large share of the agents and build alliances with low density and fast lock-ins, or they build more cohesive, denser alliances but with fewer members that also take longer time-to-lock-in. While longer run durations before lock-in appear helpful for real-world firms to counteract lock-in tendencies, for instance, the trade-offs of smaller alliances size and less density do not appear an easy balance to achieve when seeking to reap the benefits of close cooperation within an interorganisational network whose existence is based on distributed agency.

4. 6 Sensitivity analysis

When performing simulation experiments, it is necessary to make certain assumption regarding the boundary conditions of the model. These variables were displayed and discussed in the Design of Experiments (Section 4. 4) above. When running and analysing the experiments, it is important to keep track of effects that can potentially be attributed to these settings. Having performed the experiments, it is then important to test how robust the model run outcomes are when varying these boundary condition out of the range used in the actual model runs. The sensitivity analysis is the method by which such a robustness check is performed.

SimPioN explicitly varies its key assumptions on agents' decision-making models in the model runs, i.e. *maximising*, *satisficing*, and *despairing*. These decision-making models influence the process by which agents perceive and evaluate their alters and how they seek to connect to them or respond when asked to connect, all of which ultimately affect the networks that the agents create among each other, their time-to-lock-in, and network densities. One conspicuous finding above was that scenarios with `satisficing` agents produced surprising results in the scenarios where they were set to have preferences for their alters' `network` characteristics, but where the experimental initialisation varied only the individual characteristics of agents (Experiment 2c; Section 4. 5. 4). There, the runs produced no lock-ins across all factor variations, which was prominent in comparison to the results for the other scenarios in Experiment 2c. The effect was considered attributable to implementation of agents using a fixed `min-attraction=0.5` threshold level for assessing their alters' attractiveness and to the speed at which agents choose their cooperation partners without having actually allowed enough time for their alters to develop their network characteristics meaningfully enough to positively influence their attractiveness scores.

A `satisficing` firm considers and accepts connections with other firms when it considers an alter to be attractive enough. The satisficers' selection process is reflected by a threshold, i.e. a minimum level of attraction that an alter has to satisfy in order to be considered worthy of cooperating with. The satisficers' threshold level in the SimPioN experiments was set to the `min-attraction=0.5`. It is conceivable that this implementation choice might be problematic in the described scenario, above, when agents do not find alters that have gained sufficiently high values in the network characteristics for agents to reach this threshold level of `0.5` to be considered of high enough attractiveness for connecting. This would be one possible explanation for agents not creating any alliances in these runs and thus also not locking-in in this initialisation.

In order to check and assess the influence of this threshold setting, I conducted experimental runs for the sensitivity analysis in which the threshold value was varied between `0.1` and `0.9` in increments of `0.2`, while varying the individual attributes (`firm-size`, `firm-age`, `firm-resource` at both their `low` and `high` extremes) and the preferences (`individual`, `network`, both) in the typical 2k factorial design to account for the impact of the extreme values, while obviously holding constant firm-strategy and using the satisficer decision-making model.

The overall finding from the sensitivity analysis is that the different threshold levels have some systematic impact on some of the outcome variables, but this is not especially large, especially when compared to the influence of agents' characteristic of firm-size which I chose to depict for comparison (firm-age and firm-resource again showed only miniscule effects on outcomes, if any).

The percentage of runs locking-in generated in the sensitivity runs did not vary much across the threshold levels. The left segment of Figure 52 shows the mean lock-ins occurrence at around 55%. However, this mean figure also accounts for the network-oriented runs that did not actually produce any lock-ins, just as expected from Experiment 2c, which lowers the overall percentage. The mean lock-ins percentage for the both and individual-oriented runs is actually above 75%, as can be seen in Figure 53, below). As shown on the right side of Figure 52, the times-to-lock-in are slightly affected by the threshold levels, revealing a generally declining mean number of ticks before lock-in with increasing threshold levels. This trend is not considerably large, however, given that this decline is from about 16.5 to 15 ticks, indicating that the variation most likely stems from the interaction of other experimental factors than the threshold levels. The threshold level does, however, affect the number of firms that 'survive' the model run with the general trend that higher threshold levels lead to decreasing numbers of surviving firms, which is visualised in Figure 52 through the colour shades of the data dots which transition from blue (many survivors) to green (few survivors) as the threshold level increases.

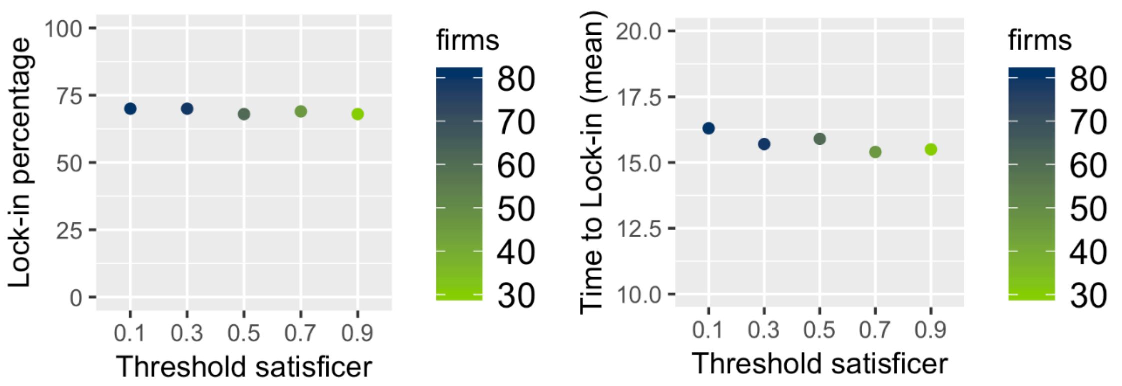

Figure 52: Satisficer threshold effect on lock-in and time to lock-in

Figure 53, below, shows that the influence of threshold levels on lock-in occurrence and on times-to-lock-in is smaller than e.g. the impact of the firm-size factor. The left side of the diagram reveals the interesting finding that the both-oriented all_small firm lock-in less often than the individual-oriented runs at the 0.5 threshold level, but for other thresholds this difference is less distinct. Further, all_large scenarios generally lock-in more likely than all_small ones.

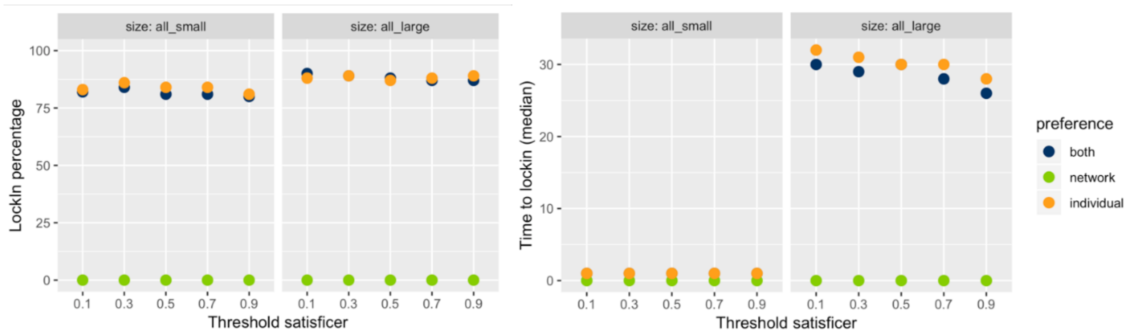

Figure 53: Satisficer threshold and firm-size effect on lock-in and time to lock-in

The times-to-lock-in are more affected by `firm-size`, with `all_small` firms locking-in swiftly. The data exhibits a small slowing-down effect on lock-in speed with increasing threshold levels, largely attributable to the stricter assessment of alters. `Individual`-oriented scenarios are fast to lock-in without thresholds playing any role when firms are `all_small`. For `all_large` firms, increasing thresholds slightly decrease times-to-lock-in due to the fewer remaining agents in the run.

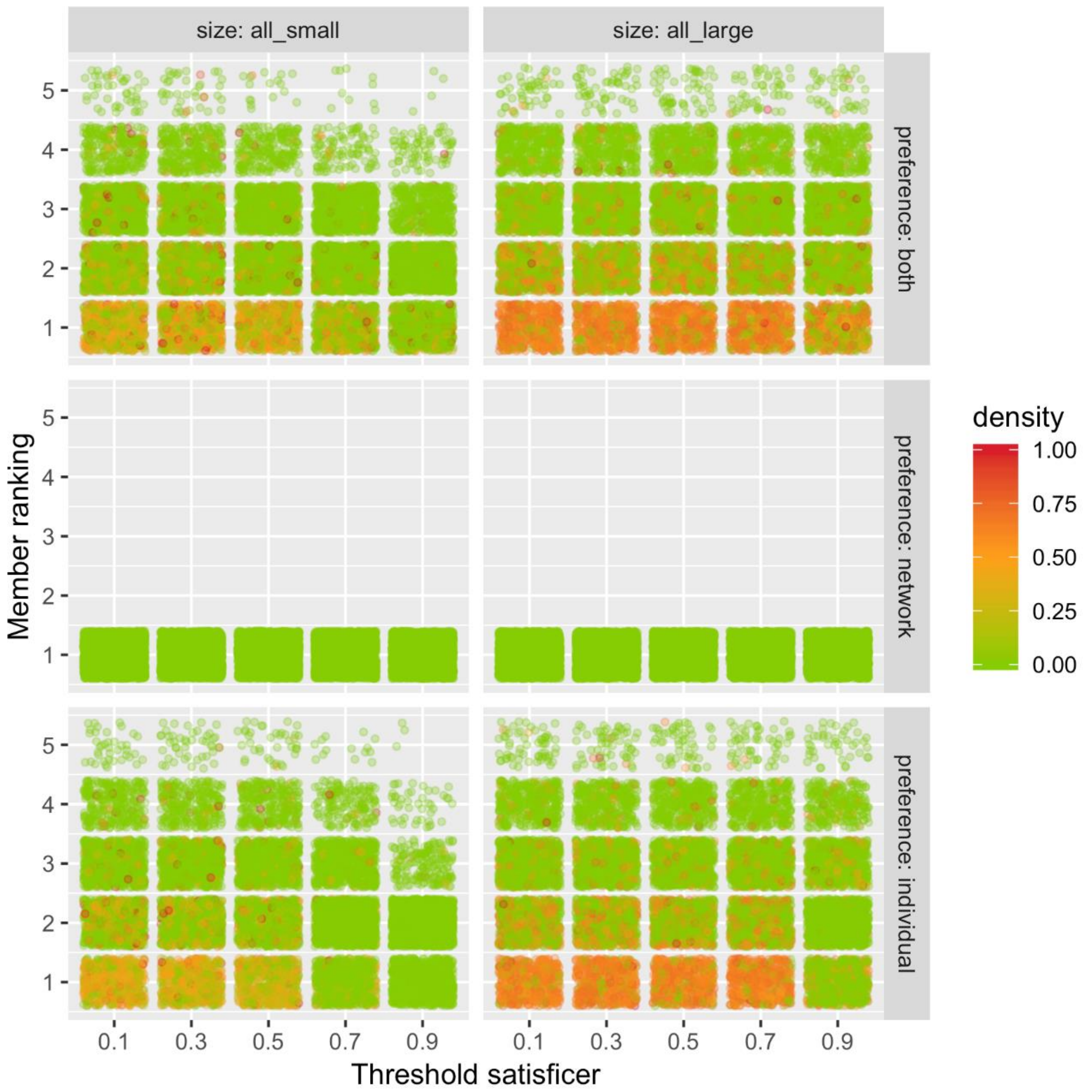

Figure 54: Satisficer threshold and firm-size effect on alliance density distributions

Figure 54, above, reveals the effect of thresholds on the alliance densities at the end of the run and its distribution across alliance size ranks. In contrast, the thresholds here exert more influence than for lock-in occurrence and times-to-lock-in with a tendency of higher thresholds limiting the densities attainable by the alliances with increasing threshold levels. Mostly the `0.9` level for `all_large` scenarios and as of the `0.7` level for `all_small` firms in the individual preferences runs lead to lower densities for the first (and largest) alliance rank. In the latter scenarios also fewer alliance ranks are filled, indicating fewer surviving alliances at the end of the run. For the both-oriented runs, the effect is much less pronounced and affects only the `all_small` scenarios with the limiting effect beginning at `0.7` threshold. These effects are consistent with expectations insofar as the higher threshold makes alters less attractive and thus indirectly affects resulting densities, and also similarly affects alliances sizes as indicated by Figure 55, below.

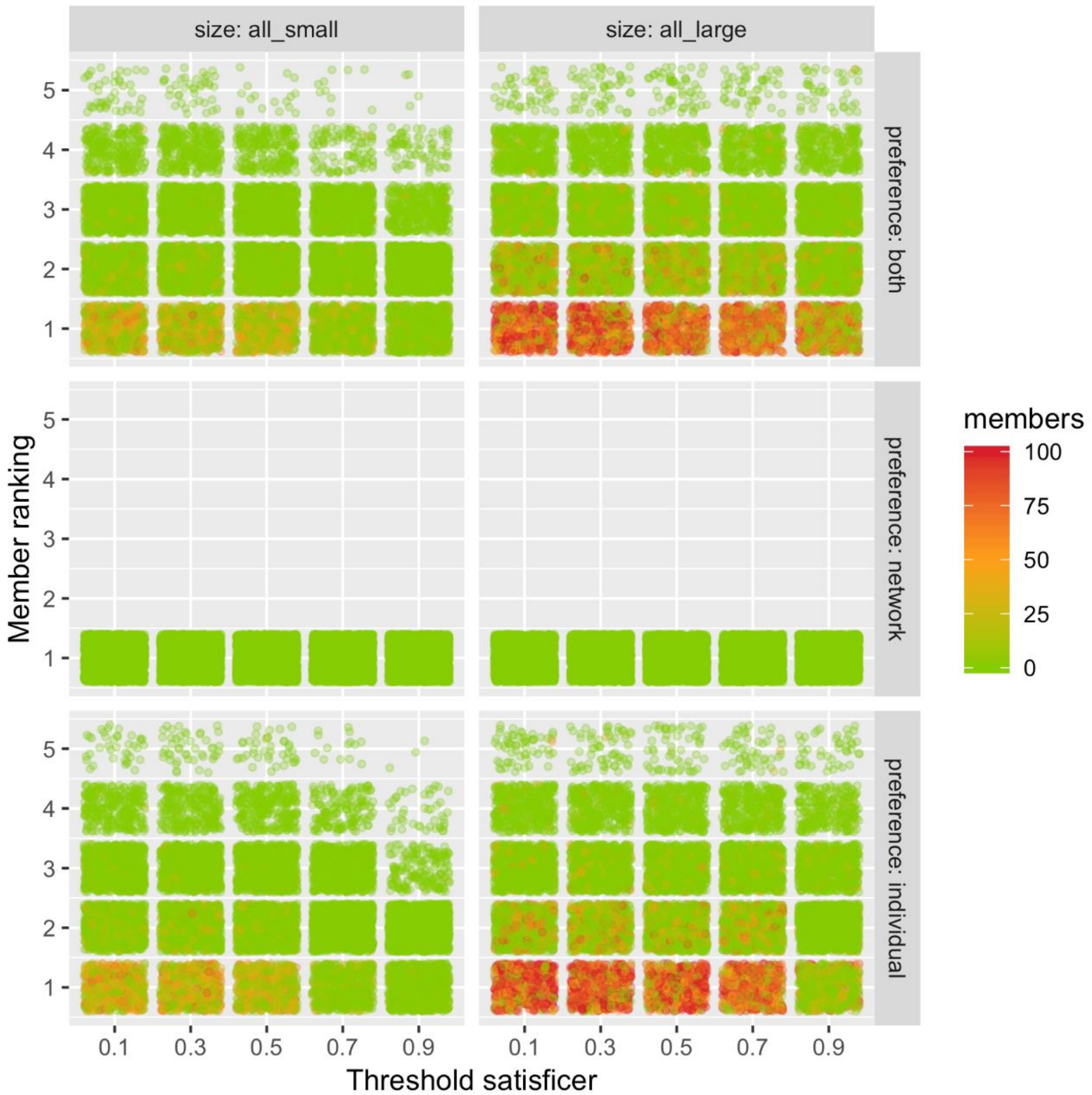

Figure 55: Satisficer threshold and firm-size effect on alliance size distributions

`Network`-oriented agent scenarios are, of course, not generating any lock-ins and the diagram thus shows neither any alliance density nor surviving members in the alliances. For the `individual-`

oriented runs, the threshold values prove similarly restrictive as they did for density, with the higher threshold 0.7 and 0.9 for all_small and 0.9 for all_large levels affecting alliance sizes in the first two alliance ranks, and these threshold levels also reduce the number of surviving alliances in ranks 3-5, especially for all_small which makes sense given their more restricted connection options compared to the all_large runs.

Comparing the results of the sensitivity analysis with the findings in Experiment 2c reveals that the differences generated by the varying threshold levels are not particularly strong. The findings on lock-in occurrence, times-to-lock-in, density and surviving alliances and their member sizes essentially echo those of Experiment 2c. Only some minor differences are introduced by the different threshold levels, especially with the higher ones restricting existing effects and the lower ones enhancing them even further. The model thus exhibits robustness to the varying threshold levels as the outcomes from the sensitivity analysis are not systematically different.

The notable finding from Experiment 2c where network-oriented satisficer runs generated no lock-ins at all was reproduced and even holds across all threshold levels. This shows that, as expected, agents lack time to develop network characteristics that make them attractive enough so that their satisficing alters would consider them as cooperation partners. Furthermore, it appears that the very existence of an absolute threshold rather than one that is too high is detrimental to agent and alliance survival in those scenarios. Running network scenarios experiments like in Experiment 3 with existing, historical connections and satisficing agents, however, would be likely to change this finding. In addition, an implementation of a relative threshold level, such as "agents are attractive that are at or above the mean attractiveness in the world" of the respective run would also change the findings.

Moreover, it appears that the experimental threshold value of 0.5 was well-chosen for the experiments with the satisficing agents since it lies right in between the extremes in the findings and permits all other effects to appear sufficiently identifiable. The interesting logic of the experimental setup is that, when seeking to make the best of the alters they find in the world, maximisers are less likely to lock-in than satisficers which are looking for agents that are 'good enough', even when the threshold for 'good enough' approaches rather high values of 0.9. The behavioural assumptions regarding agents' decision-making – here strategy and benefits-preference – are clearly the largest contributor to differences in the model outcomes and deserve greater attention in future research.

In conclusion, then, the model outputs derive more from other mechanisms than purely from the threshold levels, such as lack of time to develop suitably attractive network characteristics. The scenarios produce the same systematic behaviour across all variations of the threshold level. This indicates that a) the model outcomes are robust enough to not be influenced by the threshold levels of min-attraction and that b) the mere existence of a (any) threshold level appears to be the cause of the intriguing results of Experiment 2c, above.

4.7 SimPioN: concluding discussion

The creation and experimentation with SimPioN followed three objectives: to study an implementation of the explanatory framework developed above regarding the conditions under which lock-ins in interorganisational networks can unfold over time; exploring the model behaviour for developing theory; comparing the effects of different implementation choices and experimental scenarios. For the experimental design, I developed 5 experiments with some 42,000 runs (excluding the sensitivity analysis) which I have analysed in depth and discussed above. This section serves to reflect on the overall results, findings and implementation and experimentation choices.

Experiments 1-2b varied the behavioural assumptions (firm-strategy) for agents' decision-making and with firms' preferences set to only include individual characteristics for assessing alters' attractiveness. In Experiment 2c, alters were assessed with all three strategies and the experiment introduced the three different preferences to study the effect of their interaction. Experiment 3, in contrast, varied the network setup of the environment to study the effect of an existing, historical network structure on model behaviour regarding lock-ins and their conditions.

	Factors				Factor levels
Individual	Firm-size-distribution	all_small	all_large		2
	Firm-age-distribution	all_young	all_old		2
	Firm-resource-distribution	all_low	all_high		2
Network	Firm-strategy-distribution	Maximise	Satisfice	Despair	3
	Firm-benefits-preference	Individual	Network	Both	3
	Init-network-scenarios	oneAlliance	twoEqual	twoUnequal	3
Simulation settings	Design points: Σ = 168		Total runs: Σ = 42,000		
	Repetitions: Σ = 10,500,000		*Duration:* Σ = 21,840,000 ticks		

Figure 56: SimPioN, Overall experimental runs statistics

4.7.1 Experimental outcomes

The maximising agents in Experiment 1 were set up as a base case scenario of this experimentation and thus as a reference against which other experimental results can be compared. These runs systematically locked-in the least overall (42% of runs). Runs lock-in overall more slowly r compared with all other experimental setups (except for `individual`-oriented maximisers with pre-initialised network structures in Experiment 3) – a result of more carefully considering alters than in other scenarios. `all_small` scenarios locked-in more quickly but less often than `all_large` which still locked-in less often than most other design points outside Experiment 1. `all_small` attained lower densities and smaller alliances sizes than `all_large` runs but with higher spread in the densities. Both factors resulted in many alliances in the ranks and many agents not surviving. This finding indicated a trade-off between either becoming locked-in in a medium density alliance and barely surviving (if at all) without lock-in but with only very few network connections. Of the individual characteristics, firm-size exhibited the largest influence on lock-in conditions which reveals that the number of connections that firms can entertain has a strong influence on their likeliness to lock-in and the conditions of these lock-ins. Findings on `firm-age` show for `all_young` combined with `all_high` resource and `all_small` size (mimicking e.g. well-financed tech start-ups) that they took longer to lock-in, yet produced overall more lock-ins and at higher densities, than other combinations.

In Experiment 2a, I altered the experimental setup to satisficing agents. This variation of the base case caused runs to lock-in at a much higher rate (85%) than the maximisers, and much faster. Again `all_small` scenarios locked-in less than `all_large` ones, and were faster to do so. The newly introduced threshold level for alters' attractiveness added some interesting dynamics by locking-in runs faster, and almost removing the differences in the effects of the agents' `individual` characteristics on lock-in tendency. For alters having to meet the attractiveness threshold through the aggregate `individual` characteristics reduces the isolated influence of these. The attained densities of the runs were considerably higher compared to the maximising agents, especially for `all_large` setups – a result of agents less discriminately filing their free slots. Overall, more alliances and agents tend to survive, indicating a trade-off where being more connected to potentially less attractive agents secures survival (also that of the alliances) and remaining unconnected which leads to the demise of more agents and alliances.

Experiment 2b used the same base case setup but with `firm-strategy` set to use `despairing` agents. As expected, setting agents to accept all connection requests indiscriminately leads to lock-ins in 85% of runs with only `firm-size` having an impact on lock-in occurrence with `all_large` runs locking-in more often than `all_small`. Since agents connect to any other without assessment, the lock-ins generate high densities in the alliances, especially when firms are `all_large` and have many firm-slots to fill. `all_small` firm scenarios locked-in slower than large ones, but considerably faster than in the maximiser Experiment 1. The `all_small` agents have fewer slots to fill and since they (dis)connect at random, this behaviour leads lock-ins taking longer than when following a satisficing decision logic, since more switching occurs. Achieved densities of locked-in runs were comparable to satisficers but more concentrated around `d=0.2` and `d=0.6`, while satisficers even reached `d=0.75` and beyond. The results also echo the finding that the alliances decrease in density with every step down the dominance (=relative size) ranks. Compared to maximisers, both satisficers and despairing agents permit more alliances to survive than with the maximisers, and this similarly hold for the number of agents. This indicates there may be a further trade-off: if firm survival depends on being connected (as implemented here), then connecting more indiscriminately may lead to superior survival chances than carefully choosing networking partners.

This is not the only difference between the strategies, as revealed by Experiment 2c, which was implemented to compare the assumptions regarding agents' decision-making more directly and to introduce variations of the `benefits-preference` factor, i.e. studying the impact of firms' different strategic goals and its interaction with their preferences. Despairing agent runs lock-in almost as often as the other two strategies combined, while the impact of preferences shows that focusing purely on alters' `network` characteristics locks-in less often than on `individual` or `both`. Maximisers lock-in comparatively less frequently, and almost evenly across the preference scenarios, with the `individual`-oriented runs taking the longest time-to-lock-in. Despairing agents lock-in entirely at random and thus with the same frequency and time-to-lock-in nearly irrespective of their behavioural setting regarding preferences. For the design points with preferences purely for alters' `network` characteristics, no lock-ins occur for satisficers, while the other two preferences are almost equal in both frequency and time-to-lock-in.

This starkly contrasting result for the satisficers when only considering alters' `network` characteristics reveals that when satisficers use a fixed threshold (here `0.5`) there can be a pitfall in terms of this threshold being an overly rigid criterion when alters are almost entirely of lesser attractiveness than that threshold. Precisely this situation was induced by the lack of a developed network for the `network`-focused experimental setup above. This duration-of-run effect leaves the satisficing agents to satisfice based upon essentially variable values of zero since no individual characteristic can compensate for this lack of attractiveness (unlike in the `both` scenarios) and many agents perish due to being unconnected for too long. In this case, the satisficers actually behave more strictly than the maximisers (and despairing agents) and this indicates than an adaptive strategy using a relative threshold level (e.g. `threshold_attractivenessScore ≥ world's_mean_attractivenessScore`) may be a more sensible strategy than a rigid one, even if the threshold level is then set rather low. Satisficers, however, achieve the overall highest densities when focusing on `individual` characteristics, or `both`. Maximising agents which rank their alters relatively rather than against an absolute threshold produce runs with few lock-ins when assessing alters purely on `network` criteria. When these do lock-in, they do so rather quickly and at density levels comparable or slightly lower than those runs with `individual` preferences, albeit with fewer large alliances and more density outliers. The speed of maximisers locking-in for purely `network`-based is faster than any of the other factor combination. This finding points towards a positive feedback loop in the network characteristics, as intended in model design: while initially connections appear essentially at random (all agents start with `attractivenessScore = 0`) central actors are then recognised as desirable partners and this leads to them having more connections, leading to more centrality and more attractiveness. The sensitivity analysis showed that findings remain robust when varying the threshold levels between `0.1` and `0.9`.

Having compared the influence of assumptions regarding agents' decision-making, the findings pointed towards testing the influence of different network structural scenarios on the emergence of lock-ins. Hence Experiment 3 set out to study the model's behaviour with regard to three different settings of historical network connections among agents: with *one* large alliance, with *two* medium-sized alliances, and lastly with *two* of which *one* small and *one* large alliance, all present at initialisation. Agents strategy was set to maximise, since that promised the most useful results regarding the network characteristics (no threshold effects, but more decision-making logic than despairing).

The results are rather striking, especially when compared to the `individual` characteristics-oriented maximiser experiments above. Not only do the `network`-oriented maximisers in the network history experiments lock-in much more often than any other experimental setup above (99%), they also do so faster than the maximisers focusing on firm's `individual` characteristics, no matter what preference they have. This indicates the high relevance of historical ties that inform the continuation/ formation of new ties and make lock-ins overall fast based on the already established relations. Similarly, `network`-oriented agent scenarios were the fastest to lock-in across network structures, while `both`-oriented runs take longer to lock-in since they to need to assess alters' developing network characteristics. `both`-oriented runs behaved like `individual-oriented` runs with regard to density and its distribution but behaved like `network`-oriented runs with regard to their overall smaller alliance sizes and lock-in speed.

While their alliances reach higher density levels than for the `individual`-oriented maximisers, `network`-oriented maximisers also have higher spread in the outcome densities, especially for the scenarios with `twoAlliances`. `oneAlliance` runs attain lower densities and see fewer surviving alliances than `twoAlliance` initialisations which also exhibit more spread in density. This points towards a competition between agents belonging to the respective initialised alliance group(s) and others, with the initialised alliance(s) prevailing over emerging ones in terms of size and density. There is also a trade-off between alliance size and density with smaller alliances attaining higher densities than large ones. Initialising `twoAlliances` resulted in (at least) three ranks filled in the results points towards the existence of network brokers that bridge the network-structural holes between the alliances of the first three alliance ranks by being member in more than one.

Overall, initialising the network scenarios caused locked-in runs to be overall more numerous, faster, denser and with more spread over time and density. Resulting alliances also occupy more ranking spots than the maximising agents of previous experiments. `Network`-oriented agents expectedly exhibit the overall largest exposure to the influence of different network initialisations. Network scenarios and preferences interact to reveal systematic influences on lock-in conditions but not on the occurrence frequency of lock-ins. The `both`-oriented runs mimic real-world firms in competing interorganisational alliances, with the setup of `twoAlliancesEqual` being the closest representation of the above case study scenario. The trade-offs of smaller alliance sizes but higher density or vice versa appear to be a difficult balance to achieve within a interorganisational networks, especially given their nature of distributed agency and imperfect knowledge and control of the conditions.

4. 7. 2 Outcome measures

With regard to the outcome measures, several general patterns emerged. For lock-in occurrence, the results ranged from 42%-99%, indicating a clear impact of changing the behavioural assumptions regarding agent decision-making. Lock-in statistics also showed, in contrast, surprisingly little influence of agents' initialised `individual` characteristics with the exception of `firm-size` where `all_large` firms tend to lock-in more often, based on having more slots available for connections to alters. Strategy variations play a stronger role for lock-ins than preferences while keeping the latter constant. Maximisers with `individual`-oriented preferences are generally the least likely to lock-in and if they do, take the longest times-to-lock-in, with also the longest outliers. In the network structure experiments, the `network`-oriented maximisers locked-in the most frequently and the fastest across the scenarios, exhibiting a strong impact of network characteristics on agents' attractiveness and their tendency to create stable network structures.

Times-to-lock-in varied strongly, influenced especially by settings of the factor `firm-size`, typically, but not universally, resulting in `all_small` scenarios taking longer to lock-in than `all_large` ones. This is based on the connection consequences (firm-slots, max-new-connections) of the `firm-size` implementation. Generally, however, lock-ins tended to be quite swift with the highest median time-to-lock-in being 63 ticks and the highest mean being 65 ticks, both measured after 104 ticks with less than 5 agents switching alliances. The lowest numbers were 1 tick for median and 3 ticks for mean, indicating that some scenarios were rather susceptible to initial settings leading to near-immediate lock-ins, even if diagnosed *post-hoc*. Outliers reached as far as 394 ticks without network scenarios and 416 ticks in the network scenarios, both times exhibited by maximising agents with preferences for their alters' `individual` characteristics. Times-to-lock-in as the first measure for the conditions of lock-ins thus varied considerably, but as a tendency only outlier runs reached late ticks.

As the second lock-in conditions measure, the densities achieved by alliances in the different experimental runs indicate that satisficing agents (with individual/both preferences; Experiments 2a and 2c) achieve the overall highest density levels and highest variance, and lock-in relatively quickly, while despairing firm scenarios take similar time but result in strongly clustered densities around the levels of `d=0.2` (`all_small`) and `d=0.6` (`all_large`), depending on `firm-size` initialisation. Densities in the network structure scenarios exhibit considerable spread across scenarios, and a general trend indicates that the larger the alliances, the lower their densities, with the highest density levels attained by relatively small alliances. Density as the measure for the share of realised relationships out of possible relationships within a network are measured on an alliance level of analysis and it is also important to consider their relative sizes, i.e. dominance in the whole network.

The alliances ranked by size reveal that: the higher the number of members, the lower the resulting density, and vice versa. Additionally, the densities are plotted according to ranks 1-5 and indicate that almost in all experimental scenarios, a majority of runs lock-in with rather large alliances in the first rank, often with 75-100 members as indicated by the orange to red colours of data points. The maximiser scenarios with `individual` preferences exhibit the least amount of alliances in the ranks 2-5 than other setups, indicating that few alliances contain members at the end of these runs and the first i.e. largest one remains the only one with a considerable member count. In all other setups, however, other ranks are filled with data points and have at least orange data points displayed, with a decreasing frequency, the lower the rank. The fifth ranks generally contain rather few data points, even in the network structure scenarios, and the fourth ranks exhibit substantially fewer data points than the first three ranks with only few orange data points for larger membership numbers. This is consistent with agents being able to become members of up to three alliances, i.e. sustain relationships to alters connected with these alliances. New experimental designs could (and should) experiment with this value in order to test for e.g. exclusivity effects of memberships, although, notably, none of the alliances in the case study required exclusivity.

In the `twoAlliance` scenarios in Experiment 3, substantial numbers of data points are also located in the fourth rank, with considerably fewer data points in the fifth rank. This indicates that initialising more alliances also leads to more alliances surviving until the end of the runs. These remain small alliances, however, unless agents have `individual`-preferences when even the fourth rank exhibits orange dots. Predictably, initialising `oneAlliance` leads to hardly any data points beyond that first alliance for `network`-oriented agents since they optimise on the network characteristics of their alters and only have agents from this first alliance with values signalling an adequate degree of attractiveness. This main alliance continues to be the main source of attraction until the end of the run and, while the second alliance rank is hardly occupied, the third rank does, interestingly, exhibit some data points where a third alliance has emerged, most likely based on overlap with the first, though, since those agents are the only ones attractive enough to connect to.

In Experiment 2a where satisficer agents focus on `individual` characteristics, all alliances' size ranks become filled, with substantial numbers of runs seeing more alliances survive until end-of-run in the first four ranks. In the majority of other setups, runs result in up to three high-membership alliances and often few to none smaller alliances, or only with comparatively low densities in the lower ranks, i.e. smaller alliances. This points towards a trade-off of either becoming locked-in in large (small) alliances with low (high) density but surviving the experimental run, or surviving with only very few network connections, leaving firms comparatively isolated or more frequently ceasing to exist entirely for lack of connections, as implemented here.

4. 7. 3 Implementation, limitations, and future extensions

Taken together, the evaluation and interpretation of the simulation experiment results leads to rather insightful findings. While `individual` firm characteristics like `firm-resources`, `firm-age`, or `firm-size` (in ascending order of effect) play only a small role in agents' patterns of forging connections overall, `firm-size` remains comparatively high since it has direct consequences for agents' available connection slots. Interestingly, it is mainly agents' decision-making behaviour assumptions on `strategy` and `preferences` that define their tendency to enter locked-in system states, be it in the `individual`-oriented, in the `network`-oriented, or in `both`-oriented scenarios.

Strategic decision-making styles – unlike motivations for networking – was not a focus identifiable in the literature review on interorganisational network research in OMS and these simulation findings reveal a certain level of neglect here, which would be worthwhile remedying. It appears that assumptions regarding agentic decision-making are often not made transparent in research or these appear not to be recognised as influential issues. This is problematic since Experiments 2c and 3 clearly indicate that decision-making assumptions are of high relevancy and this may well apply to the validity of empirical findings. If empirical research assumes a maximising behavioural model and interprets data in the light of this frame of reference rather than capturing the actual decision-making mode in action, for example, this may lead to rather different interpretations of the data and potentially erroneous conclusions.

The advantage of the precision produced, and the flexibility offered by the computer simulation approach is the ability to study the consequences of changing the agents' behavioural assumptions, and the resulting differences in outcomes (and thus research findings). While the findings of the experiments obviously do not permit claims regarding the 'right' behavioural model for firms to use or for empirical research to assume, the model points out three behavioural alternatives. These, or more likely more refined and contingent combinations and/or mixtures of these, may well also exist in empirical settings. Given that indications for their importance are now revealed, a fruitful research approach could be to seek out the actual behavioural modes such as strategy and preferences of network actors in fields of practice, and to study their influence on relevant network outcome variables such as alliance entry or cooperation partner choice, and subsequent consequences for potential lock-ins. Simply assuming maximiser behaviour of empirical agents can be too critical an assumption to make without deeper, reflected knowledge, and may lead to inadequate conclusions.

The aspect of agency is particularly relevant for the path dependence literature where the debate on agentic decision-making and positive feedback developing behind agents' backs has meant that path dependence theory has received some criticism regarding a claimed under-specification of agency (e.g. Vergne & Durand 2010), or the theory being rejected on the very grounds of allowing other decision models except rational maximisers into the theory (e.g. Liebowitz & Margolis 1995). Neither argument holds entirely, however, since agency is deeply embedded in the theory and using idealised theoretic behavioural models such as *homo oeconomicus* maximisers does not solve the theoretical issues with regard to path dependence. As shown in the experiments, maximisers (with some bounded rationality) can be just as likely to lock-in as satisficers or despairing agents, depending on the kind of information and preferences upon which they base their decision-making. For instance, the network structure-focused Experiment 3 showed considerably more lock-ins (and faster times-to-lock-in with also considerably higher alliance densities) when maximising agents assess alters' attractiveness based on emerging `network` characteristics than when basing their decisions on alters' `individual` characteristics. Including `both` types of information into their consideration – since, as one might argue, maximising agents need to be modelled as closely as possible to fully informed rational agents – only makes this finding even stronger. The results thus provide a clear indication that a network structure dynamic can drive the lock-in of actor groups such as alliances, and as a whole network system even with maximising, i.e. less restricted boundedly-rational agents, but experimentation with e.g. increased perception (e.g. `reach=3`) would be of merit for studying effects of bounded-rationality differences.

The explanatory framework above argued that network 'history matters' with regard to becoming locked-in and this can clearly be affirmed for the simulation experiments built on this framework. Experiment 3 implemented three different network scenario settings (one of which was inspired by the empirical case study above) where initial alliance numbers and initial alliance member sizes were varied. These alliances exhibited attraction powers, leading many agents to heavily connect to members of these initialised alliances. Also, there were indications of some spill-over that led to agents becoming attractive through their network characteristics from their first (and/or second) alliance memberships and those with slots available were able to enter into also locking-in third alliances, the upper limit of total memberships per agent. Further experiments could benefit from testing the effect of limiting or even extending the possible alliance memberships of agents or making their number of alliance memberships dependent upon an individual characteristic such as `firm-resource`, echoing the implementation of `firm-size` and available slots. The high lock-in proclivity and spill-over into more than initialised alliances is also an indication of firms seeking to be heavily connected (and become locked-in) rather than break out of this density trap and continue activities alone or by joining a much smaller alliance, such as a challenger to the incumbents. Thus, as a flip-side, not joining an alliance can be detrimental in industries where staging technological change does depend on *not* going it alone. Not joining other agents, or not being able to because of individual or network-structural limitations, can lead to firms' demise, exclusion from common assets such as market power, technological standardisation, protection from outside challengers etc. as is the nature with the real-world effects of the social capital mechanism and involved processes.

Among the individual characteristics, the experiments established that `firm-size` is the most influential variable leading to high density and to lock-ins and interacting with `firm-age` to even increase the effect when firms are all_young. In the real world, this variable of firm-size might naturally be (called) something different. However, the purpose of the construct in SimPioN was to provide an implementation of firms' heterogeneity in their ability to sustain fewer or more relationships simultaneously, and heterogeneity with regard to how many connections firms can enter per given period (simulation tick). In the real world, such difference in networking abilities do exist, too, and firm-size (e.g. employee numbers, financial resources, turnover etc.) may not be the only relevant aspect or resource for defining this capacity to link with alters. The model experiments merely point out that especially firms with large firm-size and, as implemented, a derived high ability to connect to alters tended to lock-in the system rather quickly, while smaller firm scenarios locked in later, which is problematic since larger firms have elsewhere been found to suffer from loss of control over their relations and resources (Gargiulo, Ertug & Galunic 2009: 326-331).

The experiments, of course, necessarily used artificial and extreme value setups where (within defined parameter ranges) firms in a given scenario were all_small or all_large because such variable settings allow for gaining an understanding of the workings of the model and the bandwidth of the effects of individual factor settings on the outcome of lock-ins. Real-world scenarios would most likely have more variance in the composition of firm-size and more factors contributing to firms' ability to link with others or potentially abilities to compensate for a lack of them through e.g. alliance and/or relationship management skills. A study of this possible causal link in an empirical context would thus be a worthwhile effort for providing a 'linking ability'-based explanation of network lock-ins. Such a question is also of high importance for absorptive capacity studies where firms' abilities to acquire knowledge from cooperative partners may very much depend upon their networking ability or skills. Furthermore, the attractiveness function and its values may be more refined and specified for empirical firms and lead to more nuanced findings than the model scenario here. For the purposes of this model experimentation, however, the differentiation on this level is valid enough to explore the role of outcome network structures.

Further extension can easily be added to the model, e.g. if empirical evidence suggests including certain values or new variables. SimPioN also allows for testing competing explanations. Possible extensions could involve adding the ability for agents to make negative experiences in projects with cooperation partners and familiarity would then take a negative algebraic sign rather than the positive influence typically assumed in the literature (and used here). Also, the effects of e.g. actor centrality could be studied more in detail at an individual actor's level to identify the consequences of and for individual agents' network structural positions and their relations. Adding to this would be an implementation of agents that are not only perceiving their alters' network positions, but also those of themselves, combined with certain capabilities to (seek to) adapt these to their strategic goals. A further interesting question to ask the model would be an implementation of the different alliance management and decision-making styles identified as part of the empirical case study. This question was beyond the scope of this study's modelling exercise, but is warranted given that network administrative organisations, voting models, and hub steering are clearly differentiated management styles entailing consequences. A simulation model can study these more in detail than an empirical model where the isolation of individual causal effects is easily clouded by social complexity at other levels. SimPioN model is the (and a) first implementation of the explanatory framework for explaining and experimenting with path dependence in interorganisational networks. The methodological approach taken entailed decision-making regarding precision, i.e. the elements of underlying theory (e.g. the decision-making models used here and elements of the framework) must be made explicit and be specified in order to allow for implementation in software code – something that no current alternative explanatory model of network path dependence offers. A large part of the model implementation work requires the uncovering of conceptual gaps and inconsistencies (Sawyer 2004: 220) and the effort thus also involved a structuring of the field regarding certain model choices. Among these were the questions regarding the role of the behavioural assumption, i.e. motivations for why agents connect to one another and how they identify (subjectively perceived) suitable candidates, how they reason about their selection, on the basis of which decision-making logic they then connect (or not), and not least, which (statistical or network) measures are best used for identifying network dynamics unfolding over time in a meaningful way to capture lock-ins, densities and system stability etc.

Among the measures developed and used here, certainly the definition of lock-in is one where further investigation with varying definitions is warranted. Path dependence theory defines a path-dependent process as an increasingly narrowed-down range of available options for agents, culminating in a lock-in with problematic implications. To build a model, this process and the lock-in definitions require a translation and specification to make it measurable as a model outcome variable. Like any conceptual definition and choice, the ones used here are, of course, subject to discussion and in fact invite discussion. It is one of the strengths of this methodological approach that it enforces precise conceptual definitions that will enable, and to some extent enforce (discussing) definitional choices. One clear further advantage of a social simulation model proves especially convenient here: unlike empirical approaches, it can easily be extended to test competing definitions and their implications to spur further discussion on conceptual and theoretical clarity.

The experimentation with SimPioN as a complex thought experiment clearly showed that Vergne and Durand's (2010: 750) claim regarding the fruitfulness and strengths of computational simulation for path dependence research is completely justified. The model's scenario-based experimentation approach led to output properties and meaningfully differentiated system-level results that now inform theory development and debate which will ultimately lead to an improved explanation of the phenomenon of path dependence in interorganisational networks, as this study set out to develop.

5. Overall discussion and conclusion

"When we try to pick out anything by itself, we find it hitched to everything else in the Universe"
(John Muir 1911: 110).

In this thesis, I asked the research question "why, under which conditions, and by what processes can the interorganisational networks in which firms participate become path-dependent?" This question is highly relevant for both theory[35] development – the phenomenon was previously inadequately explained – and due to the detrimental consequences for firms that path dependence in interorganisational networks can entail in terms of decreased strategic flexibility, reduced performance, reduced ability to survive in times of (rapid) change, restricted access to know-how and resources, all of which can impede or limit firms' development. It is thus important that OMS research endeavours to address the phenomenon's problematic consequences by first providing an adequate understanding and reflection of the phenomenon. This study aims to contribute to such an understanding of the emergence of path dependence in interorganisational networks and thus seeks to shed light on this 'dark side' of interorganisational networks.

Answering the research question involved a four-stage process. A thorough literature review was initially undertaken to identify, discuss and reflect the extant literature's conceptual understanding of the phenomenon. The fields covered here are the network approach in OMS, path dependence theory, and social capital theory. The latter was discussed and conceptualised as a positive feedback mechanism that can drive path dependence at the (whole) network level through (potentially strategically-steered) increasingly dense network (sub-)groups that, while initially desirable, increasingly restrict actors' ability to strategically choose relationships with partners in- and outside their existing network (sub-)groups, thus impeding long-term adaptability and viability. This new conceptualisation remedies the lack of network dynamics representation in previous (comparative) static approaches (e.g. Walker, Kogut & Shan 1997).

Secondly, I developed an explanatory framework that integrates the relevant elements from these three schools of thought. Thirdly, I brought the explanatory framework to life by providing an empirical example in the form of an empirical case study to substantiate, elaborate and illustrate the explanatory arguments and permit further theory development by identifying how the abstract mechanisms work in practice, thus facilitating an evaluation of its plausibility. Finally, I formalised the framework into an agent-based computer simulation model to provide more fine-grained measurement and observations of the process unfolding in interorganisational networks and on the specific

[35] 'Theory' implying the development of an abstract and (to some degree) generalisable causal explanation for a phenomenon under study.

conditions of the lock-in phenomenon. In this way, uncovering the conditions of network path dependence involved studying both the causal conditions as well as the outcome conditions, i.e. the evaluation of locked-in simulation runs. Each of these four stages contributed to the development of an explanation of the phenomenon of path dependence in interorganisational networks by (1) distilling relevant processes and elements, (2) integrating them holistically, (3) substantiating and elaborating the plausibility of the framework through a confrontation with an empirical case, and (4) through exploring the impact of the explanation on specific conditions as complex thought experiments using computer simulation.

I summarise and reflect on these four stages in the following by discussing first the theory review and development (focusing on the 'how'), and the empirical case study chapter and the simulation model (focusing on the conditions).

5. 1 Theory and framework

This study set out to explore and explain why, and under which conditions, the interorganisational networks in which firms participate can become locked-in. The interdisciplinary nature of the research question involved developing the theory further so that it accounts for the socially complex phenomenon of path dependence in interorganisational networks studied here.

The review of OMS research on interorganisational network revealed that the literature is surprisingly divided on many issues regarding overly-stable interorganisational network structures. Several authors (e.g. Kim, Oh & Swaminathan 2006; Hagedoorn & Frankfort 2008) agree that there is a 'dark side' to the much-praised, allegedly hyper-flexible, network form of organisation. However, they disagree on elemental aspects, such as the name for this flipside, which has been described variously as historicity, imprinting, overembeddedness, inertia, rigidity, lock-in, path dependence etc. (in approx. increasing order of severity), and are similarly divided in their reasoning on the grounds. One common characteristic of this adverse situation which the literature seems to agree on is that firms in such networks often form competing (sub-)groups (described using terms such as 'groups', 'constellations', 'blocks', 'alliances', 'alliance blocks', 'networks' etc.) which over time become increasingly dense and closed to the outside.

An overly-stable network situation can restrict the flow of resources to firms requiring these, limit their ability to find (the most suitable) cooperation partners for certain tasks, and restrict their access to (sourcing) opportunities outside of their alliance, their overall flexibility and thus their long-term performance and viability. Many studies, however, remain unclear regarding the precise mechanism leading to such network structural rigidity, and often remain at a superficial level when it comes to identifying the causal mechanism generating the claimed rigidity. The empirical literature, in particular, currently lacks a proper understanding of the time dimension to explain how the network structure becomes locked-in, not least due to data collection issues.

Path dependence theory was identified as an appropriate candidate to address the complexity of such a network dynamic by Walker, Kogut and Shan (1997), among others, but the authors use path dependence merely in a metaphorical sense without utilising the full explanatory power of the theory regarding the process unfolding its dynamics over time. Path dependence theory provides an adequate lens for studying emergent phenomena that restrict actors as they pursue their goals. Path dependence theory was adapted from economics (David 1985) to fit management and organisational contexts (Sydow, Schreyögg & Koch 209). This adapted theory contains a three-stage model in which, after the initial "small events" stage, the option space of available alternative actions becomes increasingly narrowed down after a "critical juncture" through the workings of a (or several) positive feedback mechanism(s). These can drive actors into "lock-ins"– unintended situations characterised by a severe lack of alternative options, rigid stability, and the inability to resolve the situation.

This explanation of path dependence phenomena relies centrally on the existence of a positive feedback mechanism that, while beneficial at first (both in time, and at first glance), can unfold restrictive forces which develop negative consequences over time. Path dependence theory contains such positive feedback mechanisms, i.e. adaptive expectations, learning effects, unit accumulation, complementarity, and coordination effects. However, a positive feedback mechanism explicitly targeting the whole-network level of analysis in interorganisational networks was lacking originally. A suitable mechanism with the properties of narrowing down available networking options over time and finally exerting restrictive structural forces was identified in the concept of social capital from the network research stream in OMS.

Social capital had also been applied to interorganisational networks and had been found not to be positive *per se*, as the capital metaphor would imply, but to also possess a 'dark side' – just like interorganisational networks – that may restrict firms' long-term performance through strong network (sub-)group closure (Maurer & Ebers 2006: 285). When social capital was applied to interorganisational networks, it was mostly with static reasoning (e.g. Duysters & Lemmens 2003; Maurer & Ebers 2006; Zaheer & Soda 2009; Kim, Oh & Swaminathan 2006; Gargiulo & Benassi 2000; Hagedoorn & Frankfort 2008), neglecting its necessarily processual nature and using the metaphorical confusion as a substantive quantity rather than as the actual process of agent interaction (Bankston & Zhou 2002: 285). However, because questions remained open with regard to network dynamics (Todeva & Knoke 2002) an integration with path dependence theory appeared sensible to thoroughly integrate processual dynamics.

Social capital is a diversely-defined social science construct with many interpretations. Only a few of them, however, allow for dynamic network development aspects. To enable such a process perspective on social capital, I build upon and extend Burt (2005) to connect the conceptualisation of the Burtian school on the network brokerage of structural holes (Burt 2005) with the Colemanian school on the potential benefits of forming densely-knit and closed network constellations (Coleman 1990). This effort resulted in a process-oriented explanatory framework integrating a dynamic social capital conceptualisation: an initial brokerage stage of agents connecting their alters leading to (strategically enacted) increasing closure of network (sub-)groups. Rather than the classic 'substantive quantity' (Bankston & Zhou 2002: 285) metaphor of social capital, this process-oriented perspective on social capital stresses the effects of actors' strategic productive interactions unfolding their restrictive forces through the interacting cognitive, relational, and structural dimensions (Nahapiet & Goshal 1998), and of actors interactively dealing with – and, to varying degrees, reflexively influencing – their network structural conditions to the extent that they are aware of them.

This mechanism then extends path dependence theory's applicability into the interorganisational network realm with a whole-network focus. Network actor (sub-)groups with only few entries or exits can be considered stable or even overly stable if such structures persist over long periods of time.

Additionally, the more densely knit the relations contained, the more difficult it becomes for the embedded actors to resist the binding coercive forces of the social capital mechanism. Learning, expectations, complementary cognition, emergent norms of cooperation, economic exchanges, strategic partnering, and other activities emerge and are carried out on the basis of, and are forming, the emerging network structural conditions, potentially leading to lock-in. While network closure can be beneficial and is thus strategically sought-after initially, closure can also arise without intention or to an unintended degree, since the distributed agency of actors over time can remove the – at best imperfect – control over the process. It can also remove connection options for actors that may have been more beneficial than continued membership of their interorganisational network (sub-)group when it has come to entrap its members in a lock-in as a result of a path-dependent process in interorganisational networks, as this study sought to explain.

The framework thus connects path dependence and the positive feedback mechanism of the (process dynamic of) social capital in a novel way to explain the lock-in of network (sub-)groups in which firms participate, and how these lock-ins can entrap network members and eradicate potentially better alternatives for action. This explanatory framework is the main theoretical contribution of this study. It charts the integration of a newly-developed positive feedback mechanism within path dependence theory in order to extend its explanatory power to dynamics at the whole-network realm in interorganisational network research. Furthermore, it reunites two social capital conceptualisations which the extant literature formerly deemed oppositional, because their conceptualisations missed an explicit process lens. Overall, the framework concentrated on explaining the phenomenon, i.e. addressing mainly the "why" part of this study's research question. The aspect of the research question regarding the conditions leading to and of the lock-in situation formed part of the empirical and simulation chapters above.

5. 2 Case study and simulation model

The confrontation of newly-developed theory with empirical frames of reference is a necessary step in research if the latter seeks to go beyond a purely intellectual exercise. Like many of the phenomena studied in OMS and social science research in general, the present research does not lend itself to testing in the prototypic mode of falsification through hypothesis testing. One important reason for this is the type of research question posed in the present study, which is both a 'why' and 'how' question, and requires a more explorative as opposed to a theory-testing methodological approach. At the same time, the conceptual vagueness of the extant empirical literature reviewed made a high degree of specification desirable, since specificity is an important agent in advancing the scientific debate, when conceptual incongruences and contradictory claims and findings hinder an advancement beyond the status quo. As a result of these considerations, I developed a two-fold mixed-method approach.

Firstly, I performed an empirical case study on two interorganisational networks – 'alliances' in the smartphone industry a) to substantiate the developed framework's applicability to an empirical phenomenon of path dependence in interorganisational networks; b) to provide a solid empirical illustration and elaboration of the phenomenon (Gilbert 2005: 743); c) to motivate both the research question and the developed framework as a means to answer it; and d) because the case was unfolding and studied during the creation of the framework, providing ample thought-related inspiration– all suitable purposes for qualitative case studies (Siggelkow 2007) and additionally allowing for the identification of inductively arising elements that contribute to theory development (Sutton 1997: 99; Eisenhardt 1989). For the empirical case study, I selected the high-tech-driven smartphone industry as my overall case and context, the *Open Handset Alliance* founded by *Google* as the temporally initial embedded case and the *Symbian Foundation* founded by *Nokia* as its theoretical/literal replication in a "most similar" research design for contrasting findings (Yin 2009: 50ff.).

Data from the empirical case was coded in five data categories and analysed with regard to 'brokerage and entry', 'alliance activities', 'closure, steering and control', 'fragmentation', and finally 'lock-in / exit.' The findings from the cases provided varying degrees of support for the data categories. While "brokerage" was clearly found to take place, *OHA* in particular exhibited a stronger directive involvement of its hub firm, while *SF* displayed a board voting governance model. Both interorganisational networks demonstrated increases in their internal cooperative connections ('alliance activities'), while steering towards closure and control took place more clearly in *OHA* than in *SF*. 'Fragmentation' is an inductive data category that arose from the field. It suggests that firms are aware of the path dependence dynamics in their industry. Both member firms and industry observers appeared to be aware of the need to keep several industry players bound to one project to make it successful in the marketplace. However, while subjects were aware of some potentially negative side-effects of these network dynamics (e.g. as exhibited in the employed wedding/wed-lock analogy), they also signalled a certain inability to avoid such situations, especially for smaller "follower" firms. Large firms with more available resources, however, appeared to be following a more portfolio-oriented approach, attempting not to become locked-in.

The evidence for the data category 'lock-in / exit' is mixed: in *OHA*, first one and later two more large alliance members voluntarily locked-in to the network and technology platform, suggesting a certain willingness to take such lock-in risks, but also an ability to switch. However, evidence suggested that these occurring lock-ins were not yet problematic for the focal firms. However, further evidence from outside the time-frame of systematic data collection (Appendix B) suggests that these firms leaving *SF* and exclusively joining *OHA* resulted in *SF*'s hub firm Nokia de facto closing down *SF*, with *Nokia* even selling its entire smartphone and mobile phone business shortly after. This closure of *SF* has caused large problems for remaining firms, many of which were much smaller and thus unable to adapt and make a similar switch to compensate, and thus lost considerably in terms of market opportunities, stability, profitability, and viability. *OHA* with hub firm *Google* steering the cooperation rather strongly has meanwhile become the only remaining open mobile platform and currently attracts approx. 85% of the market share, competing only with *Apple*'s closed *iOS* platform.

Contrasting the cases additionally revealed a concurrence of network brokerage and closure – a conceptually interesting finding, indicating that while brokerage logically needs to occur before closure, temporally the process seems to be taking place simultaneously, albeit for different firms and relations. This finding is in line with the process-oriented perspective on social capital as a path dependence mechanism that was developed for the explanatory framework where arguments of interaction stages, the three dimensions, strategic distributed agency, and the imperfect control over developments lead from initial brokerage to closure of the network with high density, and ultimately lock-in.

Overall, the case study provided insights into how these complex dynamics play out in practice, advancing theory development and reflection, such as the finding on the concurrence of brokerage and closure, and the case data generally substantiated the framework. In reflection on the case study, some questions remained open as far as details on the conditions of the lock-in situation are concerned, and new questions arose from the analysis and reflection of the case data. These include how fast lock-ins occur, how problematic and severe lock-ins are for network members, and how quantitative properties of the alliance groups develop, e.g. what density levels are attained. Furthermore, the overall structure at the whole-network level of competing alliances, the occurrence of entries and exits and the effects of existing historical relationships are interesting with regard to conditions and development of lock-ins. Moreover, firms in the case study exhibited considerable heterogeneity in terms of individual and network-related characteristics such as size, age, available resources, (networking) skills, network position, but also in their strategic orientation and pursuance of network relations. Thus, it is interesting to study how such differences affect lock-in tendencies at system level.

The remaining key questions lie in the realm of study that is best addressed by a high degree of formalisation such as that offered by a simulation study. A systematic analysis of contrasted virtual scenarios can answer such questions through experimentation with a computer simulation model, and the questions served as the guidance for the creation of response variables and model elements.

As a second stage, I subsequently created an agent-based computer simulation model. This relatively new method is an excellent choice for this (kind of) study since its methodological properties ideally match the requirements of advancing path dependence research (Vergne & Durand 2010: 750). It further serves as a fruitful approach for complex 'thought experiments', e.g. exploring different scenarios, to provide conceptual clarity and is not restricted by data gathering limitations like classical empirical research (one limitation of the case study). Simulations provide fine-grained data points for studying dynamics unfolding over time in great detail and, together with the ability to experiment with many different initialisation settings in terms of asking the model specific questions, it can overcome other methods' limitations and is ideally suited to the purposes of this study (Gilbert 2008).

Creating the simulation model named SimPioN was a precision-inducing exercise – an aspect that is relevant in its own right, since it provided a very first formalised implementation of the developed framework. Since no existing agent-based model could be adapted for the present purposes, SimPioN was created anew. This had the advantage (and disadvantage in terms of resource-intense efforts) that all model choices were made by the author before and during implementation. SimPioN involved the creation of a model environment in which agents are heterogenous network actors with certain individual characteristics (size, age, resources etc.) and network properties (familiarity, Betweenness, degree centrality, alliance membership). These are perceived by their alters which assess them as potential networking partners. The assessment of alters' attractiveness is performed subjectively, and agents weigh alters' attributes subjectively according to their heterogeneous preferences, their decision-making strategy, and their own characteristics. These assessments of potential networking partners serve the purpose of leading agents to connect and consecutively generate interesting network structures, the analysis of which help increase our understanding of path dependence in interorganisational networks.

Experimentation with SimPioN involved 5 different scenarios that were grouped into 3 experiments. In Experiment 1, I ran a base case with agents that follow a `maximising` strategy and focused only on alters' `individual` attributes. These runs provided the frame of reference for comparing and discussing results of subsequent runs. These `individual`-oriented maximisers produced the longest durations of runs before locking-in their alliances at system level, and also proved the overall least likely to lock-in, concomitantly producing generally small alliances. `Satisficing` agents in Experiment 2a assess their alters against a 'good enough' threshold of attractiveness (here 50%, or `0.5`) and do not attempt to connect based on maximum attractiveness scores. These runs were much more likely and substantially faster to lock-in. The densities emerging in these networks differed remarkably. While the maximisers, which are stricter in assessing their alters, connected less densely within their alliances, the satisficers generated much higher levels of density, often double that of maximisers and reaching around d=0.6-0.75, especially when firms were initialised as all_large. Additionally, it became clear that the maximisers are paying a price for their higher level of precision in assessing their alters: many firms and in these runs, and 3 out of 5 alliances did not survive until the end of the run.

Satisficers, in contrast, had most firms and, in most runs, at least 4 out of 5 alliances surviving until the end of run. This indicates an interesting trade-off between maximisers avoiding lock-ins but exhibiting problems in survival unless in a medium-density and small alliance, and the satisficers connecting more indiscriminately, but surviving in most cases and also attaining higher densities. In the scenarios with despairing agent in Experiment 2b, agents would connect essentially at random without considering alters' attributes. These were used as a strongly contrasting 'worst case' to compare to the base case, representing firms in market environments where an isolated strategy of "going it alone" appears impossible e.g. for resource or market clout reasons. Here, according to expectations, agents locked-in just as much as the satisficers and thus far more than maximisers. Interestingly, the conditions of the lock-in were different from the satisficers, however: while the despairing agents also locked-in faster than the maximisers, they attained longer run durations before locking-in as a tribute to their near random pattern of connecting which leads to more switching and makes system level lock-ins take longer. Despairing firms produce similarly high densities as satisficers but clustered into low density and high density runs, while again, most alliances and agents survived the runs.

Experiment 2c introduced additional heterogeneity by adding benefits-preference as a factor determining whether agents would be orienting themselves towards alters' individual characteristics or their network attributes, or both equally weighted. Results for scenarios where agents were individual-oriented essentially were similar to the above. Overall, despairing agents locked-in the most and the second fastest after the satisficers and both were more numerous and faster to lock-in than maximisers. Changing the settings to network-oriented considerably decreased the times-to-lock-in for maximisers, and the effect was less pronounced for despairing firm scenarios. Remarkably, the threshold-oriented assessment of their alters led satisficing agents to not lock-in at all when focusing solely on alters' network characteristics, but these runs also saw no alliances form and thus no firms surviving until the end of the run. When changing agents' strategic orientation towards both characteristics equally, the individual characteristics compensated for this initial lack of attractiveness from the satisficers' perspective and they saw mostly 4 alliances out of 5 survive until the end of the run with typically two of these being rather large. Maximisers, when assessing alters in a purely network-oriented manner, then had an advantage of using only a relative measure of assessing alters, while satisficers used an absolute reference value, and saw no opportunities for connecting and thus surviving long-term.

This finding points towards an absolute threshold being an overly rigid criterion when agents at runs' beginning have not yet established connections so that assessing alters could base their attractiveness assessment on the same. As the sensitivity analysis confirmed, varying the threshold levels between 0.1 and 0.9 did not substantially change outcomes, indicating the model's robustness to this change, and also that the mere existence of absolute threshold levels may be problematic for satisficing agents.

Overall, it turned out that the `individual` attributes that agents assess in their alters played less of a role in forging network connections than much of the literature on empirical networking antecedents leads us to believe. Strategy and preferences proved much better predictors of lock-ins than firm's individual attributes. These implementations of boundedly rational agents are rather interesting thought experiments: counter-intuitively, the alliances of the more rationally perceiving and decision-making maximisers had less survival chances than that of other agent conceptualisations.

Of the individual actor attributes, `firm-size` proved to be the most influential one regarding lock-in, since the model implementation made the number of possible connections a firm can hold dependent upon this variable. While, in the empirical reality, this variable may be (called) something different, firms' differing abilities to establish and maintain connections are clearly factual. The simulation experiments showed the consequences of these abilities: in the simulation model, it was consistently the larger firm (i.e. with better networking capabilities) scenarios where agents locked-in more, faster, and more densely than in small agent scenarios with more restricted networking capabilities. Larger agents can sustain more relations, and these runs thus locked-in faster and more often. This occurred not because agents' size was perceived as attractive by alters, but because their ability to sustain more simultaneous relations led to faster and more numerous, yet stable connections and subsequent system level lock-ins. This result reveals an interesting counter-point to one case study finding in which several larger firms used a portfolio approach aiming to reduce their likeliness of becoming locked-in to their alliance(s) of choice. In the real world, then, such larger agents, despite pursuing what seems to be a risk-balancing alliance portfolio approach, may instead similarly contribute to faster, denser system level lock-ins than the smaller, but necessarily more flexible firms. These may become dependent upon their alliances' bigger players but may be more likely to switch, especially when using a maximising strategy – these were runs with the longest duration in the experimental runs before locking-in.

After experimenting with agents' ways of assessing each other by `individual`, `network`, or `both` types of attributes, I used Experiment 3 to study the additional effect of an existing network history on lock-in likeliness and conditions. Given satisficers' and despairing agents' tendencies to lock-in very often and quickly, I concentrated on the maximisers and varied their focus on alters' `individual`, `network` or `both` characteristics. The three network history setups established one or two alliances (once equally big, once differing in size) at the beginning of the run and added agents to these. Across all three alliance setups, these runs locked-in even faster, more densely, and overall the most frequently (99%) than the even more boundedly-rational decision-makers (satisficers, despairing).

Thus even the maximisers are susceptible to overwhelmingly frequent and fast lock-ins when they find themselves embedded in existing network structures, indicating how strongly the historical ties inform the continuation/formation of new ties. In the scenarios, the `network` characteristics-oriented agents were the fastest and most likely to lock-in, while `both`-oriented runs behaved like `individual-oriented` runs with regard to higher density and more spread but behaved like `network`-oriented runs with regard to their overall smaller alliance sizes and lock-in speed. Runs with only one historical alliance attain overall lower densities with less variance with agents being more concentrated in the first alliance rank than in the runs with two initialised alliances. These runs exhibit more surviving agents and alliances at the runs' ends with mostly four out of five alliance ranks being occupied. The runs most closely approximating the real-world case study scenario were the `both`-oriented runs with two `twoAlliancesEqual`. The data on these runs exhibited higher densities but overall smaller alliance sizes in these scenarios, which appears a delicate trade-off to balance within interorganisational networks. Interestingly, a substantial number of runs exhibited high alliance densities with some even at the `d=1.0` level, indicating the full connectedness of smaller alliances of up to 20 members. Such high density will be relatively rare in real-world settings, but suggests a tendency of especially smaller alliances gaining higher densities in a trade-off with network size. In that sense, there may be a difference in large networks' tendency to rigidify at lower densities and smaller networks' tendency to produce stable, much denser systems.

In conclusion, the simulation model experiments demonstrate the importance of explicitly studying the networking *behaviour* of (real-world) agents with a focus on their networking *preferences* and their decision-making *strategy*. These two aspects appeared to be the strongest predictors of lock-in tendencies and lock-in conditions such as time-to-lock-in which is relevant for practice regarding potential interventions. The experiments revealed clear indications on how network structure dynamics can lock-in actor groups such as alliances and also whole-network systems, even with maximising agents, and suggest that network 'history matters' greatly in that respect.

5. 3 Limitations and caveats, ability to generalise

One important aspect of interorganisational networks is the fact that firms with large resources, in particular, are able to maintain memberships in several strategic alliances (e.g. Zaheer, Gözübüyük & Milanov 2010: 70-74). The case study could not shed sufficient light on the aspect of dual membership of both subcases that some of their members exhibited. It is conceivable that these portfolio approach-driven decisions can contribute to risk avoidance and allow agents to reflect more substantially on their network situation. The simulation model allowed for agents to become members (through connecting to another members) of up to three networks simultaneously to reflect this portfolio approach. The results clearly showed that rather a lot of (in some setups most) runs still lock-in, depending on the firms' strategies and connection preferences, potentially rendering such risk-balancing portfolios ineffective.

One further limitation is that there is currently no data on the individual actor-level in order to analyse the question of whether and to what extent these lock-ins are inefficient or ineffective for the actors on the basis of both case study and model experiments. A severely reduced strategic flexibility was shown in the case study, and arguments exist regarding why this alone is problematic for firms. Severe consequences of an interorganisational lock-in were mostly found for the actors in the *SF* case where hub firm *Nokia* de facto closed the network unilaterally and left others with severe problems. While *Nokia* itself subsequently experienced years of serious difficulties until its ultimate demise, these can then more readily be attributed to a lack of an established interorganisational network rather than the lock-in to one.

Additionally, the length of time a network actor (or agent) could potentially avoid becoming trapped in the locked-in alliance(s) and how such an ability may be influenced by the number of alliances an actor can simultaneously be a member of remains unclear. This question, however, was not at the centre of the case or the model-building exercise and the question of how these portfolio approaches work is more or less prompted solely by the present research findings from case and simulation experiments, in which agents were allowed a maximum of three memberships to partially mimic the case study.

In its present implementation, the SimPioN model is not geographically explicit. This plays little role in the model's internal validity and the findings produced with the experiments in the present study, and even the representation of cases like the highly internet-networked and geographically-dispersed smartphone industry studied here. However, in its current state, SimPioN cannot be used to study the mechanisms and effects of geographically embedded interorganisational networks such as the popular Silicon Valley or the Ruhr area (e.g. Grabher 1993) which have been used as examples of geographically-dependent path dependence in interorganisational networks.

Network lock-ins may not be problematic *per se*, they are essentially a system state and that in itself reveals no information on the nature of the consequences of such a lock-in for the agents and for their activities. The decision to not implement potentially negative consequences of network lock-ins into SimPioN was made because, arguably, any lack of strategic flexibility is potentially problematic for firms, and because the focus in and of this study was to provide more understanding of the phenomenon, rather than studying the consequences of lock-ins in interorganisational networks. Of course, such an extension makes sense if certain consequences are of interest that use the locked-in stage of the network as an input, such as studies on path-breaking. Further implementations of problems such as arising or eroding market opportunities, groupthink, responses, or more diverse options such as the going-it-alone option would require the implementation of necessary concepts, interaction with other model elements and potentially newly devised output measures.

The findings from the simulation are, of course, complex thought experiments in the virtual world and cannot automatically apply to real-world processes in the exact same manner as a statistical generalisation could infer from a sample to a population. However, together with the case study which analysed two empirical alliances, it can be posited fairly safely that interorganisational lock-ins are relatively likely, and fast if agents are connecting indiscriminately without paying particular attention to their alters' attributes. When agents are attracted by alters' network characteristics such as seeking to connect to a hub firm, this can have similar effects. Additionally, the situation of alliance competition found in the empirical case applies to many modern 21st century industries: networking is an increasingly typical way of organising economic activities. The memberships of substantially heterogenous actors within such networks and their lock-in tendencies are affected especially by agents' (strategic) decision-making behaviour and by their more or less reflected level of knowledge about their own preferences and, similarly importantly, those of their alters.

5. 4 Conclusions and implications

This study set out to explore the reasons for and conditions under which interorganisational networks can become locked-in and entail problematic consequences for their members. Conditions studied involve both the conditions leading to and the conditions of the lock-in stage. Overall, conclusive indications exist that the explanatory framework developed here has merit and provides an adequate understanding of the phenomenon of path dependence in interorganisational networks. The purported view that interorganisational networks are *per se* flexible clearly needs to be re-assessed: too much evidence points to the contrary. Now, a new, holistic, and process-oriented explanation is available: the social capital process as a driving mechanism of path dependence in interorganisational networks was identified, specified as the dynamics of three interacting dimensions over time with distributed agency, observed, modelled, and analysed. Path dependence in interorganisational networks through the resulting lock-in to network actor (sub-)groups such as alliances and system-level lock-in was specified in and for the computer simulation model and exceeded the specifications of this network dynamic in the extant literature. The findings and the explanatory framework have several implications for both theory development in the literature and for business practice.

Firstly, three streams of literature gained contributions from this study. For OMS network research, this study finally answered the repeated calls to research the 'dark side' of interorganisational networks and initially provided a broad overview of the extant literature. Findings from both the case study and the simulation model experiments add explanatory power to previous research and echo that, while networks at least initially exert positive effects, attention always needs to be paid to the turning points when positive effects may entail a vicious cycle. The integrated explanatory framework developed provides a suitable and working explanation for why and how such turning points can occur. The social capital process can drive the emergence of path dependence in interorganisational networks. This process-oriented re-conceptualisation with a focus on social capital's structural and temporal dynamics and the three interacting dimensions (cognitive, relational, and structural) of multiple actors hold great potential for application in future studies on problems in interorganisational networks, and especially for those in which path dependence is the phenomenon under study. Framing potential networking issues such as structural rigidity and other network (structural) dynamics through a lens of a development process with several interacting dimensions makes sense, especially given that OMS research deals with organisations that can hold multiplex, even contrary-oriented and competing relations with other organisations.

The methodological implication for empirical work based on this study is that multi-method, interpretative approaches, and research utilising computer simulation appear suitable because capturing several dimensions of a process, their interaction and an endogenous nature in an alternative cross-sectional manner appears difficult, if not impossible. Much of the established toolset of network measures employs essentially static reasoning, for instance. Developments over time may be traceable by multiple measurements but they do not account for reflecting actors recognising and (re-)actively seeking to influence the network structure around them; or for organisational units having relations of contrary nature (e.g. top management vs. sales) since such developments are difficult to account for numerically. The prevalent cross-sectional nature of much empirical work in extant OMS literature may also explain why such a process framework had been missing to date. New criteria such as time-to-lock-in or densities combined with network size rankings were some of the measures developed as part of present endeavours, but subsequent research questions are likely to entail the development of new measures and possibly inferential statistics that can cope with the several ways in which simulation data differ from empirical data, to address differences in variable distributions and assumptions on the relationships among variables, for example.

The path dependence literature has gained a newly conceptualised mechanism for researching the interorganisational network realm at the whole-network level of analysis: the process perspective on social capital. The implication of this extension is that scholarship could now revisit those cases in the literature where networking among members may have contributed to path dependence, but in which path dependence was only used in a metaphorical sense, and/or where data (access) restrictions led to a lack of data over time. Reassessing previous findings on e.g. the *VHS* vs. *Beta* case, or the similar and more recent case of the *DVD* successor standards *Blu-Ray* and *HD-DVD* may lead to cases being understood more effectively, with renewed attention being paid to the intelligent networking and contracting among agents that went on behind the introduction and general adoption of *Blu-Ray* technology. As already argued above, it is eventually less the actual technologies which caused these market standard lock-ins, although they certainly also play their role. Rather, the technological dimension is an expression of the social and organisational dimension where lock-ins to systems such as interorganisational network like alliances are easily overlooked when focusing entirely on the technology side.

Clearly, it should no longer be argued that path dependence has no conceptualisation of agency in the theory. Agency was already a substantial part of the theoretic foundations of path dependence. As part of the SimPioN experiments here, I explicitly studied how several contrasting behavioural assumptions regarding agents' decision-making and networking preferences affect networking outcomes and lock-in tendencies. Indications exist that empirical research would similarly benefit from a more thorough confrontation with the idea that agents/actors may be less of the maximisers they are often assumed or portrayed to be. It appears fruitful to make such different behavioural assumptions a new subject of path dependence research and also to be explicit about behavioural assumptions when carrying out theoretical or empirical work. Testing different assumptions in path dependence research or interpreting empirical findings with the background knowledge of alternative explanations in the realm of decision-making models appears a rather productive avenue for research.

Findings from the empirical case study suggest that firms may be more aware of path dependence dynamics than previously discussed in the literature debate. The inductive data category of 'fragmentation' indicates that firms were quite aware of the need to keep several and certain important industry players bound to one project rather than develop their own projects or software forks on the side, since that would counteract the networks' purpose. Some of the industry players studied also exhibited clear awareness of the potentially negative consequences of such locking-in dynamics (e.g. in the wedding analogy), if focusing mainly on the technological aspects of the lock-ins.

Explicitly adding the potential for such (self-) awareness entails consequences for conceptualising path dependence and its mechanisms in the literature debate, and it may help address some of the criticism regarding the alleged lack of agency in path dependence research. This could imply a conceptualisation of actors by including awareness and knowledge of possible means and approaches for recognising, avoiding, or tackling situations of lock-in if they arose. It is also important to include the possibility that agents lose their necessarily imperfect control of such processes and/or make assessment errors relating to the same. Moreover, the literature certainly needs to reflect on agents' and empirical subjects' awareness of the potentially detrimental lock-in situations, including their driving mechanisms, such as their being informed by the theory for recognising it (just as for reactivity of the field in empirical work). Such a consideration has profound implications for the interpretation of empirical findings if agents or subjects are either actively steering a lock-in or are attempting to 'hedge their bets' by utilising a portfolio approach, however potentially misguided their belief in their ability to steer or balance such processes of distributed agency may (turn out to) be.

For management practitioners, knowing that depending on certain cooperation partners and groups of partners such as alliances may entail a lock-in could imply the ability to avoid such potentially negative situations. Hence dealing with their network situation in a reflected way, harvesting (some) fruits of collaboration while constantly monitoring the risks of density and overembeddedness, increasingly) heavy reliance on key actors, and the cognitive dimension of social capital such as groupthink, shared mental models, technology etc., appears suitable for activities in interorganisational networks. However, contingency plans may be advisable for the situation that an organisation should find itself (in-)voluntarily locked-in, given that such balancing and monitoring is far from easy, precise, or often impossible altogether, when lock-ins develop behind actors' collective backs. Recognising such a possibility, however, and increasing awareness of it, including knowledge of potential mechanisms that lead into lock-ins may work to alleviate, if not avoid, some of the negative consequences of lock-ins if and when they do arise.

It goes without saying that it is impossible to make direct, specific business recommendations based on the explanatory framework, the case study, or the experimentation with the SimPioN model. However, business practice *can* learn from this study that closely monitoring the activities of key actors in interorganisational networks and their potential consequences appears apt, just like entertaining close communication with them and others and to continuously reflect on network-internal and external developments through suitable organisational and communication formats (such as information material, mailing lists, joint events, steering committees, network administrative organisations etc.).

The models' implementation of different behavioural models in the experiments revealed that, somewhat ironically, a seemingly less rational behavioural model may lead to better outcomes in certain situations, if e.g. coping with a lock-in is perceived to be easier than waiting for the 'ideal' network partner and as a result lose business activities and/or risk firm survival. Certainly, inducing reflection on the rationale and the means by which firms make decisions in the context of complex dynamic systems in practice can lead to fruitful debates in both science, practice and among the two realms.

Having worked on a high-tech industry, and more specifically on smartphones and related economic actors that became attracted to these networks during the time of study, it appears important to recognise the importance that networking represents for business ventures. Many industries rely heavily on network structures and are frequently unable to avoid becoming members of them, even if this may seem desirable. Reliance on resources of alters or on jointly-created assets in interconnected business relations such as the technological platforms arising or already dominating the present internet-driven so-called *new economy* appears to be the *de facto* default mode of operation. For these, as indicated by the model's experimental results, the times for reflection (i.e. 'time-to-lock-in') may be rather short depending on the makeup of an industry environment and its dynamics. If avoiding a lock-in seems unlikely or even impossible, the question of which platform to join, gains uttermost importance. Consequently, an early recognition and reflection on choices, behavioural options and their consequences appears more important than ever in the light of the findings of this study.

5. 5 Outlook for future research

Future research on questions of alliance development and interorganisational network dynamics could further deepen our understanding of the (in-)flexibility-related implications of joining interorganisational networks and (sub-)groups such as alliances. Interorganisational networks similar to those studied here exist in many present-day industries, and their modes of organisation can vary depending on many context-related variables. Given that not all industries are of a similar high-tech, new economy nature, certain other industries would make for interesting comparison cases. For example, financing networks of venture capitalists or banks, supply-chain aspects such as horizontal and vertical alliance configurations, as well as the overlapping of several different industries within one alliance were aspects usually avoided in the creation of the simulation model, but were made relevant by the case study of the mobile communication platform market situation.

Empirical research on technology alliances will find that these aspects remain important for the many alliances in the empirical world. It may be of interest to address issues of different modes of industrial organisations, 'cultural' differences such as voting mechanisms for agreement/disagreement, arising legal or quasi-legal structures, governance mechanisms that entail certain modes of operation, and norms of cooperation (an aspect consciously not represented in the present model implementation) that affect the formation of network ties as well as the likeliness of firms becoming trapped in their locked-in networks. Future research could also study the consequences of decision-making behaviour assumptions and actual decision-making strategies and preferences, in both real-world empirical settings and in simulation models. While SimPioN clearly showed that varying these assumptions has significant consequences, more in-depth and comparative work is required to identify both deeper and more general patterns, be it on alliance membership, cooperation partner choice, or other, even non-network related contexts.

Further research with SimPioN could begin by experimenting with the remaining multitude of design points (experimental scenarios) that were possible with the presently implemented experiments but not used for the purposes of this study. Some extensions to the model can be added more easily than others, but much room for experimentation certainly exists. Future iterations of computer simulation experiments of network dynamics can also study aspects such as the effects of the geographical distribution of agents on the likeliness of these networks to lock-in within, or even beyond, their geographical locality. The implementation of geographical space was avoided in the implementation here, as well as the application of more empirically-realistic network constellations as initialisations. The necessarily artificial initialisation scenarios used in the five SimPioN experiments were constructed to uncover the effects of more 'extreme' setups for identifying the major effects of the model and its factors. Empirically calibrated setups such as different distributions of agent characteristics or different topologies of historical network structures could provide more insight on the consequences of and for networks. Moreover, this may shed more light on the situations of individual actors within the model environment, rather than on only the system level studied here. In particular, the influence of heterogeneous agents within single experimental setups, rather than across them as used here, may provide such insights.

Further possible SimPioN extensions could implement agents with the ability to make negative experiences with cooperation partners, i.e. familiarity taking a negative algebraic sign rather than the positive influence as typically pointed out in the literature, and also used here. Negative experiences from cooperation may, in theory, lead to a readier dissolution of ties and potentially related alliance membership. However, the question remains whether this would actually have an effect on lock-ins, given that actors often have no or only limited control over these dynamics. Furthermore, the effects of actor centrality could be studied more in detail at an individual actor's level to identify the consequences of and for individual agents' network structural positions and their relations, for instance, such as brokerage positions and potential lock-ins to these.

Actors' (self-) awareness of their positions and an (imperfect) ability to influence their network structural positions and relations would be a worthwhile avenue for further research, since it would be a(n) (abstract) representation of attempts at strategic network positioning, as indicated in the case study findings, i.e. the existence of hub firms and some alters self-identifying as their "followers". Given the ability of computer simulation to explicitly model agent cognition and provide extensive data on the cross-level micro-macro phenomenon, this intriguing phenomenon could be studied quite precisely. A further question to ask the model would be an implementation of the different alliance management and decision-making styles identified in the empirical case study – a question that was beyond the scope of this study's modelling exercise, but warranted given that network administrative organisations, voting models and hub steering are clearly differentiated management styles entailing consequences. A simulation model can study these more in detail than empirical research where the isolation of individual causal effects is easily clouded by social complexity at other levels.

Overall, future research should be inspired to employ more formal models in the social sciences. While the precision enforced by creating formal models such as agent-based social simulation 'feels' uncomfortably exact at first, the ability to systematically vary behavioural assumptions, decision-making models, the high internal validity of models, and the ability to test competing alternative explanations for phenomena make formal models in general, and (agent-based) computer simulation in particular an exciting, fruitful, modern and also necessary approach when it comes to advancing knowledge on many of the interesting research questions that lie beyond the borders of individual scientific disciplines.

Similarly, working with several combined methods, as used here, shows how a mixed-method approach can be productive, especially for expanding and contrasting findings, thus aiding theory development through both implementation and experimentation. Such an approach can be used particularly to ask questions regarding multiple variable interactions over time, which are more advanced than those offered by many traditional cross-sectional and similar methods. Qualitative or quantitative findings from empirical research can inform the elements in the creation of simulation models and/or the calibration of factor levels, or experimental setups, in which the empirical reality needs to be represented abstractly enough to be able to model it, yet precise enough to be able to study the effects and phenomena of interest.

Overall, such mixed-method approaches can unite the theories, methods, and scholars from different scientific fields to make advances beyond the state of knowledge in their individual disciplines. Computer simulation, while obviously not providing a single answer to all methodological questions, can at least partly serve the function of integrating scientific knowledge across domains, generating fruitful findings from experimental scenarios that address questions still to be answered in the cross-sections of approaches, fields, and schools of thought. Many of these are of a complex adaptive system nature, similar to those here, with interacting (social) entities giving rise to phenomena across levels of description and analysis, often involving an environment that can be reactive and/or trigger behavioural changes in the model. Agent-based modelling is thus uniquely suited to many such endeavours, since it is essentially able to represent any type of agentic entity, and can be used to represent multiple levels of analysis, such as those required to answer the research question on the reasons and conditions of emergent path dependence in interorganisational networks, as posed by the present study.

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Appendix A: History of mobile communications

In order to appreciate the significance of the mobile communications industry and the relevance of smartphones, the following historical overview is instructive in outlining the origins and developments. It points out important milestones in terms of technology and industry/market structure and provides the historical context for the data used in the case study (Section 3. 2) and its epilogue further below (Appendix B). [36] Smartphones rely on many technological functionality elements, such as physical mobile communication networks and devices. Developments in technologies and industries surrounding and influencing smartphones are included in this overview where appropriate.

a) The early beginnings

Building on early electric cable telegraphy, the telephone's invention marks an incisive step in the proliferation of electronic communication. Despite competitors disputing his claim, Graham Bell gained the patent for the first functioning telephone apparatus in 1876 (Krückeberg & Spaniol 1990: 425). His *Bell Telephone Company* (est. 1877) grew fast, and the first generation of telecommunication technology spread rapidly (Krückeberg & Spaniol 1990: 425). The USA, for instance, counted 1.4 million phone users among its 76m inhabitants as early as 1900, increasing to 11.4 million for (then) 96m people within 10 years.[37] The expansion of telephone usage required a network to connect the users. Consequently, many countries extended their existing telegraphy landlines with cables to subscribers and built exchanges between local networks. Subscribers, then, were not assigned numbers to make phone calls directly. Instead, the connection required a manually-operated telephone exchange board. This process was standard until the 1950s, but soon replaced by automatic telephone exchanges in the 1960s.

Another crucial ingredient for wireless mobile communication is electromagnetism. Building on the work of earlier physics theorists Michael Faraday and André-Marie Ampère, the English physicist James C. Maxwell was the first to create a coherent electromagnetism theory (Maxwell 1865). When testing Maxwell's theory, the German scientist Heinrich R. Hertz proved the existence of electromagnetic waves which are essential for taking communication from cables to over-the-air (Hertz 1887). The first application to use the new 'radio' technology was Morse code telegraphy using Samuel Morse's 1837 creation (Krückberg & Spaniol 1990: 424). In 1899, Guglielmo Marconi received his patent, and nine years later, he was awarded the Nobel Prize in Physics for long-distance radio signalling.

[36] Appendix A serves as context for the case study (Section 3. 2) and its epilogue (Appendix B). It was written in cooperation with Tobias Meyer and also forms his PhD thesis (Meyer 2012).

[37] Population data: https://www.census.gov/history/www/through_the_decades/fast_facts/. Status: 2015-03-14.

Radio communication was first used chiefly by government agencies and in commercial transportation. Ships and aeroplanes, in particular, continue to employ long-distance radio today, with the famous mayday call by the sinking *Titanic* in 1912 already transmitted by Morse code radio telegraphy (Klußmann 2001: 386). The warring armies in World War I used radio Morse technology to control troop movements with so-called field telephones. 1915 marked the first wireless voice communication, and the Detroit police department used one-way voice radio to disperse information among staff as early as 1920 (Klußmann 2001: 648). As antenna towers and personal radio receivers became established, one-way radio AM, and later FM transmission were developed, and radio transmissions gained a growing audience. One-way radio transmission is still used today. However, two-way radio communication also quickly gained a foothold as longer distances for telephone calls were crossed by the use of radio.

The first transatlantic radio telephone call was made in the year 1927 (Klußmann 2001: 386). By that time, landline networks were commonplace, and telephones still had to be connected to a landline, even if long-distance calls were transmitted by radio. The first tests for detached mobile communication were carried out in Germany in 1926 on trains connecting Berlin and Hamburg. They only covered rather short distances with limited usability (Klußmann 2001: 648). When television commenced regular operation in 1936, it intensified the use of radio waves. Initial ideas for mobile telephones gained attention after World War II. A technical challenge, however, was the limited transmission power of mobile telephones due to the requirements of portability. Thus, they could not connect to long-distance switch boards. After initial success with local mobile telephone networks, *Bell Laboratories* conceptualised a first cellular mobile telephone network in 1947 (Evans, Hagiu & Schmalensee 2006: 184).

b) Analogue mobile communications

The first analogue technology mobile telephony networks were established throughout the world in the 1950s. Germany's *A-Netz* was one of the most advanced, because it already fully connected to the landline network. The telecommunication devices of the time were mobile, yet not portable. Installations could be found on trains and motorised vehicles. While usage increased, subscriber numbers remained low not least due to costs (Klußmann 2001: 648). Operators thus sold phones subsidised at lower prices. They came with attached continuous payment contracts to spread the initial device costs over time – a practice still commonplace today. An important event in 1957 was the USSR launch of the *Sputnik 1* space satellite. This first satellite proved human's ability to not only send objects into space, but to also communicate with them – *Sputnik 1* was controlled by radio waves. These events laid the foundations for satellite communication – now a common technology

– but also led to the creation of *ARPA*[38] (Klußmann 2001: 496). This US military research institute was founded with the objective of beating Russia in the 'space race' (Greulich 2002: 466). It proved pivotal in the development of technologies for global communication, which by then had become a strategically important technology, a "big technology" (Meyer 2008: 5), serving many official and private purposes.

Other technologies were created in the 1960s that would later have a strong impact on communications: programmable computers and home electronics. *IBM*[39], among others, developed computers, initially rather large machines, with early research on computer networking beginning in 1965 when *ARPA* established an initial data link between computers (Klußmann 2001: 498). Cooperating with *UCLA*[40] scientists, *ARPA* developed a permanent computer network and an email programme in 1971 (Klußmann 2001: 499). At the same time, home electronics devices for audio and video tape recording became available and quickly popular. Communication firms focused on the facilitation of self-dialling for phone users and increasing the coverage of mobile networks. A shift to new frequencies permitted more subscribers and second generation analogue mobile networks entered operation across Europe. Germany was the first country to launch a fully automated second generation analogue mobile phone network called *B-Netz* in 1972 (Klußmann 2001: 650). In the same year, *ARPA* launched *DARPAnet*: the first computer network building on packet-oriented data traffic among cable-connected computers from US military and academic institutions. Its purpose was to provide redundant communication networks with US defence in the event of a Russian nuclear military strike during the Cold War. It would later expand to become the *internet*.

The first fully cellular mobile phone network was launched by *AT&T*[41] in Chicago in 1978 (Klußmann 2001: 650). Cellular technology offers the advantage that more users in a network can simultaneously initiate or receive phone calls, because this technology offers more channels (Krückberg & Spaniol 1990: 402). Another feature of cellular networks is *automatic handover*. This term refers to users' ability to move around while making phone calls and automatically migrate from one radio cell to the next without losing connection. Furthermore, cellular technology abolished the need for callers to know the current location of the mobile phone they sought to call. Because phones are closer to the network's antennas, cellular phones require less power for transmissions and could thus be considerably diminished in size. At the *CEPT*[42] meeting in 1982, France and Germany initiated a unified European mobile phone standard. They created the *Group Spéciale Mobile* (GSM) which still

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38 Advanced Research Projects Agency, later: Defence Advanced Research Projects Agency, abbreviated as *DARPA*.
39 International Business Machines, abbreviated as *IBM*.
40 University of California at Los Angeles, abbreviated as *UCLA*.
41 American Telegraphy and Telephony, abbreviated as *AT&T*, the successor to the Bell Telephone Company.
42 European Conference of Postal and Telecommunications Administrations, CEPT: the acronym stems from the French title of the institution: Conférence Européenne des administrations des Postes et des Telecommunications.

governs the technological development of mobile communications standards in Europe and around the world. Simultaneously, *ARPA* created the TCP/IP data link protocol which connected all *DARPAnet* computers.

In the 1980s, the third and final generation of analogue mobile communications networks launched on a global scale, (Klußmann 2001: 650) and the German *C-Netz* became the first widespread and mobile communications technology, but still mainly among professional users. These networks delivered better sound quality and allowed multi-mode use, i.e. speech and increasingly telefax transmission which laid the foundations for subsequent data communications (Greulich 2002: 588). Analogue user numbers doubled almost every year, creating the need for more network capacity. The *GSM* gained new members and became the first industry-wide consortium with quasi-standardisation authority, and developed the first generation of digital mobile networks to address the need for more network capacity. The use of landline technology intensified, and by the late 1980s most households in the developed world had a telephone line. The European research computer networks, such as *EUnet* and *JAnet* were connected to *DARPAnet*. This was achieved on the basis of the newly established TCP/IP standard. This international computer network grew rapidly via intercontinental cables and satellites which then became technically and commercially viable (Klußmann 2001: 502). In the early 1980s, *Microsoft* established its operating systems business and bundled its *MS-DOS* and later *Windows* with *PCs* from *IBM*. This cooperation set a quasi-standard and made *Microsoft* the biggest and most successful software company, a position it continues to occupy today.

Networks	Frequencies	Introduction	Switch-off	Users	Capabilities
1st gen. "A-Netz"	150 MHz	1958	1977	10,500	Manual switching; operator required; calls only among mobile devices
2nd gen. "B-Netz"	148,40 – 162,94 MHz	1972	1995	27,000	International roaming; half-automatic switching; calls could be made to the mobile phone if its location was known
3rd gen. "C-Netz"	451,3 – 465,74 MHz	1986	2000	850,000	Automatic connections to and from the mobile phone

Table 35: Analogue (1G) mobile technologies in Germany (adapted from: Schnabel 2010)

c) The transition to digital mobile communications

For the communications industry, the year 1990 marked the beginning of a new era (Schiller 2006: 11): the introduction of digital communications standards at many levels. Landline communications introduced fully automatic digital switchboards, ISDN[43] networks (particularly in Europe) could carry high quality voice calls, but also simultaneously transmit fax or data through its two channels. Landline phones became cordless and the still popular DECT[44] standard was gaining worldwide adoption (Schiller 2006: 12). Home electronics became digital and CDs and DVDs or digital satellite and cable television became popular. PCs based on microchips compatible with or developed by *Intel* became affordable for many households in the developed world. PCs shrank considerably in size and grew powerful enough to support multimedia usage and permit the emergence of laptops. Miniaturisation reached new levels with *Apple*'s 1992 introduction of the *Newton* PDA[45] handheld computer (Greulich 2002: 694) and the founding of *Palm* which became the most successful PDA manufacturer (Evans, Hagiu & Schmalensee 2006: 156). Its biggest competitor was *Microsoft*, which offered handhelds using the *Windows CE* implementation of its successful *Windows* operating system as a basis for calendar, notepad, calculator, and address book applications.

The most incisive change for the communications industry was, without doubt, the invention of the World Wide Web (WWW) by Tim Berners-Lee at *CERN* [46]in Geneva, Switzerland (Greulich 2002: 457) in 1992. This software layer built on the already functioning internet and enabled users to access internet information much more easily, quickly and comfortably than ever before. As a result, global user figures exploded immediately: from 0.8 million in 1992, numbers doubled every 9 months to reach 100 million in 1998, five years earlier than expected (Klußmann 2001: 503-505). Big commercial companies discovered the internet and, in 1995, *Amazon.com*, currently the biggest online store, sold its first book, and the largest online auction platform *eBay* was created. Many private and commercial undertakings "went online" during the 1990s, creatingmany millions of websites, to reach 200 million by 1998. Search engines were created to retrieve text documents, images, audio and increasingly video files and streaming services desired by users. The search engine *Google* was founded in 1998 as a *Stanford University* spinoff venturing to improve search results. With increased desirability and internet traffic doubling every 100 days (Klußmann 2001: 505), demand for speedy and stable access grew rapidly. Network operators invested heavily in extending and upgrading existing landline telephone networks for data use. New technologies such as DSL[47] and broadband cable technologies were developed. By the end of the decade, the majority of countries were connected to the internet, and daily World Wide Web usage has been commonplace ever since.

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[43] Integrated Services Digital Network, abbreviated as ISDN.

[44] Digital Enhanced Cordless Telecommunications, abbreviated as DECT.

[45] Personal Digital Assistant, abbreviated as PDA.

[46] Conseil Européen pour la Recherche Nucléaire, abbreviated as CERN. A leading European nuclear research laboratory still in operation today.

[47] Digital Subscriber Line, abbreviated as DSL.

Mobile communications were initially still disconnected (literally) from the internet, but foundations for mobile data access were laid with the newly-developed European digital GSM-900 and GSM-1800 standards that launched as 2nd generation mobile networks (2G) to replace the 1st generation (1G) analogue systems (Khosrow-Pour 2005: 1985). They also provided features such as call encryption, text messaging (SMS), telefax, and, later, internet access. As another novelty, private enterprises commenced network operations in addition to government monopolists. Most notable among these was *Vodafone*, now one of the biggest global network operators (Coenenberg 2007: 9-10). Technology advances shrank device sizes and improved battery life so that *Nokia* launched its influential *Communicator* device in 1996 (Evans, Hagiu & Schmalensee 2006: 184). This device was the first to combine phone and fax capabilities with PDA features such as contact management, text messaging, calendar, email, and notepad functions: in short, the first globally available smartphone.[48]

The actual term ‘smartphone’ was first coined by *Ericsson* in 1997 for its *GS88* handset (Stockholm Smartphone: History[49]). Because these smartphones proved successful among professional users, their features spread to lower-priced devices at the end of the 1990s. As demand increased, manufacturers integrated technologies from other high-tech industries. Multimedia features such as MP3 audio players and internet access were added. Due to technological restrictions such as narrow bandwidth, low screen resolutions and slow processer power, the first smartphones could not access the by then common HTML web pages. To solve this issue, the WAP[50] standard was developed in 1997 by the *WAP-Forum*, an industry standardisation body that spread the technology among member firms, which quickly increased in numbers (Klußmann 2001: 1079-1080). Also, in 1997, mobile phone services became available in the form of prepaid options without costly monthly subscriptions. These tariffs enabled the less affluent to buy mobile phones and proliferation and usage increased strongly in consequence.

By 1998, *Nokia* had become the market leader for mobile phones, creating the industry consortium *Symbian* with *Motorola*, *Ericsson*, *Matsushita*, and later *Siemens* (Teather 2001: 28). *Symbian* integrated the former company *Psion* with the goal to produce a joint, device-independent operating system called *Symbian OS* that built on *Psion*’s PDA operating system *EPOC* (Evans, Hagiu & Schmalensee 2006: 184). The consortium members held 80% of the mobile phone market share at the time (Sosalla 2001: 4). In late 1999, *Nokia* introduced the first *Symbian OS* mobile phone with WAP internet access: the *7110*. Demand for this technology was so high that WAP phones were hardly available, hence the

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[48] As Evans, Hagiu & Schmalensee (2006: 184) note, it is not the first marketed smartphone. The IBM Simon launched a year earlier, but exclusively in the USA and was commercially unsuccessful.

[49] http://www.stockholmsmartphone.org/history/ ; status: 2015-07-20.

[50] Wireless Application Protocol; abbreviated as WAP. Also famously used as an acronym for “Where Are the Phones”? coined because the delivery of WAP phones was slow due to high demand and initially low production.

phrase "WAP – Where are the phones?" became a popular adage (Klußmann 2001: 1080). In the same year, *Research in Motion* (*RIM*) introduced its first dedicated mobile email computer, the *Blackberry 850*. In Asian markets, mobile internet usage spread more quickly than in Europe and America, because *i-mode*, a local competitor to WAP, performed more strongly there (Evans, Hagiu & Schmalensee 2006: 185).

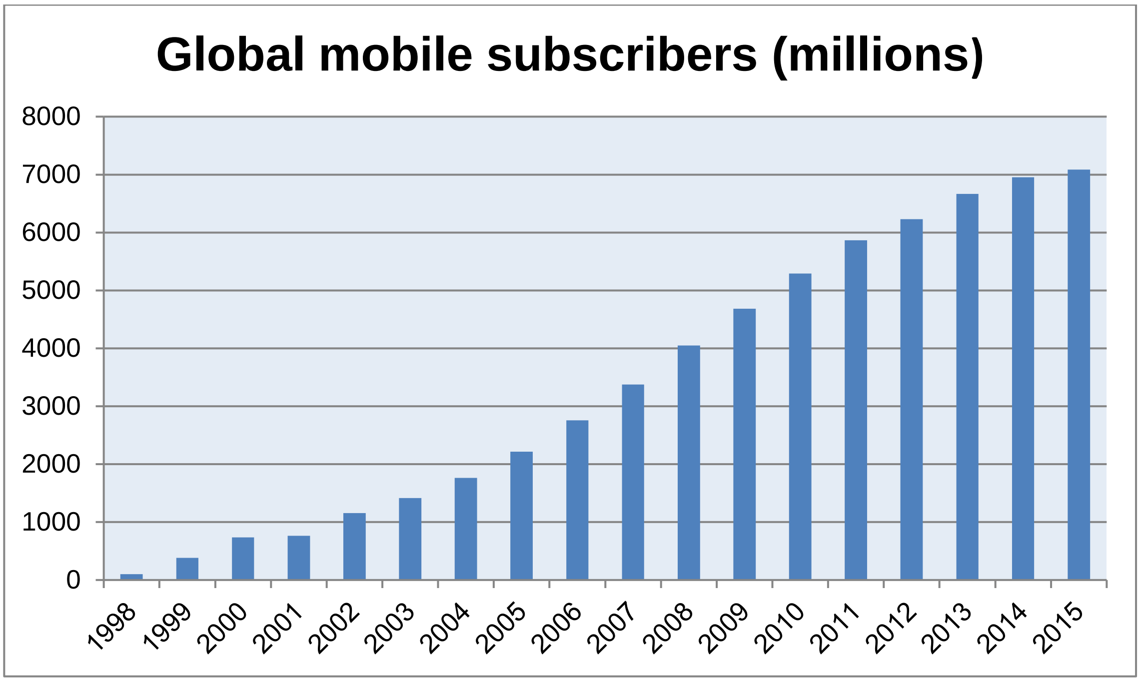

Figure 57: Global mobile subscribers (sources: ITU 1999, ITU 2002, ITU 2010, ITU 2011, ITU 2015[51])

When WAP and *i-mode* were introduced, connection speeds were still low, so higher-speed radio technologies arose (Khosrow-Pour 2005: 1985) and the so-called 2.5G technologies were developed. The first, HSCSD[52], combines several time slots of conventional circuit switched connections. The second technology is GPRS[53], the first cellular network technology to use data packet-oriented IP-protocol connections from the internet world, rather than circuit switched methods from telephony (Sauter 2011: 4). In the 2000s, HSCSD and GPRS were combined and extended to become EDGE[54], still in operation at present. Asian and U.S. operators used the slightly different CDMA[55] standard that offers somewhat higher speeds. It is incompatible with GSM, and intercontinental travellers thus typically have had to change phones accordingly.

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[51] The respectively current global subscriber numbers and other statistics can be obtained at : http://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx (status: 2015-07-23).

[52] High Speed Circuit Switched Data, abbreviated as HSCSD.

[53] General Packet Radio Service, abbreviated as GPRS.

[54] Enhanced Data rates for GSM Evolution, abbreviated as EDGE.

[55] Code Division Multiple Access, abbreviated as CDMA.

Technology	Frequencies	Max. download bandwidth	Introduction (approx.)
2G CSD	824 – 1920 MHz	9.6 kbit/s	1992
2.5G HSCSD	824 – 1920 MHz	43.2 – 115.2 kbit/s	1999
2.5G GPRS	824 – 1920 MHz	114-171.2 kbit/	2000
2.75G EDGE	824 – 1920 MHz	473.6 -553 kbit/s	2003
2.75 E-EDGE	824 – 1920 MHz	1 Mbit/s	2006
V.90 / ISDN	Landline	56 kbit/s / 2x 64 kbit/s	1994

Table 36: 2G mobile technologies (adapted from: Sauter 2011)

d) The digital century

The new millennium started with a key development in mobile communications: third generation (3G) mobile radio frequencies were licensed to network operators, in many countries through auctions held by local frequency administration bodies. Successfully bidding operators paid multi-billion euro fees (e.g. €40bn in Great Britain, €50bn in Germany). They also made substantial investments in mobile infrastructure, because user numbers grew so strongly that the available bandwidth was becoming restrictive. Internet access for email, WAP, the new Multimedia Messaging Services (MMS) and media streaming required even higher bandwidths than 2G networks could offer (Khosrow-Pour 2005: 1986).

Modern smartphones started to integrate a camera, audio and video player, address book, calendar, and email client, offering functionality beyond PDAs (Branscombe 2003: 14). The latest devices offer full internet browsers, GPS satellite navigation and even TV reception, and are typically controlled via touchscreen-operated user interfaces. Towards the end of the millennium's first decade, even mid-range phones provided such features and were increasingly used for tasks formerly performed by PCs (Boeing 2004: 2). Despite manufacturers adding functionality, demand rose for independent software producers to contribute own applications to add to phones' functionality. *Motorola*'s *i50sx* in 2001 was the first mobile phone to be able to run simple Java applications, called MIDPs[56], which were used for (then) primitive mobile games and productivity tools.

Microsoft's launch of *Windows Mobile* in 2002 indicated that, after desktop PCs, operating systems were also becoming an influential factor for smartphones. *Microsoft* attracted *Motorola* as a *Windows Mobile* licensee, and *Motorola* consequently reduced its commitment to the *Symbian* consortium, despite having been on board early on. Shortly afterwards, *Nokia* launched three different *Symbian OS* software architectures for mobile phones and smartphones, the 'Series 40', 60 and 80 (Evans, Hagiu & Schmalensee 2006: 184) and Samsung invested £17 million in the consortium (Wray 2003: 24). This indicated the availability of several operating systems that could be used across devices from different

[56] Mobile Information Device Profile, abbreviated as MIDP.

manufacturers for the first time. Therefore, these events can be considered the beginning of the "fierce struggle to establish the standard operating system for the next generation of mobile phones" (Teather 2001: 28). Another competitor, PDA manufacturer *Palm*, announced its *Palm OS*-based *Treo* handset in 2001, and later won *LG* as a licensee (Müller 2005: 131).

With *Palm*, *Microsoft* and *Symbian* as the main competitors (Pogue 2003: 1), industry experts anticipated a showdown between the latter two with the biggest market share. "I think we have now got them all" said *Symbian* CEO David Levin (quoted in: Lohmeyer 2002: 37). And *Symbian* seemed confident that it would attract the majority of companies to its platform. Indeed, it did prove successful in selling licenses, despite *Microsoft*'s aggressive sales strategy (Borger & Kroder 2003: 4). This was evidenced by *Motorola*, a big *Microsoft* licensee also launching a *Symbian*-based handset in 2003 (Economist 2003). However, *Microsoft* expected high revenues from this fast-growing market for smartphone operating systems (Wihofszki 2004: 4). *RIM*, whose operating system is only used by its messaging-oriented smartphones under the *Blackberry* brand, conceived its products predominantly for the corporate or SME market segment (Norris 2004: 7; Young 2005: 22). *Microsoft* partnered with Taiwanese manufacturer *HTC* to produce phones for the same segment (Hille 2006: 7) and their cooperation proved fruitful. Nevertheless, with a market share of 70%+, *Symbian* clearly dominated the nascent smartphone industry (Müller 2007: 4) and, in 2007, *Palm* entered financial difficulties due to declining sales (Hillenbrand & Müller 2007: 5).

Meanwhile, PCs had become cheaper and more powerful, continuously fulfilling Moore's Law.[57] They too became mobile, and people increasingly purchased laptops rather than desktops. Most came with a pre-installed version of a *Microsoft Windows* operating system. New internet services such as *Google*, the biggest search engine and online advertiser, *YouTube*'s video streaming platform, the *Flickr* online photo memory, the auctioning platform *eBay*, social networks such as *Facebook*, *Twitter*, LinkedIn or *Xing*, Voice over IP (VoIP) services like *Skype*, payment systems such as *PayPal*, online stores like *Amazon*, the free and editable encyclopaedia *Wikipedia*, internet banking and brokerage, news services and countless private websites and increasingly easy-to-use blogs[58] became standard services that users sought to access anywhere and everywhere. Shopping for media such as music, films, eBooks, or audiobooks turned from traditional hardware media purchases into digital downloads and, more recently, digital streaming. All these services require higher bandwidths than that available at the end of the 1990s. Broadband technologies began spreading for domestic use, and home networking via Wi-Fi became the standard manner of connecting computers to the internet (Schiller 2006: 30). Technologies such as Bluetooth also allowed devices to connect with each other for data exchange.

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[57] Moore's Law states that, given a constant growth rate, processing capacity doubles every two years. It is named after Gordon Moore, the co-founder of semiconductor firm Intel.

[58] Formerly: WebLog

The 1.2 billion global mobile users (in 2002) started to demand a similar internet experience in a mobile format. Bandwidth increases were thus added to the technical standards by the *UMTS Forum*, the body for the creation of the UMTS[59] standard, another standard-setting industry consortium of many operators, manufacturers etc. Presently, mobile data speeds equal – or in some places even exceed –landline connection speeds. This development was achieved towards the end of 2000s, when over 4 billion users were already engaging in mobile communication and network operators in developing countries, in particular, decided to skip the costlier extension of landline networks altogether in favour of investments in mobile communications networks.

Technology	Frequencies/lines	Max. download bandwidth	Introduction (approx.)
3G (UMTS)	800 -2200 MHz	384 kbit/s	2000
3G HSDPA	800 -2200 MHz	7,2 Mbit/s – 14 Mbit/s	2006
3G HSPA+	800 -2200 MHz	21 Mbit/s – 84 Mbit/s	2011
4G (LTE)	700-2600 MHz	108 – 300 Mbit/s	2009
4G (WIMAX)	2000– 6000 MHz	100 Mbit/s – 1 GBit/s	2005
ADSL (2+)	Landline (copper)	1,5 Mbit/s – 12 Mbit/s	1999
ADSL2+	Landline (copper)	5 Mbit/s – 24 Mbit/s	2005
VDSL (2+)	Landline (copper)	100 Mbit/s – 300 Mbit/s	2008
G.fast	Landline (copper)	500 Mbit/s – 1 Gbit/s	2016
DOCSIS 3.0	Cable TV network	50 – 400 Mbit/s	2007
DOCSIS 3.1	Cable TV network	500 Mbit/s – 10 Gbit/s	2016
FTTC/FTTH	Landline (optical)	1 GBit/s – 100 Gbit/s	ongoing

Table 37: 3G, 4G and landline broadband technologies (adapted from: Sauter 2011)

Smartphones have since overtaken PCs as the main internet access devices and have continued to grow and outgrow other internet access devices in sales and usage. The events of the years 2007-2011 are described more in detail as the contextualisation for the case study above, since they are of more immediate importance than the historical foundations outlined here. However, smartphones, just like any other technology, have a profound influence on us, which warrants a brief examination below.

[59] Universal Mobile Telecommunication System, abbreviated as UMTS.

e) Excursus: consequences of smartphones

The development of new technologies has individual, social, societal, and even political implications which deserve consideration. As a result, the advent of smartphones has attracted criticism and debate, as is the case with most technological advances. For the purposes of critical appraisal, the following section briefly reflects on some relevant arguments.

Smartphones are influential in people's daily lives because, beyond calls and messages, they integrate the internet wirelessly and lead to what has been called an "always-on culture" – a mobile society with constant internet connectivity (Völker 2010: 30). This is important since the internet itself has been noted to have a major impact on communication and information behaviour (Bargh & McKenna 2004: 586-587). Information search and usage patterns have changed; not only because the internet facilitates extremely rapid access to data and information, but also because it provides a large variety and quantity of information that users can access simultaneously. Selecting and filtering appropriate sources and relevant information for a given task may itself not be a new skill. Since the arrival of the internet, however, this skill has increased greatly in importance as the amount of information exposure has increased. Given that smartphones essentially provide users with internet access anytime anywhere, this can lead to issues for individuals and social relations:

i) The individual level: smartphone addiction

At the level of individuals, constant internet availability can lead users to consume a high amount of information. This can overwhelm some users and lead to information overload or even "data addiction" in which users need constant "digital stimulation" (Grossman 2007). In the wake of the now recognised clinical disorder "internet addiction" (Young 1998), the equivalent compulsive phenomenon in its mobile format has already been termed "smartphone addiction" (Park & Lee 2011). Increasingly, users of smartphones become so attached to their device(s) that they can hardly switch it off in order to relax. The BlackBerry device was nicknamed 'CrackBerry' to signify this trend of smartphone addiction, which is characterised by users carrying their Blackberry work phone even on holidays (ZDnet 2008). They are "eating into personal time and are creating an awkward imbalance in people's lives" (ZDnet 2008), because they allow their users to constantly read and write work emails or read news. Not switching smartphones off often enough can lead to an imbalanced situation in which an individual is always mentally "at work" or at least not fully relaxed in their private time. Consequently, the usual distinction of private and working hours becomes blurred, and the blessing of instant internet access can turn into a "curse" (ZDnet 2008). Research has further pointed towards cognitive trade-offs from smartphones, and indicates that their mere presence (even when switched off) reduces users' cognitive capabilities, even when they resist using their device, since this seemingly simple act appears to bind attention resources (Ward et al. 2017). Additionally, research points towards altered electrophysiological changes in the brain from heavy smartphone usage resulting in impulsivity, hyperactivity, declining social cognition and inattention problems (Hadar et al. 2017). In response to such worrying findings and arguments, the French government recently enacted a drastic, blanket smartphone ban at schools for all students until the age of 15, seeking to reduce smartphone addiction issues such as declining student attention and performance (Chrisafis 2018).

In addition to the aforementioned psychological and neurophysiological consequences of smartphone usage, questions regarding the potential detrimental nature to health of electromagnetic radio waves have arisen several times in recent decades. Mobile phones and similar devices continuously receive and transmit electromagnetic radiation through their antennae in order to connect to their networks. These waves are not substantially different from microwaves which are used in kitchen appliances to heat food. Typical GSM mobile phones are allowed to emit energy of up to 2W per kilogram of body mass. The Specific Absorption Rate (SAR) measures the rate at which this warmth-increasing radiation is absorbed by the human body. It represents the figure by which customers can identify how much radiation a given device emits. Studies concerning the negative effects of electromagnetic radiation on human health, such as cancer or brain tumour development have, however, not shown scientifically valid and unambiguous results (Saße 2011). Smartphones are now even more a subject of discussion since they emit ever-increasing radio activity as a result of the integration of Wi-Fi, Bluetooth and other radio technologies that are also almost continually connected.

ii) Social relations and smartphones

Smartphone addiction or highly-frequent usage can also be problematic in social settings. Most observably, the ability to communicate remotely and constantly means that users can and often do stay connected with friends, family and colleagues at all times, even across long distances. However, since smartphones can invade private spaces, as described above, they may also disturb people's social life. This can occur, for example, if a discussion is interrupted to check facts online using the always-available smartphone before voicing an opinion on topics, or when a conversation is interrupted to check emails between sentences (Völker 2010: 22). Also, during professional meetings, conferences, presentations, lectures and other work situations, smartphone usage can distract participants and thus reduce productivity. It follows that users need to become or be made aware of their smartphone's effects, since the impact on social relations may have direct consequences for their personal attainments in the workplace and the quality of their private life. Being constantly connected to others through a smartphone can also lead to increased stress levels, e.g. if attention needs to be split between people or activities or if several different social claims are being made simultaneously (Fortunati 2002: 517).

Furthermore, people's reliance on electronic messages and usage of online social network has increased with the advent of smartphones. An increased number of (distant) online relationships may lead to looser social connections and individual isolation overall (Völker 2010: 23). However, increasing internet communication does not lead to isolation or disconnection from real-life close relations in the vast majority of cases (Bargh & McKenna 2004: 580). In fact, people nowadays rely on social network technologies such as *Facebook* or *Twitter* etc. to stay connected with a bigger group of contacts than was formerly possible, slightly in contrast to the findings of e.g. Dunbar (1992). While close relations gain a kind of online augmentation, many of the additional contacts would be looser connections, but nevertheless increase individuals' social sphere. Social science research also indicates that looser social connections may occasionally matter more than close ones (e.g. when searching for jobs: Granovetter 1974), which makes this development desirable rather than concerning. Consequently, internet users have described their devices and their capabilities as positive, both socially and psychologically (Bargh & McKenna 2004: 580). Smartphones "merely" add the use of these technologies in a mobile form and enable people to connect to others whenever they wish.

Additionally, smartphones allow users to share apps and digital content which brought about new social applications, such as competitive mobile gaming (e.g. the popular "Words with Friends"). This formerly individual and disconnected activity has turned into a social activity through the means of smartphones that are now gradually replacing hand-held game consoles. Not least for that reason, mobile games make up a large share of the apps available in platforms' respective app stores, and game software producers are eagerly tapping into this smartphone market (SonyEricsson 2011).

iii) Societal impact of smartphones

While smartphone usage has consequences for individuals and their relations, also social aggregate of society as a whole has also been strongly influenced by smartphone proliferation. Smartphones can record video, audio and images and thus turn users into 'citizen reporters.' New platforms like *Periscope* or *Merkat* tap into these technical capabilities and even allow live-stream reporting, a technological feat formerly reserved for large TV channels. Now, even major TV channels show users' data as live-feeds via high-speed mobile data networks that are becoming available even in developing countries and allow for citizen reporting on natural catastrophes, for instance. Communication and multimedia capabilities anytime, anywhere also allow smartphone users to record and report criminal activity, misconduct of public figures such as politicians or celebrities, or services and government or administration wrongdoings, among other transgressions.

Recent politically revolutionary movements in the North African states of Tunisia, Egypt and Libya – the "Arab Spring" – were greatly aided by the usage of smartphones to collect evidence of the abuse of political power or illegal acts of war (Bleich & Kuri 2011: 86-89). Smartphones also support political activists in organising spontaneous demonstrations via social networks such as *Facebook* or social media like *Twitter*. In a public appearance, US senator John McCain, who visited the North African countries during the Arab Spring, described one particular event he eye-witnessed in Egypt, where he saw a young man "who held up his blackberry and said, 'I can get 200,000 people in the square in two hours' [sic!] via *Facebook* groups" (quoted in Mayton 2011).

While smartphone support in North Africa has its limitations in terms of restricted network coverage and the number of available activists (Nelson 2011), there is no doubt that smartphones aid demonstrations and spontaneous social gatherings such as 'flash-mobs'. Moreover, officials must expect to be held accountable when smartphone users are present. In that sense, smartphones have become "a catalyst for democracy" (Bleich & Kuri 2011: 86, translation by the author) through their technical capabilities. However, for governments, the temptation to disable communication networks to quell such movements is high.

iv) Mobile internet as a medium for content and advertising

Smartphones are devices for mobile internet content consumption. Since the internet is a mass medium, mass information and cultural influences are thus also present on smartphones. Unlike radio or television, however, internet usage is interactive, and users are changing and influencing internet technologies as they consume and use content. The mobile internet increased this social and cultural interaction ability even more. Users can now share photos, videos, audio, texts, their location etc. directly with friends and family without even needing to start up a computer. Mobile has thus become a medium in its own right, with the particular characteristic that it is not bound to any definitive locality or space (Völker 2010: 9-21).

However, apart from interactive use in the sense that users can manipulate online content and information, this influence also works in the other direction: manipulation of the user. For instance, mobile internet content and apps are often financed by advertising. Advertising even constitutes *Google*'s main reasons for joining the mobile communications industry (see above) since the accruing income from mobile advertising is substantial. Market analysts expect "that by the 2014 time-frame or so it will be well north of $3 billion" (quoted in Bartz & Dobbyn 2011), from location-aware advertising alone. This increase in mobile advertising on smartphones raises several questions.

Firstly, users' general exposure to advertising increases through the additional access on smartphones. Advertising can be perceived both as positive (informative and relevant) and negative (annoying and irrelevant, e.g. in the form of SPAM emails). Excessive exposure to advertising has been shown to have negative consequences for people, and can contribute to behaviour such as "the elevation of consumption over social values, the use of goods to satisfy social needs and general dissatisfaction with one's life" (Phillips 1997: 109). Furthermore, advertising may have manipulative effects on individuals and limit their autonomy and free choice (Sneddon 2001: 15). Based on such scientific findings, advertising for certain products, e.g. alcohol and tobacco, has been legally restricted to protect certain societal groups, especially those of a younger age. The negative aspects of advertising, however, may be exacerbated due to greater exposure of the smartphone users. If many activities become top-heavy with advertising, users may increasingly experience the ascribed negative effects and potentially reduce their usage subsequently.

Secondly, smartphones track the location and activities of their users (incl. hobbies, travel, and sleeping, eating, working, and consumption patterns etc.). The data is used to make mobile advertising more relevant to users, and thus more effective. However, this approach leads users to become restricted to information and advertising about things they already know and do. New, relevant, or interesting information could be neglected in consequence, thus undermining the novel aspect of advertising. In general, as Grech (2011) emphasised, the internet actually adapts our social context rather than (only) the other way around: "Our physical location, social contacts and preferences shape the information we receive. […] 'Context' has now become just as important as 'content' " (Grech 2011). Some critics even accuse their all-knowing smartphones of dictating their activities: "Where were we all going? To the CollegeHumor party around the corner. How did we know it was time to go there? Because our smartphones told us so" (Carr 2010: 1).

A third issue arising from smartphone advertising with location and activity awareness is data collection itself. In order to tailor advertising to people's tastes, platform companies such as *Google*, *Apple* and *Microsoft* gather large amounts of data on smartphone users and on internet users in general. As Jeff Chester of the Washington DC Center for Digital Democracy[60] describes: "…they're creating these sort of mobile digital dossiers based on what you do on your mobile phone and where you are" (quoted in Bartz & Dobbyn 2011). This data collection and profiling exceeds what critics consider healthy for democracy (Gaschke 2010) and some users are now taking legal action to defend themselves against the data gathered on them, their location and usage context and content (FTD 2011a). Based on this collection of data, a central concern of lawmakers and civil rights activists is the issue of privacy and data protection.

v) Privacy and data security and protection

When the internet began to thrive, users were mostly unknown to internet firms and content services. The only relationship in which control existed was the one between account subscriber and network operator, this mainly for billing reasons. For users, landlines had the additional advantage that their network identification – their IP-address –typically changed dynamically every time they (re)connected. This disenabled much of the tracking companies could conduct, but the firms found solutions to this in terms of cookies and other means of user tracking. The formerly high privacy enjoyed by internet users is thus changing rapidly, and even more so for smartphones.

[60] https://www.democraticmedia.org/staff-board (Status 2015-04-23).

Smartphones are logged-in to their network(s) virtually continuously and can be traced by a unique identifier. The cellular networks layout per se is designed to permit the tracking of users' geographic position via Gauss-Krüger network coordinates or with now standardly-integrated GPS functionality (Markoff 2008: 1). The networks' location tracking ability allows users to exploit much of their smartphones' functionality, such as in location-based services (LBS) when searching for infrastructure including local restaurants, banks or car parks, automatic search for weather forecasts, comparing shop prices, and, of course, route navigation for automobiles, bicycles and pedestrians including new traffic concepts like interactive routing and traffic management.

Besides the convenience, however, there is also a 'dark side' to these abilities. The platform operators' ability to locate smartphones also implies the identification of their users' location. Particularly, search providers like *Google* and *Microsoft* gather location data together with the search terms and online activities of users (Hansell 2009: 8). For them, this ability is naturally advantageous since their business model is based on making advertising relevant to users. Hence location is lucrative (Carr 2010: 1), and Google's (then) CEO Eric Schmidt claims:

"We don't need you to type at all. We know where you are. We know where you've been. We can more or less now [sic!] what you're thinking about" (Eric Schmidt, quoted in Thomson 2010).

The resulting "End of Privacy" (von Bredow et al. 2010: 58-69), however, is problematic for users. *Google*, *Microsoft*, and also *Apple* can and do trace user movements, in some cases without the latter's consent, and are thus able to create complete movement and activity profiles, with the result that the smartphone becomes a "spy in the pocket" (Graf 2010: 7). This leads to authorities becoming interested in the data gathered (O'Brien 2010), not least because it generally permits the tracking of criminal activities. Even if this is valid and of legal interest, the fact that this data gathering is not carried out by a democratically-controlled authority, but rather by private enterprises, remains problematic. The privacy issues arising from these operations are likely to keep the courts of law occupied for some time (FTD 2011a). Users additionally store increasing amounts of private data in online services such as *Facebook* or cloud-based storage services like *Dropbox*. Such systems essentially allow the providers of these services to access users' data and files, be it for avoiding criminal activities or copyright issues.

However, problematic data security breaches such as experienced by *Sony* (Sony 2011a) and device manipulation through software viruses (Biersdorfer 2004), for example, allow criminals to break into user accounts and steal sensitive information such as credit card details or private addresses. Moreover, lost or stolen smartphone devices can cause severe data privacy problems, since the finder or thief has easy access to much of a user's private information including addresses and passwords for other internet services, thus enabling a thief to commit fraudulent identity theft. Some critics already think that "privacy may turn out to have become an anomaly" (Markoff 2008). Such warnings may be quite realistic given that *Facebook*'s CEO Mark Zuckerberg announced that "privacy is no longer a social norm" (quoted in Johnson 2010). Similarly, *Google*'s chairman Eric Schmidt posited in an interview that:

"If you have something that you don't want anyone to know, maybe you shouldn't be doing it in the first place, but if you really need that kind of privacy, the reality is that search engines including Google do retain this information for some time, and it's important, for example that we are all subject in the United States to the Patriot Act. It is possible that that information could be made available to the authorities." (in Interview with CNBC 2009)[61]

Despite invoking the 'if you have nothing to hide, you have nothing to fear'-fallacy (Solove 2011), Schmidt's 2010 statement constituted a type of forecast. As early as 2000, news that the US government agency *NSA* had created an international cooperation with the British intelligence service *GCHQ* in order to intercept internet data communication as part of the surveillance programme "Echelon" (Campbell 2001) reached the public sphere. However, the documents revealed by Edward Snowden, a former NSA subcontractor turned whistle-blower in 2013, showed that secret service and government agencies in the USA, UK, Canada, New Zealand and Australia were collaborating to gather a so-called "full take" of all accessible communication data, including all that on the internet, with the motivation of identifying and stopping terrorists and organised criminals (Spiegel Online 2013).

The services also interacted with their foreign counterparts in Germany, France and other countries in order to tap resources beyond their immediate means. Much of the data gathered this way stems from mobile network surveillance and from extracting data from online social network and advertising platforms. The democratic legitimacy of these activities continues to be questioned, including in legal proceedings by citizen rights activists and privacy advocates (Heise 2015). Together with the ongoing net-neutrality debate and the censorship potential of platform providers (Diederichs 2010) which China is using to heavily restrict its citizens' knowledge of certain topics, for instance, the arrival of smartphones thus raises many concerns about the fundamental rights of citizens (Khosrow-Pour 2005: 1987). These concerns remain justified, as indicated by continuing media revelations relating to the most recent data scandal, in which the heavily smartphone app-driven social media platform *Facebook* was revealed to have shared individual user profile information on an unprecedented scale, with organisations seeking to influence political agendas, elections and referenda such as the 2016 UK referendum on EU membership and the 2016 US election (Cadwalladr & Graham-Harrison 2018).

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[61] Rather ironically, however, Schmidt himself sought to protect his personal data and privacy. When the internet portal Cnet published details of his private neighbourhood, income, hobbies and political donations etc. (http://www.cnet.com/news/google-balances-privacy-reach-1/) – all of which was, incidentally, obtainable through Google searches – the search firm responded by not talking to Cnet journalists for an entire year afterwards (CNN: http://money.cnn.com/2005/08/05/technology/google_cnet/).

Appendix B: Epilogue to the case study: 2011-2018

This Appendix B is an epilogue to the case study (Section 3. 2) and provides a brief overview of important developments for key industry players, subsequent to the period of systematic data collection.

2011 – Continuing trends

Towards the end of systematic data collection for the case study, *Nokia* CEO Stephen Elop wrote his 'burning platform' email (Elop 2011) and *Nokia* decided to adopt *Microsoft Windows Phone* as its single future smartphone operating system (see also case study contextualisation, above). This decision entailed the closure of *Nokia*'s *Symbian* development unit and the transfer of 3,000 staff to the technology consulting firm *Accenture* which was contracted (Accenture 2011) to maintain the *Symbian* code base until 2016 for *Nokia*'s continuing feature phone[62] business (Wang, Hedman & Tuunainen 2016: 21), when Nokia launched its final *Symbian* phone (ibid.: 22). In time, the former Nokia employees were re-trained and transitioned to new projects at *Accenture*. Discontinuing *Symbian* support activities appeared in line with closing the *Symbian Foundation* to the public in late 2010, when *Nokia* had been left as sole contributor to and maintainer of the *Symbian* code base (Arthur 2010). *Nokia* also launched its first *Windows Phone*-based devices in November 2011 and its only ever *MeeGo* device (Wang, Hedman & Tuunainen 2016: 22), marking the last time it ran several platforms in parallel.

Similarly, *HP* decided to close down the *webOS* ecosystem due to continuing sales problems with its *Touchpad* tablets (FTD 2011b) but announced no immediate switch to other platforms. Additionally, *HP* laid-off 525 *webOS* developers (Zota 2011) and later in the year decided to open-source the w*ebOS* code base (FTD 2011c). *RIM* – manufacturer of *Blackberry* devices – decided to give its operating systems the ability to run *Android* apps because *Blackberry OS* hardly attracted native apps from developers. The new *BBX* platform was launched as a hybrid attempt to capitalise on existing *Android* apps and developers but build its own ecosystem around this compatibility (Laube 2011).

Online store market leader *Amazon* launched its *Kindle Fire* tablets series based on the *Android* operating system. The company, however, did not join the *Open Handset Alliance* (Weintraub 2011), instead deciding to fork *Android* into 'Fire OS' (Gillmor 2011). This fork has seen continuous development over the years and is still in use on a variety of Amazon devices including *Fire tablets*, *Fire TV* products, the (unsuccessful) 2014 *Fire Phone* etc. The fork has been criticised by *Google* because *Amazon* circumvents the common app store but could not be avoided given the open-source nature of the code.

[62] 'Feature phones' or simply 'mobile phones' are mainly communication devices, but share some capabilities with smartphones, e.g. many have calendars, cameras and MP3 players. They lack the ability to run apps other than preinstalled ones or add software features. Feature phones target the lower end of the market and are primarily sold in developing countries. Since about 2013, smartphones have decreased in price sufficiently to out-sell feature phones.

A major development in *OHA* was the purchase of *Motorola* by hub firm *Google*. It was assumed that the main grounds for the purchase of the struggling phone maker were not *Motorola*'s hardware business, but rather its strong patent base. *Google* sought to protect the *Android* platform from legal attacks based on patent claims made by *Apple* and *Microsoft* against *OHA* members like *HTC*, *Samsung* and others which resulted in temporary market bans for certain *Android* products in certain markets in subsequent years. The purchase of *Motorola* found the support of other *OHA* members, even though it made *Google* a hardware manufacturer whose devices compete with those of other *OHA* members (Briegleb 2011a).

In late 2010, *Google* announced a further Linux-based operating system called *Chrome OS*. This system is aimed at complementing *Android* and runs on so-called *Chromebooks*, a netbook-type product category of lightweight laptops with the main feature being cloud-only devices with the devices' hard drives merely serving as buffers for the sole function of a browser-like web-access device. Like *Android*, these devices are designed and produced with hardware partners, although the first Chromebook prototype (and a few subsequent products) bore *Google*'s brand. While many of *Google*'s hardware partners (e.g. *Asus*, *Acer*, *HP*, *Lenovo* and *Samsung*) are also *OHA* members and sell *Android* devices, in contrast to the approach taken for the latter, *Google* announced no interorganisational alliance for *Chrome OS*, relying on joint development projects alone rather than a formalised network group. In 2011, these cooperative ties bore fruit, with *Samsung* and *Acer* launching *Chromebook* laptops (Chromium Project 2018).

As emerged in the course of legal proceedings, *Microsoft*'s patent licensing income for *Android* devices was exceeding its profits through sales of *Windows Phone* licences (Arthur 2011). This may have led *Google* to take considerable financial risks as regards the *Motorola* takeover (Briegleb 2011b) as a means to discourage a potential exodus of *OHA* members to the *Windows* platform. *Google* also launched *Android TV* to extend the platform beyond phones and tablets, and the platforms version 4.0 achieved much-needed integration across the various versions operating on existing devices.

Furthermore, *Google* persuaded *Microsoft*'s long-term hardware partner *Intel* to join *OHA* to work on new devices. *Intel* subsequently scaled back its efforts on the *MeeGo* system it had previously "inherited" through a previous cooperation with *Nokia* (*MeeGo* is the merged codebase from *Nokia*'s *Maemo* and *Intel*'s *Moblin* projects). However, *Intel* did participate in the attempts by *OHA* members *Samsung* and *Linux Foundation* to develop the new *OS Tizen* which later (2013) also absorbed *Samsung*'s open-source *bada OS* to consolidate efforts and strengthen the OS as a Linux-based alternative to *Android*. With its own supporting alliance *Tizen Association* (Tizen 2013), *Tizen* enlisted several *OHA* members such as *Huawei*, *NTT DoCoMo*, *LG*, and *Vodafone*.[63] However, *Samsung* remains the only manufacturer

[63] https://www.tizenassociation.org/members/ Status: 2018-01-20.

using *Tizen* on devices, commencing with *Tizen*-based cameras in 2011 and extensions to smart-watches (as of 2013) and to smartphones (as of 2015) with limited sales.

Despite continuing device and app sales growth for the *iOS* platform, 2011 heralded negative news for *Apple* as its founder, long-time CEO and *iPhone* innovator Steve Jobs first resigned due to illness and later died of the same (Cheng 2011). Having been a major advocate of *iOS* and *Apple* devices and an industry visionary, commentators feared a slump in innovative drive at *Apple*. If such a decline ever occurred, it never showed in sales figures. However, *Android* app downloads exceeded those of *iOS* apps for the first time in 2011, a trend that would continue in the following years. *Apple* showed innovative potential, however, when launching the industry's first voice-operated virtual assistant called "Siri" - a low-level form of *artificial intelligence* that can answer users' questions and control *iOS* devices from the *iPhone 4s* onwards (Velazco 2011).

2012 – Escalating patent wars

In 2012, the smartphone industry was dominated by the continuation and escalation of patent lawsuits, with parties from all sides suing others for damages arising from alleged patent violations. Granting patent licenses to other firms, even competitors, is customary in the industry due to regulation requiring the fair, reasonable and non-discriminatory (FRAND) licensing of a technological standard's core features. However, the precise definition of "fair" proved problematic. Other cases, like *Apple* vs. *Samsung*, concerned the pursuit of hardware sales bans based on alleged design patent violations and large damage penalties. In a decision subsequently overturned, a jury awarded *Apple* the prestigious sum of $1.05bn in damages (BBC 2012). Some cases continued for several years (*Samsung*'s penalty was downgraded to $539 in May 2018) and resulted in damage payments and even (temporary) sales bans for certain products. 2011-2 were certainly the most intense years in the "patent wars"[64] that observers criticised as being against public interest since "companies will compete more at (sic!) the courtroom than in the marketplace" (Economist 2012).

In terms of cooperative ventures, *LG* and *Intel* announced the development of new *Android* hardware (Wirtgen 2012), and *Google*'s recent acquisition *Motorola* also launched a phone with an *Intel* chipset, a direct result of integrating both into *OHA*. At both *CES* and *MWC*, OEMs launched a plethora of new, mainly *Android* devices. *Google* launched its *Nexus 7* tablet in cooperation with *HTC* (rather than subsidiary *Motorola*) which was perceived as a commitment to continuing technology partnerships despite the *Motorola* purchase. *Google* positioned its tablet as a budget device to explicitly compete with *Amazon*'s successfully selling *Kindle Fire* tablets based on the *Android* fork *Fire OS* (FTD 2012).

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[64] See https://en.wikipedia.org/wiki/Smartphone_patent_wars for a well-researched and annotated list with sources.

OHA's *Android* ecosystem was challenged when *Acer* – an *OHA* member – announced a new device developed with Chinese firm *Alibaba*, *Amazon*'s biggest competitor. The device was running an *Android* fork called 'Aliyun.' At the threat of being banned from *OHA*, *Acer* never launched the finished device it had developed, despite rumours of a defection from *OHA* (Duncan 2012). This suggests a problematic lock-in of *Acer*: *OHA* membership had not been successful for *Acer* so far and cooperating with *OHA* outsider *Alibaba* may have been beneficial. Further evidence of *OHA* lock-in appeared when *OHA* member *LG* announced that it planned no further *Windows Phone* devices because of high demand for *Android* devices. Despite contrary assurances, this was interpreted as a withdrawal from *Windows Phone* and a concentration on *Android* for future devices (Wölbert 2012). For *OHA*, enforcing this "members-only benefit" strategy appeared crucial to maintain traction in the Chinese market and to achieve internal cohesion as indicated by *Android* inventor Andy Rubin's comment "if you don't want to be compatible, then don't expect help from OHA members" (quoted in Arthur 2012a). Late that year, *Google* announced a further device in cooperation with *OHA* member *LG*. Meanwhile, *OHA* membership did not automatically result in success, as indicated by *Sony*'s striving for greater profitability and subsequent staff layoffs at several locations (Lopez 2012), indications of a struggle that would last several years.

Microsoft launched an updated version of *Windows Phone* to create traction for its ecosystem, and *Nokia* used this in a high-profile smartphone which promised to leave *Android* in the shade with its unparalleled camera function. However, even this device, was unable to attract substantial customer numbers, as *Nokia* reportedly struggled due to lacklustre smartphone sales (Briegleb 2012). To cut costs, *Nokia* decided to cut 10,000 jobs (Heise 2012), yet made a crucial strategic mistake in announcing just after launch that its new *Lumia 900* flagship device would not be upgradeable to the next version of *Microsoft*'s *Windows Phone*. *Microsoft* was planning serious code-related changes to align *Windows Phone* with the PC version of *Windows*, yet this rendered previous devices and apps incompatible. This issue led to lower-than-expected sales, as some network operators refused to sell the device (Barczok 2012), highlighting the importance of aligned hardware and software development, and the requisite close collaboration of respective industry players. Sales discounts helped the achieve better sales than feared, and *Nokia*'s stocks valuation increased, but its debt crisis was still not over and led *Nokia* to close its remaining Finnish production (Parbel 2012). Positive for the *Windows Phone* ecosystem was *Samsung*'s launch of the *ATIV S* smartphone running *Windows Phone 8.1*, and *Microsoft*'s launch of the tablet computer *Surface* which ran yet a further *Windows* version positioned between phone and desktop capabilities. *Nokia*'s former *Symbian* activities were further reduced by closing some of its *QT* development offices concerned with building *Symbian* application suite support (Genauck 2012), and *Accenture* laid off 330 Finnish workers from *Nokia*'s former *Symbian* development unit (Tung 2012).

For other platforms, 2012 held mainly bad news. *RIM* laid off 2,000 staff (FTD 2012), and another 5,000 later on in attempts to cut continuing losses due to problems with its new *BB10* OS (Wilkens 2012). At *MWC* 2012, the *Mozilla Foundation*, the non-profit developer of the famous *Firefox* browser, launched the *Boot to Gecko* initiative together with Spanish telco and *OHA* member *Telefónica* and gained support from *OHA* members *T-Mobile* and *Qualcomm*. This OS was named after the *Gecko* browser engine underpinning *Firefox* but renamed *Firefox OS* just 6 months later. The platform was based on *Linux*, like *Android*, and initially designed to run on select *Android* phones to replace *Android*, but devices preinstalled with *Firefox OS* would launch later. *Jolla* – a further new mobile OS from Finland – announced its purchase of *Nokia*'s remaining *MeeGo* team. Building on *MeeGo* code, it launched *Sailfish OS* with its own supporting interorganisational network (later: *Sailfish Alliance*) (Tung 2013). *Samsung* announced its first device building on *Tizen* – the OS developed together with *Intel* (Diedrich 2012).

Apple's *iOS* received a version update, and new devices were announced, including the *iPad Mini*, which competed with the popular small *Android* tablet range. Sales of devices and apps increased, and *Apple* launched its own *Apple Map* service and an app designed to remove advertising revenue and market share from *Google*, which was now becoming an increasingly strong competitor in the device markets so important for *Apple* (WSJ 2012). After ensuing conflicts between the companies, *Apple* decided to pursue *Google*'s services market via strategies including (location-based) advertising and replacing the *Google* maps app on its *iOS* devices.

2013 – Advent of smaller platforms

2013 began with the news that *Samsung*'s *Tizen*-based smartphone would launch on Japanese *NTT DOCOMO*'s network, both notably being *OHA* founding members. Linux company *Canonical* launched *Ubuntu for phones* –a further mobile OS competitor (Metz 2013). The platform sought to appeal to consumers through its unified user interface and app platform across devices such as desktops, tablets, and smartphones, and to developers by using popular programming languages for apps (e.g. HMTL5). While the platform was hailed for its design and ambition by commentators, it was also criticised for slow development, lack of OEM support, and for offering network operators options for customising the OS which would likely lead to fragmentation – a situation *OHA* was seeking to avoid for *Android* – and for being generally late to join the market (Woods 2013).

Jolla announced that *Sailfish OS* would become compatible with *Android* apps, a move copying *RIM*'s decision, and despite not participating in *OHA* and the related lack of access to the *Google Play* store for apps, this eased conversion and adaptation efforts for app developers considerably (Tonekaboni 2013a). The company could not reveal any partners for apps, however, but launched a device with Russian search engine *Yandex* which hosts an application store for compatible *Android* apps (Tonekaboni 2013b). *Firefox OS* gained some traction and launched an app marketplace with considerable industry support at *MWC*, and several large app developer firms promised contributions (Heise 2013). Devices would launch only months later when further cooperation with industry players, especially network operators who welcomed the customisability of *Firefox OS*, were announced (Tung

2013). The first two budget phones developed by Spanish *Geeksphone* and Chinese *ZTE* were initially sold by network operators *Telefónica* and *T-Mobile*, with further handsets announced by *Alcatel*, *Huawei*, *LG* and even *Sony* (Briegleb 2013c). It is notable that these devices and *Firefox OS* collaborations appear to be side-projects of *OHA* members, aimed at reducing *Android's* market clout with an alternative platform in their portfolios, and at providing a customisable alternative to network operators whose influence on the devices they sell had considerably decreased through the introduction of the platforms *iOS* and *Android*. Also notable is the Linux kernel basis for all these new platforms and some of the challenger platforms, e.g. *Sailfish OS* and *RIM*, are even compatible with *Android* apps (Tung 2013b). Overall, "there seems to be some interest in alternative platforms to Android. This is driven on the one hand by vendors that do not want to put all their eggs in one basket by supporting only Android, and also by operators who do not want to become too dependent on Google" (Carolina Milanesi from Gartner, quoted in Woods 2013).

RIM renamed itself *Blackberry* in 2013, and also made its *BB10* platform compatible with *Android* apps, but sales did not develop better than in the previous year. While media reviewers were generally impressed with the firm's latest *Blackberry Z10* device, it did not achieve the sales necessary to halt the firm's debt crisis. One reason for this may have been the lacklustre app supply in *Blackberry World*, the company's app store. *Blackberry* had tried to copy *Google*'s initial approach to host so-called "port-a-thons" – long weekend developer competitions where developers converted some 30,000 *Android* apps to the *BB10* system (Kirsch 2013). Some commentators considered the comparatively smaller number of apps a non-issue since systems like *Ubuntu* and *Firefox OS* hinted at trends towards single app development across devices and platforms (Briegleb 2013a), helped by newly available cross-platform development frameworks (Neumann 2013). This prognosis by *Gartner* appeared adequate, since the market now had about eight different platforms that app developers needed to support to be present across devices. A further factor in low device sales was the announcement that *Blackberry* would not release a further tablet device – a booming device category on platform like *iOS* and *Android*, taking away market share from traditional PCs. Former smartphone leader *Blackberry*'s position further declined, however, and the company laid off even more workers, closed down part of its manufacturing, outsourced the rest to *Foxconn*, and started looking for a company buyer (Rushe 2013).

Former contender *webOS* of *HP* was sold to *OHA* member *LG*. *LG*, being fully committed to *OHA* and *Android* for smartphones and tablets, announced that it would only use *webOS* as a user interface on its smart TVs. *LG* could also have chosen *Android* as a TV OS (such as *Sony*), but the repurposing of *webOS* clearly removed it from the mobile OS competition (Kui 2013). *HP* had meanwhile joined *OHA* and announced a tablet with its *Android* operating system at *MWC*. *OHA* achieved the milestone of over 1 million apps available in the *Google Play* app store with some 50bn downloads to date. It gained two notable new members with aspiring Chinese OEMs *Huawei* and *ZTE*. While *Google*'s dominance in *OHA* had been a subject of discussion in previous years, *Samsung* now took on that particular role: contrary to other OEMs, it was successfully selling multiple devices – amounting to

40% of all Android devices – and became arguably the most dominant player in *OHA*. Reports indicated that staff at *Google* were concerned about S*amsung*'s influence and anticipated an *Android* fork, with others considering *Google*'s purchase of *Motorola* an insurance policy against *Samsung* (Efrati 2013). *Samsung* sales had additionally overtaken *Apple iOS* device sales, so that the *Android* platform was now bigger than *iOS* with *Samsung* alone. *Android* had grown to an overall 70% market share (Heise 2013) and the OS was extended to a new product category: smartwatches which were developed by *Google*, *Samsung* and *LG* and rumoured at *MWC*.

There were some challenges to *Android*'s ecosystem, however. Hub firm *Google* was under investigation by the *European Commission* for anti-competitive measures in its search engine. *Google* was suspected to have restricted users' ability to find competitors' products or services when searching on *Google*, and to have displayed *Google*'s own products and services more favourably than those of others. This would violate the principle of 'equal treatment' (Arthur 2013a). After a similar *FCC* investigation launched in the US a few months earlier (Arthur 2012b), these were the second anti-monopoly investigations *Google* was facing. While they did not concern *Android* directly, the *European Commission* announced that – following a formal complaint from a competitor group involving both *Microsoft* and *Nokia* – it would next investigate whether *Google* requiring *OHA* members to preinstall *Google*'s apps on *Android* devices and giving *Android* away for free would amount to anti-competitive measures such as predatory pricing (Arthur 2013b). *Google* was later fined a record €2.4bn by the *European Commission* in 2017 (EC 2017a, EC 2017b) for abusing its search engine market position, and in 2018 the fine for *Android*'s antitrust violations almost doubled that imposed in 2017. *Amazon*, still using its *Android* fork *Fire OS*, introduced a virtual currency called *Amazon coins* as an attempt to make it even easier for customers to purchase apps on *Amazon*'s own store, and this payment option would be extended to eBooks, films, tv shows, music and other content if successful (Metz 2013).

By 2013, social media company *Facebook* had grown to become *Google*'s biggest competitor in the online advertising market, and was gaining on *Google* in market share with over 1bn users (Dembosky & Palmer 2012). This increasingly powerful player was also closing in on *Android*, when rumours had it that *Facebook* might launch its own phone, potentially using an *Android* fork (Siegler 2013). Instead, however, *Facebook* created its own *Android* home screen app: a launcher called *Facebook Home*. This launcher integrates deeply with *Android* and replaces the common *Android* home screen with a *Facebook*-oriented home screen featuring the user's *Facebook* newsfeed. This launcher can essentially run on any *Android* device, and thus has arguably more market potential for mobile advertising than a forked *Android* version might. Notably, while several alternative launchers exist for *Android* and often even come OEM-preinstalled (such as *Touchwiz* on *Samsung* devices), *Apple* would not allow such customisation, highlighting the open vs. closed system nature of the mobile OS competition. While *HTC* developed a phone with *Facebook Home* preinstalled (*HTC First*), *Facebook*'s attempts at winning *Samsung* as a partner for such a device failed, not least because *Facebook Home* and the *HTC First* sold badly (Briegleb 2013b). *Google* grew discontent with *Facebook*'s procedure for updating its numerous

Android apps. These updated directly through *Facebook*'s own servers rather than using *Google*'s *Google Play* store servers where they would tie in with *Google*'s statistics etc. To change *Facebook*'s behaviour, *Google* unilaterally changed the *Google Play* update mechanisms and obliged all *Android* app updates to go through *Google*'s update service. This rendered *Facebook*'s behaviour non-compliant and *Facebook* reacted soon after this show of *Google*'s power in the *Android* platform and adjusted its update process accordingly (Beer 2012).

Apple's *iOS* platform also reached important milestones with over 40bn app downloads from its *App Store*. Apple, too, was investigated by the *European Commission* regarding anti-competitive measures suspected in the terms and conditions of the distribution contracts between *Apple* and network operators that forced their retailers to adhere to *Apple*'s pricing policy, sales guidelines, device presentation rules and profit-sharing agreements (Schwan 2013). Furthermore, *Apple*, with its premium-priced product strategy, decided for the first time to access to the lower end of the market with its cheaper *iPhone 5C* (Garside 2013a). However, this proved unsuccessful since the market segment had already been adequately targeted by *Android* devices. Hence, the cheaper *iPhone 5C* devices lasted only for a single generation. Adding to the already intense market competition between the two largest handset makers, *Apple* and *Samsung* further escalated their lawsuits against each other, resulting in temporary sales bans on *Apple* and *Samsung* devices, respectively.

Given the seemingly positive market position of *Nokia* as second biggest phone maker, 2013's most dramatic industry development was clearly the latter's sale of its entire mobile device business to *Microsoft* (Arthur 2013c). Due to low smartphone sales, *Nokia* commenced the year with more layoffs to address cost issues. Furthermore, it closed the remaining *Symbian* business and activities in spring 2013. No more smartphones with *Symbian* would be built, even feature phones would only use heavily UI-reduced *Symbian* versions. For all smart devices, *Nokia* now focused exclusively on *Windows Phone*. Given that other manufacturers like *Sony*, *LG*, and *Motorola* had already left that platform earlier and committed to *Android*, *Nokia*'s news heralded the end of the *Symbian* platform (Thomas 2013). *Nokia* and *Google* discussed the former potentially joining *Android*, too, but the idea was discarded when *Nokia* made predictions about *Samsung* becoming the largest manufacturer by far. Joining *Microsoft* instead offered the differentiation of a third platform supported by software clout (Arthur 2013d).

Microsoft's strategy of separating *Windows Phone 8* and *Windows 8 RT* for tablets was not paying off. Given the earlier strategic failure of a lack of coordination between device makers and platform development (when new devices would not upgrade to new OS versions), a strategy of integrating a device maker more closely appeared sensible and renewed *Microsoft*'s commitment to hardware devices and the software ecosystem. For *Nokia*, however, selling its traditional core business was an intense step and initiated a continuing discourse of failure about and at the company whose decline lends itself to be used as a learning case (Laamanen, Lamberg & Vaara 2016: 2). Under the sales agreement, *Microsoft* was allowed to continue using *Nokia*'s brand name and sub-brands like *Asha* for feature phones for ten years and continue the *Lumia* brand, while *Nokia* was banned from using its brand name for smartphones during that time. Predictions about the potential success of this new integrated device maker were divided, even though *Windows Phone* was the third largest platform in 2013 and was projected some potential for growth. One issue with the new strategy was the possibility that *Microsoft*'s OEM partners might leave given the new competition from the integration of *Nokia*, just as was it considered for *Google*'s purchase of *Motorola*. Furthermore, *Microsoft* had the history of buying *Danger* – an early smartphone maker that innovated the app store concept and was founded by later *Android* chief engineer Andy Rubin – only to close its development weeks after purchase in 2008 (Markoff 2008: 9). *Nokia*, meanwhile, repositioned itself to focus on its network infrastructure subsidiary *Nokia Solutions and Networks* (NSN) – a consolidated network equipment manufacturer composed of the mobile infrastructure business of *Nokia*, *Siemens*, and *Motorola*; its *HERE* location and map services; and *Nokia Technology,* an engineering subsidiary for creating licensable innovation.

Overall positive news for smartphone platforms was the fact that smartphones outsold basic mobile phones and feature phones (Garside 2013b) for the first time. The device market was divided between overall leader *Samsung* with 32% market share (from *Android* devices and feature phones), *Nokia* with 25% (accounting largely for feature phones and far fewer *Windows Phone* devices), *Apple* with 14% (down in a relative sense from 19% despite absolute sales increases), and *Huawei*, *LG*, *Lenovo*, *Sony* and *ZTE* with *Android* and feature phone devices trailing behind. Platforms ranked similarly, with *Android* leading, *Apple* second and *Microsoft* managing to overtake *Blackberry* whose market share decreased despite a prestigious new product launch.

A development with high impact on the smartphone industry was the revelation of the *NSA* scandal by whistle-blower Edward Snowden. Many of the exposed technologies such as *PRISM*, *Tempora*, *XKeyScore* etc. were collecting vast amounts of (mobile) internet user metadata[65], phone metadata, device location data etc. in near real-time without judicially-authorised surveillance orders, and on an unprecedented scale. The five countries USA, UK, NZ, Canada, and Australia were implicated in these revelations as collaborating to monitor, survey and collect international data streams indiscriminately (Spiegel Online 2013; Heise 2015; Khosrow-Pour 2005: 1987). Many mobile users had previously been unaware of the surveillance potential of their devices, so some industry experts suspected a decline in device sales and usage. The main consequence, however, was the increasing usage of encrypted peer-to-peer messaging apps like *Signal* or the integration of encryption algorithms into existing apps such as *Whatsapp*. Instead, smartphone usage and sales increased further, as evidenced by sales records and even a substantial crowding-out of PC sales by phones and tablets, with the latter also predicted to achieve more sales than PCs by 2015 (Sokolow 2013).

[65] Metadata is information on the properties of a voice or text conversation or internet activity. Metadata includes start, end, duration, URLs visited, service used, etc. but typically no content.

2014 – Further industry consolidations

While 2013 was the year of smaller platforms, 2014 saw some of them removed from the market: as a direct result of the developments between *Nokia* and *Microsoft*, the *OVI* store for *Symbian* apps and *Nokia*'s *MeeGo* store were frozen, never to be reopened (Tung 2014). While *LG* launched a series of TVs based on *webOS* for internet access, the platform did not return for mobile devices. There was no good news for *Samsung*'s *Tizen* OS, either, since Japanese network operator *DoCoMo* announced its intention to pull out of the launch of the *Tizen* device announced a year earlier. While *Samsung* showed phone prototypes and announced a smartwatch and cameras running the OS, the phone prototypes did not attract much attention and gained no release dates (Hanna 2014). Finnish *Jolla* launched its first device *Jollaphone* with *Sailfish OS* preinstalled. Its main feature was the ability to run *Android* apps, and the phone carried an application interface allowing users to install apps from the Russian app store *Yandex.Store* (Tonekaboni 2014). This cooperation was necessary because *Jolla* – with its own OS – cannot join *OHA* and use the *Google Play* store and related services. Simultaneously, *Jolla* introduced its app store *Harbour* to which the submission of both native *Sailfish* and *Android* apps was accepted. At *MWC*, *Jolla* announced that *Sailfish* OS would be adapted to available phones (e.g. from *Sony* and even *Google*'s Nexus device) that originally come preinstalled with *Android*. This strategy allowed the company to keep its hardware development investment low, but also caused user uncertainty as regards potentially voiding their original warranty when installing *Sailfish OS*, with many users lacking the technical skill to perform such an installation. *Firefox OS* had launched in 2013 with relatively low-performing phones that did not sell well. To improve sales, hardware partners *Alcatel* (the brand name meanwhile owned by *TCL*) and *ZTE* launched notably better devices (incl. one tablet) than the distribution partners, e.g. *T-Mobile*, would go on to launch in several new markets (Bager 2014). *Mozilla Foundation* also offered new developer tools, making it easier to design and program apps for the platform at *MWC*.

For *OHA* and *Android*, the situation was looking up. *Google* extended *OHA*'s partnerships into the automotive sector, where *Android Auto* was integrated into manufacturers' in-car entertainment systems and linked up with *Android* devices running apps that relied on cooperative relations with several app developing firms (Wilkens 2014). *Android Wear* was launched as another extension of the *Android* platform, this time into the wearable electronics market with devices such as smartwatches, smart clothing, smart home automation devices etc. (Heise 2014). Just like *webOS* had been ported to TVs, *Android TV* was launched for smart TVs and streaming devices with hardware from *Sony*, *Sharp* and *Philips* (with the brand name owned by *TP Vision*) (Dredge 2014). These three platform extensions signify a considerable effort of solidifying *Android*'s presence, in terms of technology, networking and market. The technology running on more types of devices beyond smartphones and tablets serves as an indication of its technological capability and adaptability which may attract further new partners. This in turn increased *Google*'s network of cooperative relations with TV manufacturers and watchmakers joining the overall platform, albeit not becoming *OHA* members due to their different focus.

Since *Sony*'s and *Sharp*'s handset divisions were already *OHA* members, for instance, these firms appear to have become even more locked-in to the network and its technology. Moreover, the increase in both partners and device form factors significantly increased the market size for developers, thus creating more opportunities to benefit from the two-sided market nature of the platform competition with related strong lock-in potential for participants on either side (Meyer 2012). *Google* additionally made its *Chrome OS* laptop operating system compatible with *Android* apps, so that apps from the *Google Play* store can also be used on this device type - although it took over a year for said devices to gain full compatibility in 2016 (Neumann 2014).

Google sold *Motorola* on to *OHA* member *Lenovo* but kept much of its patent base as an asset to defend the platform against incoming lawsuits, such as the key suit brought by *Microsoft* against *Google*. The sale of *Motorola* was interpreted as a concession to *OHA* members, as directly after the announcement, *Samsung*'s relationship with *Google* reportedly intensified in terms of a patent sharing agreement and *Samsung* treating *Google*'s apps more prominently on its devices. This intensification was attributed to *Google* no longer being a direct competitor to *Samsung*'s device business (Kuri 2014). Market research firm *Gartner* counted more sales of *Android* tablets than of *iOS* tablets for the first time, repeating the trend from phones of 2013 (Gartner 2014).

OHA also faced some challenges beyond the continuing litigation against *Android* device manufacturers and *Google*. *Amazon* announced the *Fire Phone* – a smartphone based on its *Android* fork *Fire OS* – the firm's first phone to use non-*OHA* compliant version of *Android* after the top-selling *Fire* tablets (Cunningham 2014). Despite relatively good hardware, the *Fire Phone*, however, was not successful in the marketplace and thus discontinued after less than a year, with reasons identified as pricing strategy and lack of integration into the *Android* ecosystem (Rubin & Cheng 2015). *Amazon*'s lack of links to *OHA* and *Google* appears to have made the *Fire Phone* unattractive to customers and developers who have still not contributed a high number of major apps to the *Amazon* app store, as many rely heavily on the *Google* services which *Fire OS* devices cannot use.

A second challenge for *OHA* was initiated by the *Free Software Foundation Europe* (*FSFE*) – an organisation promoting free and open-source software, and privacy and data protection for users. Recognising the trend of *Android* becoming the largest mobile platform with strong attachment to *Google*, the *FSFE* started a campaign[66] for users to free their *Android* of *Google*'s influence by uninstalling *Google* services or switching to one of the community-driven open-source *Android* forks such as *Linage OS* (formerly: *CyanogenMod*). While the success of the campaign remains limited, the forks have attracted some tens of millions of users over the years, but precise statistics are difficult to create for reasons that many forks – due to their privacy agenda – do not even record download figures. For the average user, however, the installation of alternative Android forks remains a challenge, not least

[66] https://fsfe.org/campaigns/android/android.en.html

due to a typically incurred loss of warranty.

iOS as the second largest platform managed to grow in absolute numbers, while having to concede market share to *Android*. This did not stop *Apple* from becoming the *world*'s most valuable company based on excellent *iPhone 6* sales (Schwan 2014). By contrast, *Apple*'s main competitor (also in the pending litigation) *Samsung* began struggling with *Android* competition from China. *Apple* also extended its platform with new features such as the integration of the payment function *Apple Pay* within its devices. A further technological feature called *Apple-SIM* (essentially an early *eSIM* implementation) became an issue with network operators (Schwan 2014b). An *eSIM* is a replacement of an operator's SIM-card with a software solution built into the device, removing the need to insert a hardware SIM card to set up a device and thus facilitates different hardware designs. However, this functionality involves features such as being able to change network operator contracts at the click of a button on the device screen. When roaming abroad, for instance, this functionality could make it easier for users to save roaming fees and thus reduce network operator's roaming fee income. Another issue for the network operators is the fact that, in order for this software solution to work, the platform operator – *Apple* in this case – would have control over which network operators become listed for the user to choose from. Network operators, which had already been reduced in market power by the smartphone platforms, were suspecting further loss of market influence and were hesitant (Becker 2014). This first variant of the *Apple-SIM* was removable like a normal SIM card and while US network operators delivered *Apple*'s *iPad 2* with the *eSIM* functionality (*Apple* appeased the network operators with the ability to customise the *eSIM* features), European networks chose not to join this technological step until later.

As the third largest platform, *Windows Phone* remained in difficulties. Former device maker *Nokia* (the company) managed to cut much of its losses through selling the device business to *Microsoft* and used the resulting financial resources to purchase *Panasonic*'s network infrastructure business, adding to its subsidiary *NSN*. The new device business at *Microsoft*, however, appeared to have purchased *Nokia* (the brand) issues as part of the package, and cut 12,500 more jobs less than a year after the acquisition (Elop 2014). *Microsoft* also discontinued the *Nokia* brand and used *Lumia* for devices and *Windows* for the platform to align with the desktop and tablet brand, and to signal the impending convergence of the platform. An even more surprising decision was the relinquishment of *Windows Phone* license fees which *Microsoft* announced would in future be given away for free to manufacturers for all devices with a display size under 9 inches, meaning essentially all phones and smaller tablets. Larger tablets would be sold with a derivate of desktop *Windows*. This decision surprised observers and appeared as an almost desperate attempt to gain hardware manufacturer support for the platform since the license fees had no substitute in *Microsoft*'s business model (Wirtgen 2014), essentially repeating *Nokia*'s *Symbian* decision from years earlier. Rather than making the platform more attractive, however, the third largest OEM *Huawei* announced it would stop selling *Windows Phone* devices (and stop exploring *Tizen*) and commit fully to *Android* and join *OHA* (Briegleb 2014). While *Microsoft* pursued *Samsung* for alleged patent violation, the case was settled out of court with *Samsung* assumed to pay *Microsoft* a substantial fee for new and previously sold phones, adding to the overall perception of market observers that *Microsoft* earns more revenue with patent licenses on *Apple* and *Android* devices than with its own devices.

Relevant for the whole industry were the European Parliament's vote in favour of the abolition of international roaming fees within the EU, and of regulating net neutrality (Chee 2014). The latter is a concept related to the equal treatment of data streams without preferential or discriminatory treatment of streams such as video-on-demand or video calls and VoIP services such as *Skype*. Both decisions were deemed to be in users' favour but also curtailed network operators' potential to influence the market and reduced their revenue potential to some extent, only adding to the loss of market clout from the rise of mobile platforms.

2015 – The year of Android

Android's rising trend had emerged in 2014, as it became the predominant mobile platform, to be extended into other industry and device segments. 2015 consolidated this position even further, with *Android Auto* becoming available in first vehicles of partners *Hyundai*, *Audi*, *Chevrolet* and *VW* initially, and in another 31brands later on (Sokolov 2015). *Google* made *Android* more relevant for corporate usage by introducing device management tools, a deep separation of private and business applications, and even a separate app store to compete with *Apple* in that market segment (Weber 2015). Stressing the importance of *Android* for *Google*, the company made its former *Android* head Sundar Pinchai the new CEO as part of a corporate restructuring making *Google* the subsidiary of the new holding *Alphabet* (Hern 2015). As the EU investigation into potential market power abuse by *Google* continued, US authorities also started investigating the firm on suspicion of violating the 'equal treatment' of competitors' and its own apps (Wilkens 2015). Perhaps in anticipation of rulings in this investigation, *Google* announced that it would require OEMs to pre-install fewer of *Google*'s own apps (Barczok 2015). *Google* also added a proprietary payment service, *Android Pay* (now *Google Pay*) to compete with that of *Apple*.

After a quiet 2014 for *Blackberry*, marked by low sales, 2015 began with an unexpected announcement (Amadeo 2015): the firm divested itself of its hardware business and sold it to *TCL Communications*, a Chinese conglomerate already holding the *Alcatel* brand through which it is an *OHA* member. *Blackberry* also launched the *PRIV* smartphone – its first *Android*-based phone after reducing efforts in its own platform (Lomas 2015). Remarkably, *Blackberry*, despite joining the *Android* platform and providing several apps in *Google Play*, did not, however, join *OHA*, but still gained access to *Google Play* and all *Google* services. One reason for this decision may have been that *Blackberry* announced the launch of its software across platforms, not exclusively for *Android* but also on *iOS* and *Windows* (Weber

2015). The move is still remarkable since *Google* had formerly required OEMs to join *OHA* to gain access to the *Google Play* store and *Google* services. This decision may, however, be a further concession to anti-competition authorities as a symbolic relinquishment of control, as *OHA* partners were also demanding more liberty (Banerjea 2015), an issue *Google* sought to address by opening an online device shop listing competitors' devices (Förster 2015).[67]

For the smaller platforms, 2015 brought mixed developments. Spanish manufacturer *BQ* launched the first *Ubuntu Touch* phone (Canonical 2015) which remained at rather low sales volumes. *Jolla* sold its first *Sailfish OS* tablet after heavy delays in a crowdfunding initiative (Tonekaboni 2015) and sought to strengthen its own platform alliance through the creation of the *Sailfish Alliance* (Carroll 2015). Also, after more delays, *Samsung* began selling its first *Tizen*-based phone in India, targeting the developing country market with a budget device (Samsung 2015), which *Samsung* replaced with a successor model within the first six months. *Firefox OS*, in contrast, was discontinued. The initially most promising – given its alternative fully open-source and web-based approach – of the smaller platform contenders threw in the towel, citing lack of sales and new hardware partners. The discontinuation also showed how, despite solid relationships with hardware partners like *Huawei* and network operators such as *T-Mobile*, the lack of apps and developer support means the platform saw no sustainable development in terms of customer demand (Lunden 2015).

While Stephen Elop left *Microsoft* (Briegleb 2015a), Satya Nadella became *Microsoft*'s CEO as the company tried to cut its losses in the smartphone business by slashing 7,800 more jobs and writing off the remaining *Nokia* assts (Briegleb 2015b). The takeover of *Nokia* can thus be considered a failure since it never fulfilled the market share expectations of *Microsoft* that saw it overtake *Apple*. Instead, *Microsoft* achieved around 3% market share with *Microsoft* remaining as the only major hardware maker with *Windows Mobile* devices. *Microsoft* also decided to discontinue certain *Lumia* apps before launching its most competitive devices yet: the *Lumia 950* and *Lumia 950 XL*, featuring the newest OS version *Windows 10* that finally merged desktop and mobile platforms. Seeking new initiatives to counter the decline of former *Nokia* devices and the *Windows Mobile* platform, *Microsoft* entered into several cooperative agreements with players from the *Android* platform. Among these were market leader *Samsung* and OEMs like *Dell* (Johnson 2015) and later *LG* and *Sony*, which would deliver their *Android* devices with certain *Microsoft* applications preinstalled. Further movements towards the *Android* platform included *Microsoft*'s unveiling of its own *Android* launcher *Arrow* – an alternative *Microsoft*-oriented device home screen similar to that developed by *Facebook* – and a cooperation agreement with *Cyanogen* – the company involved in making the most popular fork of the open-source *Android* available, and liberating it from *Google* products and services (Bort 2015). *Nokia*, meanwhile, concentrated its efforts on becoming a solid infrastructure provider by selling off its navigation and location- based service subsidiary *HERE* to a conglomerate of automobile firms (Titcomb 2015), giving it the financial

[67] Offers on store.google.com have since been reduced to Google devices only once more.

means to finalise the integration of *Alcatel-Lucent* into its network infrastructure division – becoming, at the time, the world's second largest behind *Ericsson* (Rosendahl & Abboud 2015).

With *iOS* sales continuing to account for approx. 15% of the market share, *Apple* managed to reap the highest profits in the smartphone sector, as many competitors (even *Samsung*) encountered profitability issues (Schwan 2015). *Apple* also launched its successful smartwatch *Apple Watch* with an *iOS* derivative serving as OS, thus further extending its reach in other market segments, a model which would remain the most successful smartwatch device for years to come.

2016 – A duopoly-market taking shape

In February, the *MWC* once more witnessed the launch of more smartphone and tablet devices than ever before. However, fewer OS were represented overall, with *Firefox O*S defunct and *Jolla* and *Ubuntu* selling only quite small volumes of devices. *Jolla*, with difficulties in selling its crowdfunded tablet device, announced a discontinuation of that project after only a few buyers had received the hardware. It announced a new focus on porting *Sailfish OS* to existing (*Android*) devices (Brors 2016). *BQ* again announced a *Ubuntu Touch*-based phone and tablet but remained the only manufacturer apart from *Meizu* to do so (Barczok 2016). Overall, five hardware devices based on *Ubuntu Touch* were thus on sale. *Tizen*-based devices remained few in number, as only *Samsung* announced another device for the Indian market (Samsung 2016). As a countermeasure to the lack of *Tizen* apps, *Samsung* offered awards to developers submitting apps to its *Tizen* Store. *Samsung*'s copycat strategy, namely, to create *Tizen* as a means to become less dependent on *Google* and *Android*, mirroring the latter's approach, did not prove successful (Schumacher 2016).

In 2016, *Android* became available in a new version which introduced a fundamental change in its *Java* engine to address issues raised in lawsuits seeking to prevent future damage payments – a decision that appeared superfluous in retrospect when the courts (somewhat controversially) found in favour of *Google* (Mullin 2016). *Google* also launched *Daydream* – a virtual reality reference device integrated with *Android* as yet another extension of the platform into a new market segment. *Android* apps became natively supported on *Google*'s *Chrome OS* with full *Google Play* access, and observers speculated whether *Google* would push for a unified OS merging *Android* and *Chrome OS* under the name *Andromeda* (Spier 2016). As a continuation of *Blackberry*'s new strategy, the firm announced more *Android*-based *Blackberry* phones, the subsequent abolishment of its own former platform *Blackberry 10* and a full focus on *Android* (Weber 2016), with *Blackberry* apps also becoming available for phones from other manufacturers through the *Google Play* store. Finally, *Blackberry* announced the closure of its hardware business (Griffin 2016) and the sale of the same including exclusive *Blackberry* brand rights for hardware to *TCL* – the *OHA* member through its *Alcatel* brand (De Vynck. 2016). This move finalised the ongoing platform switch that meant former smartphone leader *Blackberry* relinquished its hardware business and own software platform with limited app support and resulting user attractiveness in favour of an *Android*-based software integration business.

While this development was favourable for the *Android* platform, *Dell* discontinuing its *Android* tablets was not, and a testament to the overall declining tablet market. Despite not planning new devices. *Dell* remained in *OHA*, though (Nowak 2016). *Google*'s own *Nexus*-branded devices did not sell well. but revenues from mobile advertising increasing strongly (Sokolov 2016). Revenues from *Google*'s *Play* store sales, however, remained problematically low, with most users not buying apps (Wilkens 2016). While no problem for *Google* with its advertising revenue, this situation signified more difficulties for developers who struggled to turn their software into profits. For *iOS,* this situation was largely similar; however, in comparison with *Apple*'s *App Store*, *Android* users appeared to spend less money. Further challenges for *Android* hub firm *Google* were ongoing *European Commission* investigations into Google's alleged abuse of market power over anti-competitive measures such as requiring manufacturers to pre-install *Google* apps on *Android* devices (Wilkens 2016), and taxation deals the company had made with countries like the UK (Mason & Rankin 2016). With the investigation closing in 2018, observers expected heavy fines not least because the *European Commission* had already found the formal complaints warranted, citing specifically *Google*'s anti-fragmentation measures as objectionable (EC 2016a).

Microsoft continued its 2015 strategy of divesting from *Windows Mobile* and investing in cross-platform, and especially *Android* software. Another major decision was to discontinue the *Lumia* brand for phones, to sell the *Nokia* brand and the remaining hardware business including feature phones, and to cut the remaining former *Nokia* jobs (Guardian 2016). While *Microsoft* continued its support of *Windows Phone* and existing devices, it announced that no further devices would be launched. In addition, *Microsoft* invested in the cooperation with *Cyanogen*, the *Android* fork developing firm with which it had previously entered a collaboration, and now contributed *Microsoft*-developed software modules to it (Wirtgen 2016). *OHA* member *Lenovo* joined *Microsoft*'s partner companies to sell phones with preinstalled *Microsoft* applications.

Microsoft's remaining hardware business and the *Nokia* brand for phones was purchased by start-up *HMD Global*. With manufacturing outsourced to *OHA* member *Foxconn*, *HMD* had access to the full *Android* platform and *Google* services (Hern 2016). Despite not becoming an *OHA* member, *HMD* partnered with *Google* to develop a virtually unaltered *Android* version ('vanilla') for new devices, mimicking *Google*'s *Nexus* device strategy. *HMD* immediately announced the development of several *Android* smartphones to be sold under the *Nokia* brand by spring 2017 (Gibbs 2016). While *Nokia* holds no shares in *HMD*, the company consists mainly of former *Nokia* staff and even its headquarters are located in the vicinity of *Nokia*'s. Hence, this new situation arguably marked a resurgence of *Nokia* as a player in the smartphone industry, yet depending on *OHA*'s Android platform rather than *Symbian* or *Windows Phone*. For *Google*, in turn, the additional non-*OHA* member with full access to *Google*'s

Android services and tools signified a strategic change that may have led to other manufacturers pursuing an *Android* strategy outside of *OHA,* but all members remained in *OHA*.

The second largest platform, *Apple iOS,* saw overall beneficial developments in 2016 with sales continuing to attract around a 15% market share and achieving the sales record of 1bn *iPhones* sold within 9 years of the inauguration of the touch smartphone market (Schwan 2016), with total *iOS* devices having exceeded that figure already in 2014. With its *App Store*, *Apple* achieved twice the turnover of the *Android* platform but with only half as many apps downloaded. While *Google Play* attracted more apps overall (*iOS* apps also grew), *iOS* managed to give developers better revenues (Becker 2016). This development of higher profitability of *iOS* apps vs. *Android* apps signals an important trend which persists at the time of writing in 2018. Given that at least larger developers are deeply embedded into *OHA* and developers cannot afford to lose access to *Android*'s 85% market share, this implies being trapped in an unprofitable situation to some extent. *Apple* furthermore introduced the *Apple-SIM* that had been announced two years earlier in its new *iPad 2* device to *iPhones*. Despite many success stories for the platform, 2016 also marked a severe penalty for *Apple*. The *European Commission* found *Apple* had negotiated and been granted an illegal indirect subsidy through an individual tax agreement with Ireland where *Apple* bases its EU headquarters. As the judgement in this high-profile case, *Apple* was ordered to repay €13bn in saved taxes (EC 2016b).

Many smartphone industry players met and began testing the next even faster level of technology, 5G, at the industry event *Berlin 5G week* (Fraunhofer-Gesellschaft 2016). 5G technology promises better coverage and speeds of up to 1000 Mbit/s in mobile usage. 5G is considered to be of great importance in the industry since it will enable future innovations that maybe able to compensate for the shrinking tablet and PC markets (Holland 2016). A further innovation capturing the attention of millions of users was the launch of the first large-scale augmented-reality (AR) smartphone game called *Pokémon Go*. The game heralded the arrival of new applications for superimposing smartphone camera images with digital real-time elements for augmented location-based services, online shopping, games etc. While in itself not new, smartphones' increasing computational power enabled the technological "game-changer" (Kuzru 2016) that can profoundly influence and alter the way society perceives (or not) a shared reality. For the mobile platform providers, AR, and by extension also VR, can largely be considered an important future revenue source, not least for its many industrial applications (Gennies 2016). AR and VR technologies were addressed by *Google*'s *Daydream* and later with *Apple*'s *ARKit* and *Google ARCore* APIs, that have been integrated into the respective platforms and run on sufficiently potent devices.

2017, 2018 – A two-horse race. Mostly.

For *Apple* and its *iOS* platform, 2017 marked the ten-year anniversary of the launch of its first *iPhone* in 2007 and thus the birth of the smartphone platform market. Over this ten-year period, *iOS* had seen many software version iterations, and app sales through *Apple*'s *App Store* achieved approx. $30bn in 2016 alone (Becker 2017a). It had become an important revenue source for both developers and *Apple* thanks to its 30% sales commission. Following *Google*'s strategy, *Apple* also made *iOS* apps compatible with its desktop operating system *Mac OS X* which extends the reach of *iOS*. For some developer firms, access to their apps or platform rules changed unilaterally, or prices raised by *Apple* proved a big issue (Schwan 2017a; Becker 2017b). *Apple* faced backlash for this behaviour in the form of the creation of a 'union' – *The Developers' Union*[68] the year after, a direct response to its directive approach (Goode 2018). More positively for *Apple*, the firm settled a patent conflict with *Nokia*, with *Apple* paying *Nokia* an outstanding €1.7bn and future license fees (Schwan 2017b).

For *OHA* and *Android* overall, market leadership remained firmly established in 2017-18. *HMD Global* as the newest addition to the platform announced several *Android*-based phones under the licensed brand name *Nokia* throughout 2017 and achieved moderate sales in several market segments (Gibbs 2017). While the devices attracted moderate reviews in the press, *HMD* made ambitious claims, aiming to rank among the three largest manufacturers within five years (Barczok 2017). Such a claim would require it to outstrip sales by *Huawei* – the best-selling Chinese brand currently claiming third place after *Samsung* and *Apple*. While it remains to be seen whether *HMD*'s strategy of unaltered *Android* experience paired with Nordic design will be successful, it managed to attract two powerful partners with *Google* and production partner *Foxconn* which had been manufacturing *Apple*'s iOS devices since 2007. With *HMD Global* praised for its *Android* implementation only a year later (Amadeo 2018), the partnership with *Google* appeared to be heading towards success. After more losses, *Blackberry*, the second major newcomer to *Android.* decided to go beyond outsourcing its hardware production to *TCL* and sold it its brand name rights for hardware and ceased developing hardware (Weber 2017a). The firm also opened its messenger platform to outside developers by issuing an SDK (Weber 2017b), together marking nothing less than a full reversal of the former exclusivity-driven strategy. After the firm had failed with its two proprietary platforms *Blackberry OS* and *BB10* and the initially unsuccessful *Android* implementation, a small recovery appeared in 2017.

Google itself made several changes to the platform strategy by extending its cooperation with automotive manufacturers like *Volvo* for the even deeper integration of *Android* into cars (Wilkens 2017). Yet another foray into other industries came in the form of *Google*'s announcement of *Android Things* for smart home and *Internet of Things* devices with the aim of becoming the leading platform for hardware

[68] www.thedevelopersunion.org

control (Hanna 2017). Furthermore, major platform changes concerned the tackling of fragmentation. As outlined in the case study, fragmentation can occur for several reasons, but must be avoided to keep adaptation efforts low for developers and thus keep the platform attractive to them. In 2017, *Google* retired its API support for devices running *Android* versions older than API level 14 (Android 4.0.3) – a version that had introduced substantial feature changes (Wirtgen 2017a). In addition, the 2017 release of Android 8 carried a library of all *Android* devices in order to make it easier for developers and manufacturers to adapt their apps and other software and measure performance (Sokolov 2017). *Google* also introduced Treble – a new software layer project between *Android*'s kernel and the OEM adaptation, aiming at speeding up update processes that were often held up by manufacturer efforts (Wirtgen 2017b). With the Kotlin programming language, *Google* also accepted a new and easier way for developers to code *Android* apps in an effort to increase attractiveness and innovativeness of the platform (Schmid 2017).

Google still earned the largest revenue from its advertising in *Android* and browser search requests but was heavily challenged in this business when fined €2.4bn for an anti-competitive violation of the 'equal treatment' requirement by favouring proprietary services and products over competitors in the search result display (EC 2017a, EC 2017b). Notably, this fine did not yet include the €4.34bn penalty imposed on *Google* for requiring *Android* device manufacturers to pre-install certain *Google* apps such as the web browser *Chrome* or its *Google Maps* app. This fine was issued in July 2018 (Chee 2018; EC 2018). While the penalty itself was to be expected given that the official Statement of Objections had already been issued (EC 2016), the amount itself broke all previous records (EC 2018).

With ongoing patent litigation, *Google* invested further in protecting the platform against legal challenges. When former *Android* device pioneer *HTC* continued to struggle in 2017, *Google* purchased patents and approx. 2,000 staff from *HTC*'s developer base (Heise 2017). *Google* brought the patents acquired in this deal, those from Motorola's acquisition years earlier, and others into a newly devised patent pool called 'PAX: the Android Networked Cross-License Agreement' (Google 2017). The 18 industry partners within this pool agreed to royalty-free sharing of more than 230,000 patents and their application to qualify *Android* devices with the purpose of essentially halting patent litigation within *OHA*.[69] Notably absent from the sharing agreement was *OHA* member *Huawei* that had sued fellow *OHA* member *Samsung* for patent violation damages in 2016 (Holland 2016). *Google*'s *PAX* initiative can thus be considered a peacekeeping initiative within *OHA*.

For *Windows Phone*, 2017 marked the culmination of a long decline. *Microsoft* announced the end of its support for *Windows Phone 8.1* devices, rendering them vulnerable to security issues and thus unfit for use (Ranger 2017). Industry observers had long suspected that *Microsoft* would officially discontinue the entire *Windows Phone* system. Citing lack of app support, the firm shortly afterwards announced

69 www.paxlicense.org/

the end of phone developments and the *Lumia* brand while continuing security updates for *Windows 10*-capable devices (Bright 2017a). In an interview reviewing the development of *Microsoft* under his leadership, including *Windows Phone* and the acquisition of *Nokia*, former *Microsoft* CEO Steve Ballmer admitted "our formula was working! We were Software guys. So, for us, it was always like a religious transformation" (quoted in Hogenkamp 2017). Ballmer's statement reveals an insight into the issues with *Microsoft*'s handling of its phone business: The firm self-identified as a software provider rather than a hardware manufacturer and strategically oriented itself towards this 'winning formula' while neglecting the new, and immensely important, smartphone sector.

This signifies nothing less than a lock-in to a mental model of a software firm not being involved with hardware and explains the lacking integration and alignment of OS iterations with supporting hardware. It can be considered a severe strategic error that, after *Nokia* had switched to *Windows Phone*, their recent hardware would not be supported by the platform's next iteration – something which occurred twice. Both with the switch from *Windows Mobile 7* to *Windows Phone 8*, and again from version *8* to *8.1* (and later *10*), customers were unable to upgrade recently purchased devices, very unlike *Microsoft*'s desktop business, and very much unlike the two major competitors *iOS* and *Android*. Further, the self-perception as a software firm explains part of the culture clash experienced at *Nokia* when *Microsoft* manager Stephan Elop took on the post of *Nokia* CEO – traditionally self-identifying as a hardware manufacturer. The resulting misalignment of software and hardware and ineffective subsequent integration of *Nokia* into *Microsoft* after the 'burning platform' speech of Elop's tenure (Kiljander 2017) certainly contributed to the decline of both platform and brand. Beyond *Windows* for desktop, *Microsoft*'s mobile efforts now focused on providing apps for *iOS* and *Android* and device enhancements like the home screen launcher. Additionally, any future return to smartphone devices appears more difficult in the light of the increased support *Microsoft* is providing for the other platforms.

Two other platforms witnessed their official end in 2017: *Firefox OS* was discontinued, with even the support team laid off by *Mozilla*, thus rendering any future updates to the platform impossible (Bright 2017b). *Ubuntu Touch* was discontinued, similarly, on the grounds that it lacked app support by developers (Shuttleworth 2017), and a final community edition issued that enjoyed no great success despite receiving *Android* app support, albeit without *Google Play* access. While *Samsung* launched another phone running on *Tizen* OS (Samsung 2017), the company did not sell the device in many markets, and OS success remains limited, except on *Samsung*'s relatively high-selling smartwatches. *Jolla* attracted *Sony* as a hardware partner to port its *Sailfish OS 2.0* to *Sony*'s *Android* devices (Briegleb 2017). No device launched with native *Sailfish OS*, however, and despite attracting a new Chinese partner in the *Sailfish Alliance*, the few supported devices of alliance partners only marginally increased the market success of the system. Users can also purchase *Sailfish OS* licenses to run on *Sony Xperia X Android* phones for €50, but the added costs over *Sony*'s premium *Android* phone, the extra installation effort for users, limited hardware support, lack of featuring apps despite native *Android* app compatibility, and only 12 months of guaranteed software updates (Bergert 2017) all ensured that the *Sailfish OS* market share remains negligible and rather niche.

The overall important industry player Facebook reached 2bn active users in 2017 (Condon 2017), contributing much data traffic for smartphones to overtake PCs as the main internet access device for the time being (Krempl 2017). This trend was further stimulated by fees for international roaming being abolished in the European Union (Mansmann 2017), after many years of regulatory reductions of the same. While network operators berated the voiding of their income source, data usage and the necessary tariff subscriptions continued to increase.

The latest market figures initially indicate sales decline for 2017 (Briegleb 2018), signifying market saturation. Analysts *IDC* and *Gartner* saw market shares at approx. 85% for Android, and 14% for *iOS* with remaining platforms like *Windows Phone* at 0.1% levels accounting for the small residue (IDC 2017; Gartner 2018). *Jolla*'s *Sailfish OS*, despite Version 3 bringing improved *Android* app support even on feature phones, attracted only negligible sales (Spier 2018). Tizen, despite major industry support from *Samsung* and its smartwatch sales, remained a niche OS with little gain. Regarding device manufacturers, *Samsung* and *Apple* continue to vie for the top spot in sales, followed by *Huawei*, *Xiaomi* and *OPPO* that have continued their international expansion into markets outside China. For tablets, *Apple* remained the clear market leader (Becker 2017c) and the firm continues to outperform all rivals taken together with regard to revenue, attracting just over half of all smartphone sales turnover (Becker 2018). The app store situation is remarkably similar with the total number of apps and downloads much higher in *Google Play*, but higher revenues for *iOS* despite much lower download figures (Kraft 2017). Profitability thus remains the main challenge for the *Android* platform, while market share device sales and app downloads are clearly led by the *OHA* camp. Interestingly, however, the Chinese *Xiaomi* and *OPPO* are not members of *OHA* and still gained access to all *Google* services, like regular *OHA* members, at least for their Western market products, while operating proprietary app stores in China.

2011 – 2018: Summary

With their continuing yearly update cycles, the two main platforms *Android* and *iOS* took over the market and continued to dominate. *Microsoft*, despite all the efforts of integrating device manufacturer *Nokia*, failed with its platform and essentially left the market. OEMs *Samsung* and *Apple* sell the most devices, but with *Android*'s overall market share of approx. 85%, the smartphone industry entered a state similarly stable to the PC market, albeit with *Android* taking the place *Microsoft* holds on PCs. Other platforms like *webOS*, *Firefox OS*, *Ubuntu Touch*, *Symbian*, and *Blackberry* failed and were discontinued. *Blackberry*, *HP* and *Nokia* abandoned their former platforms. *Blackberry* and *HP* joined *Android*, *Nokia* went with *Microsoft*, which ultimately purchased it. *Microsoft*'s strategic errors and its own path dependence led it to abandon smartphone efforts and start producing apps for *iOS* and *Android*.

While many notable names have vanished over the course of the past decade, the *Nokia* brand has reappeared since former *Nokia* staff under new leadership purchased and resurrected it after yet another platform switch, this time to *Android*. In a testament to the superior management of *OHA, Google* and the attraction of a much larger developer base than any of the other platforms, *Google* succeeded in establishing a (virtual) monopoly (Auletta 2009: 208) which secures its mobile advertising revenues.

In contrast to the prediction of industry experts towards the end of systematic case data collection in 2010, all predictions erred in terms of players and number of players. *Palm*, *Microsoft*, and *Symbian* were seen as the main competitors (Pogue 2003: 1) when current market leader *Android* had just started being developed. None of the early three survived the market dynamics, however, and two new platforms now dominate almost the entire the market. Only two very niche platforms *Jolla* and *Tizen* remain, but without significant market share in mobile devices. *Windows Mobile* and other legacy devices remain a small installed user base, of course, but lack of new hardware sales will result in these existing user numbers declining sharply.

Given that *Apple* is an integrated device manufacturer and sells no *iOS* licenses to others, *Android* remains the only major <u>open</u> smartphone platform. The mobile OS market has thus become as divided as the PC market, where *Apple*'s *Mac OS X* and *Microsoft Windows* remain the main platforms (with Linux attracting market share, however, especially in the server market, and as a basis of Chrome OS devices). The significant technological difference in the smartphone market is that the mobile platform *Android* builds on the open-source Linux kernel, while the PC platform *Microsoft Windows* is proprietary and closed source. *Microsoft*, in contrast, is not the biggest player in mobile platforms, but rather has become a supplier of *Android* and *iOS* apps, an unexpected role for the PC OS champion. *Google*-steered *Android* has, arguably, become 'the Microsoft of mobile platforms' albeit with a vastly different, network-driven strategy, and, with even more extensive spread into other industries (automotive, hardware control, watches, etc.), is unlikely to disappear soon. Instead, it will be interesting to see how *Google* adapts a future strategy around *Android* and the emerging *Andromeda* and *Fuchsia* projects it is running alongside this, as potentially integrated successors for mobile's *Android* and PC's *Chrome OS*.

Appendix C: SimPioN software code

As implemented in NetLogo 6.0.4:

The SimPioN software code is available online under a Creative Commons CC-BY-4.0 license at: https://www.comses.net/codebases/1e8b7d0e-80de-4373-aa8f-d3c6a0336ead/releases/1.0.0/

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;SimPioN - Sept 2018

extensions [ nw ]

globals [ BOTH INDIVIDUAL-PREF NETWORK-PREF INC-NETWORK-PREF
OPTIMISING SATISFICING DESPAIRING
          YOUNG MEDIUM-AGE OLD-AGE SMALL-FIRM MEDIUM-FIRM LARGE-FIRM
MAX-RESOURCE MAX-SIZE MAX-SLOTS
          TWOYEARS

          alliance1 alliance2 alliance3 alliance4 alliance5 ; list of
the alliance members for each alliance
          alliance1Adds alliance2Adds alliance3Adds alliance4Adds al-
liance5Adds ; the number new of alliance members this time step
          resize         ; visualisation boolean
          numLargeFirms allianceCnt
          aware-nr       ; number of turtles a firm has on its mind /
is aware of when searching for new connections
          densityOverall allianceDensity numFirms deadFirms num-bro-
ken-links num-broken-links-accum maintain-cnt
          cnt-resource-small cnt-resource-medium cnt-resource-high
          lock-in time-to-lockIn stableCnt alliance-dec alliance-inc
alliance-exits alliance-entries new-links better-partner-count
          alliance-density1 alliance-density2 alliance-density3 alli-
ance-density4 alliance-density5
          allianceStability1 allianceStability2 allianceStability3 al-
lianceStability4 allianceStability5
          allianceNumMem1 allianceNumMem2 allianceNumMem3 allianceNum-
Mem4 allianceNumMem5
          stableCnt1 stableCnt2 stableCnt3 stableCnt4 stableCnt5

          allianceDominance1 allianceDominance2 allianceDominance3 al-
lianceDominance4 allianceDominance5
          timeOfCollapse ] ;defines globally available variables

turtles-own [
  firm-strategy            ; the behaviour selection process: optimis-
ing satisficing
  firm-preference          ; represents the way the agents values at-
tributes of other agents: fully_individual_orientated, network-pref,
inc-network-pref
  firm-age                 ; age of the firm (ticks)
  firm-size                ; abstract representation of a firms size
in staff/market power etc.
  firm-resource            ; abstract representation of a firm's re-
sources in finances, buildings etc.
  firm-reach               ; network path length visible to firm.
  firm-centrality          ; firm's betweenness centrality in its net-
work
  firm-slots               ; max. number of links a firm can have.
  firm-free-slots          ; number of connections a firm has availa-
ble to fill.
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  firm-new-connections     ; number of connections a firm made this
tick
  firm-numConnections      ; number of connections a firm has.
  max-new-connections      ; number of new connections a firm can make
  firm-alliance-membership ; List of alliances (0,1,2,3 or 4) that a
firm is member of
  max-alliances            ; maximum number of alliances a firm can be
member of
  lifetime-without-links   ; amount of ticks a firm can survive with-
out links to other firms

  firm-no-tie-history      ; number of ticks without ties.
  maintain-options         ; List of firms that have a link is under
consideration for the current tick
  connectionCandidates     ; (Short-)List of Firm IDs that this firm
would like to connect to
  ;response variables - lock-in on individual level
  notLooking               ; boolean indicating that this agent is not
looking or considering new connections
]

links-own [
  link-age                 ; age of the link (NaN: deleting a link is
resetting the age, even when reconnecting after years/ticks?)
  project-time             ; duration of the current project
  link-duration            ; calculated end-time (tick) for the pro-
ject to be over
  maintain                 ; boolean that indicates whether this link
should be maintained while being under reconsiderations
  allianceLNK1 allianceLNK2 allianceLNK3 allianceLNK4 allianceLNK5 ;
bool indicates whether this link connects members of particular alli-
ances
]

;;;;;;;;;;;;;;;;;;;;;;;;
;;; Setup Procedures ;;;
;;;;;;;;;;;;;;;;;;;;;;;;

;The overall function that sets the world into existence, creates ini-
tial settings for all variables.
to setup
  clear-all
  init-constants
  init-dyn-vars
  repeat numFirms [ make-firm ]               ; initial number of
nodes ;; first node, unattached
  set MAX-SLOTS max [ firm-slots ] of turtles
  init-alliances
  reset-ticks
  tick
end

;;;;;;;;;;;;;;;;;;;;;;;
;;; Main Procedures ;;;
;;;;;;;;;;;;;;;;;;;;;;;

;; Makes the simulation run, i.e. move through time, by asking the
firms to seek, consider and match with other firms; perform behaviour
that produces income (?)
;; to update all measurs and advances time (tick + 1).
to go
  if (newcomers? and (ticks > 0) and (ticks mod 4 = 0)) [    ;every
new month (exept for the first month)
     make-firm ]
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```
  ;reset-counters/vars
  set new-links 0
  set alliance-inc 0
  set alliance-dec 0
  set numFirms count turtles

  ask links [ set maintain false ]
  ifelse (numFirms > 0) [
    set aware-nr min(list awareness-range (numFirms - 1))
    firms-consider-and-search
    firms-match
    update ]
  [ if (timeOfCollapse < 0) [ set timeOfCollapse ticks ]]
  if (ticks > endSim) [ stop ]
  tick
end

;; Updates the population of firms in terms of dying and ageing and
makes sure the outcome vars are updated
;; Die: Firms that haven't gotten a network tie for lifetime-without-
links ticks OR have no resources anymore
;; Age: Firms that do not die increase the age of their firm and links
;; and generate a list of connections reconsidered to maintain (pro-
ject ends next tick) if the link-age > link-duration (= project dura-
tion)
to update
  set num-broken-links 0
  ask turtles [ set maintain-options [] ]
  ask links [
    ifelse (link-age > link-duration and maintain = false) [
      ask both-ends [
        set firm-numConnections firm-numConnections - 1
        set firm-free-slots firm-free-slots + 1 ]
      set num-broken-links num-broken-links + 1
      set num-broken-links-accum num-broken-links-accum + 1
      die ]
    [ set link-age link-age + 1
      if (link-age > link-duration) [
        ask both-ends [
          let otherID [ who ] of other-end
          ;show (word "otherID:" otherID)
          set maintain-options fput otherID maintain-options
        ]]]
  ]

  ask turtles [
    ifelse (firm-no-tie-history > lifetime-without-links) or (firm-re-
source < 1)
    [ if (not empty? firm-alliance-membership) [
        remove-alliance-membership who
        set alliance-exits alliance-exits + length(firm-alliance-mem-
bership)
        set alliance-dec alliance-dec + length(firm-alliance-member-
ship)
      ]
      set numFirms numFirms - 1
      set deadFirms deadFirms + 1
      die ]
    [ set firm-age firm-age + 1
      ifelse count my-links > 0
      [ set firm-no-tie-history 0
        set  firm-alliance-membership checkMembership who firm-alli-
ance-membership my-links ]
      [ set firm-no-tie-history (firm-no-tie-history + 1)
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        if not (empty? firm-alliance-membership)[  ;removes all the 
memberships that might exist
        remove-alliance-membership who
        set alliance-exits alliance-exits + length(firm-alliance-mem-
bership)
        set alliance-dec alliance-dec + length (firm-alliance-member-
ship)+ length(firm-alliance-membership)
        set firm-alliance-membership []
        ]
      ]]]

  update-outcome-vars
  ;show (word "alliance 1: " alliance1)
  ;show (word "alliance 2: " alliance2)
  ;show (word "alliance 3: " alliance3)
  ;show (word "alliance 4: " alliance4)
  ;show (word "alliance 5: " alliance5)
end

;;Each firm forms a list of options (if they have free slots or recon-
sider to maintain current connections) and calculates the attractive-
ness of each option.
;;Note! this is the unique perception of a firm of the other firms.
;;Depending on the firm-strategy the firm selects x (= number of free 
slots) connection options based on attraction
;;-- firmstrategy = optimising => selects x most attractive options 
(top 3)
;;-- firmstrategy = satisficing => selects x first options that meet 
the min-attraction level
;;-- firmstrategy = despairing => selections x first options (= firms 
with free slots)
to firms-consider-and-search
  ask turtles  [
    let options []
    set notLooking true
    set connectionCandidates []
    set firm-new-connections 0
    if (firm-free-slots > 0 OR maintain-options != [] ) [
      let myID who
      let on-my-mind maintain-options
      if (firm-free-slots > 0) [
        set on-my-mind (sentence maintain-options perceiveFirms myID) 
;merge maintain-options with other firms the agent can perceive
        set notLooking false
      ]
      set on-my-mind remove myID on-my-mind                    ;;
just to be sure you do not consider connecting to yourself...
      ;show (word "on my mind: " on-my-mind " to maintain" maintain-
options)
      ;show firm-free-slots

      let shortlist_length min(list (firm-free-slots + (length main-
tain-options)) (numFirms) (length on-my-mind))
      ;show (word "shortlist_length: " shortlist_length " firm-free-
slots: " firm-free-slots " #maintain-options: "  maintain-options " 
#on-my-mind: "(length on-my-mind))

      if (firm-strategy = DESPAIRING) [ ;; select X random candidates 
that are on my mind
        set on-my-mind shuffle on-my-mind
        set connectionCandidates sublist on-my-mind 0 shortlist_length
      ]
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      if (firm-strategy = OPTIMISING) [    ;; select the X most at-
tractive candidates (x is the number of free slots this agent has)
        foreach on-my-mind [ [?1] ->       ;produce options to con-
sider connecting to
          let attractiveness calc-attractiveness myID ?1
          set options lput (list ?1 attractiveness) options
        ]
        set options sort-by [ [?1 ?2] -> item 1 ?1 > item 1 ?2 ] op-
tions  ; sort list from high to low attractiveness
        ;ifelse ((firm-free-slots + length maintain-options) < 1  or
length options < 1) [   ; there are no available options to (re-)con-
nect to
        ;  set connectionCandidates []]
        set connectionCandidates sublist options 0  shortlist_length ;
connectionsCandidates are a shortlist of all the possible options
(equals the number of connections a firm may have)
      ]

      if (firm-strategy = SATISFICING) [
        let index 0
        while [ length connectionCandidates < shortlist_length AND in-
dex < shortlist_length ] [
          let otherID item index on-my-mind
          let attractiveness calc-attractiveness myID otherID
          let option (list otherID attractiveness)
          if firm-strategy = SATISFICING [     ;; select the X first
attractive candidates (x is the number of free slots this agent has)
            if attractiveness > MIN-ATTRACTION [ set connectionCandi-
dates lput option connectionCandidates ]]
          set index index + 1 ]
      ]
      ;show (word "myShortList: "connectionCandidates)
    ]
  ]
end

;; Perceive firm generates a list of firm IDs that an agent will con-
sider to connect to
;; It is restricted by aware-nr (aware-range in the interface) - this
allows us to very the assumption of knowledge/all-seeingness of an
agent (all or bounded in different degrees)
;; If the firm has connection, it will use those first. The reach
(1,2, or 3) of an agent plays a role here:
;;;; reach 0: agent only has random others it meets (regardless of its
social network)
;;;; reach 1: agents only sees its connections
;;;; reach 2: agents can access/meet the connections of its connec-
tions
;;;; reach 3: agents can access/meet the connections of its connec-
tions-connections
;; any possible option left is filled with random agents that the firm
'happened' to meet
to-report perceiveFirms [ myID ]

  let my-network []
  let on-my-mind []

  ifelse (firm-reach > 1) [
    set my-network [[ who ] of link-neighbors] of turtle myID ; my
connections
    ifelse (not empty? my-network) [
      let via []
      let via-via []
      foreach my-network [ [?1] ->               ;get connections of
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my connections
        let via-connections [[ who ] of link-neighbors ] of turtle ?1
        set via (sentence via via-connections)
        if (firm-reach > 2) [ ; ==3      ;get connections of my con-
nections connections
          foreach via-connections [ [??1] ->
            let via-via-connections [[ who ] of link-neighbors] of
turtle ??1
            set via-via (sentence via-via via-via-connections) ]
        ]
      ]
      ;show (word "my network: " my-network)
      ;show (word "via via: " via " via-via: " via-via)
      set on-my-mind (sentence via  via-via)
      set on-my-mind remove-duplicates on-my-mind
      set on-my-mind remove myID on-my-mind
      ; whats the point of this function?? foreach (sentence my-net-
work myID) [ set on-my-mind remove ? on-my-mind ]
      ;show (word "on-my-mind before random adds: " on-my-mind)
      let lengthList length(on-my-mind)
      if (lengthList < aware-nr) [  ;too little firms  - add randomly
        let emptySpots (aware-nr - lengthList)
        ;show (word "emptySpots (aware-nr - lengthList): " emptySpots
"("aware-nr "-" lengthList") , # turtles: "  count turtles)
        let randomFirms [ who ] of n-of emptySpots turtles with [ who
!= myID]
        foreach (sentence my-network on-my-mind) [ [?1] -> set random-
Firms remove ?1 randomFirms ] ; remove the firms that are already in
my network
        set on-my-mind (sentence on-my-mind randomFirms)  ;add the
random firms (non-connections)
      ]
      if (lengthList > aware-nr) [  ;too many firms  - remove
        set on-my-mind sublist on-my-mind 0 (aware-nr - 1) ]]
    [ set on-my-mind [ who ] of n-of aware-nr turtles with [ who !=
myID ]]
  ] [ set on-my-mind [ who ] of n-of aware-nr turtles with [ who !=
myID ]]

  ;show (word "on-my-mind: " on-my-mind)
  report on-my-mind
end

;; The function calculates the attractiveness [0,1] of a firm (B) from
the perception of firm (A)
;; Attractiveness of  a company is based on the firm's (A) own at-
tributus (mySize,myPreference, myAllianceMembership) in combination
with
;; the attributes of the other firm (B) (age, size, resource, connec-
tions, centrality, allianceMembership)
;; myPreference {INDIVIDUAL-PREF|NETWORK-PREF|INC-NETWORK-PREF} de-
fines which of the attributes are of interest play a role the attrac-
tion function,i.e. sets the weights.
;;   INDIVIDUAL-PREF -> focus on individual attributes = age, size,
resource, slots, reach
;;   NETWORK-PREF    -> focus on network attributes = numConnections,
centrality,allianceMembership, link-age
;;   INC-NETWORK-PREF -> shift in focus from individual (ticks < 50)
to network preference, sets the weight that is given to each attribute
;; Attribute contribution to total attractiveness:
;;   firm-age: the older the more attractive
;;   firm-resource: the more resource a company has the better
;;   firm-size:  depends my own size how attractive the other firm is:
;;     small firms find large firms very attractive (+++), medium
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firms attractive (++) and other small firms minimally attractive (+)
;;     medium firms find Large firms very attractive (+++), medium and
small firms minimally attractive (+) = 0.2
;;     large firms find all sizes attractive (+++)
;;   firm-centrality: betweenness centrality
;;   firm-allianceMembership: if we are part of the same alliance in-
creases attractiveness
;; attactiveness = SUM(attributes*preferenceWeights)
to-report calc-attractiveness [ myID otherID ]
  let CI 0
  let CN 0
  let myPreference [ firm-preference ] of turtle myID
  let myAge [ firm-age ] of turtle myID
  let numFactors 0
  ;show (word "myPreference: " myPreference)
  if (myPreference = INDIVIDUAL-PREF) [
    set CI 1
    set numFactors 3 ]
  if (myPreference = NETWORK-PREF) [
    set CN 1
    set numFactors 4 ]
  if (myPreference = INC-NETWORK-PREF) [
    set numFactors 7
    ifelse ticks < 50
    [ set CI 0.8
      set CN 0.2 ]
    [ ifelse ticks < 100
      [ set CI 0.5
        set CN 0.5 ]
      [ set CI 0.2
        set CN 0.8 ]]]
  if (myPreference = BOTH) [
    set CI 1
    set CN 1
    set numFactors 7 ]

  ;;;;;;individual attribute attractions : age, resource, size
  let age-attraction ([ firm-age ] of turtle otherID) / ticks
  let resource-attraction (1 / MAX-RESOURCE) * ([ firm-resource ] of
turtle otherID) ; linear function: the more resource a company has the
better
  let mySize [ firm-size ] of turtle myID
  let otherSize [ firm-size ] of turtle otherID
  ;show (word "mySize (ID): " mysize " (" myID "), otherSize (ID) "
otherSize " (" otherID ")")
  let size-attraction 0.2 ; minimal attraction to other firms that are
the same size or smaller than me)
  ifelse (mySize >= MEDIUM-FIRM) [  ;for a large firm (=bigger than
medium) all other firm sizes are attractive
    set size-attraction 1 ]
  [ if otherSize > mySize [
    set size-attraction size-attraction + min (list (0.8 * otherSize /
LARGE-FIRM) 1) ]]

  ;;; individual-network attribute attraction: familiarity
  let familiarity-attraction 0
  if (link-neighbor? turtle otherID) [ set familiarity-attraction ([
link-age ] of link-with turtle otherID) / myAge ]

  ;;;;;network attribute attractions : connection centrality  alliance
  ;show (word "numConnections (ID): " [ firm-numConnections ] of tur-
tle otherID " (" otherID ")")
  let numConnOther [ firm-numConnections ] of turtle otherID
  let connection-attraction numConnOther / MAX-SLOTS
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  let centrality-attraction [ nw:betweenness-centrality ] of turtle
otherID

  ;show (word "allianceMembership (ID): " [ firm-alliance-membership ]
of turtle myID " (" myID ")")
  ;show (word "allianceMembership (ID): " [ firm-alliance-membership ]
of turtle otherID " (" otherID ")")
  let myAllianceMembership [ firm-alliance-membership ] of turtle myID
  let otherAllianceMembership [ firm-alliance-membership ] of turtle
otherID
  let alliance-attraction 0
  foreach myAllianceMembership [ [?1] ->

    if  member? ?1 otherAllianceMembership [
      set alliance-attraction 1
    ]
  ]
  ;show (word "individual-based attraction: " age-attraction "(age) +
" resource-attraction "(resource) + " size-attraction "(size) = "
(age-attraction + resource-attraction + size-attraction))
  ;show (word "network-based attraction: " connection-attraction
"(connections) + " alliance-attraction "(alliance) + " centrality-at-
traction "(centrality) = " (connection-attraction + alliance-attrac-
tion + centrality-attraction))
  let attraction ((age-attraction * CI) + (resource-attraction * CI) +
(size-attraction * CI) + (connection-attraction * CN) + (alliance-at-
traction * CN) + (centrality-attraction * CN) + (familiarity-attrac-
tion * CN)) / numFactors  ;make attraction a value between 0,1 (6 is
the max attraction of each attribute)
  report attraction
end

;Function mimics a matching process in which each has the opportunity
to firm ask one other firm to connect (the first on its connection-
wishlist it is not connected with)
;Firm will only approach a particular other firm IF it itself has
free-slots AND IF the other firm has space for new connections (free
slots and max-connections made this tick)
;The acceptance of the request is based on the the other firm's strat-
egy:
; = despairing => YES (will always connect when asked)
; = satisficing => connects when attraction is > MIN-ATTRACTION  (i.e.
all members of connectionCandidates)
; = optimising => only if member of connectionCandidates (less likely
to connect) OR the attractiveness is higher than the current connec-
tions it has
;Overall, all firms have an opportunity to ask, and they can be asked
during a tick, i.e. MAX-NEW-CONNECTIONS connections can be gained per
tick
to firms-match
  ;show ("firms-match")
  ask turtles [
    ;show (word "my free-slots: " firm-free-slots " and wishList: "
connectionCandidates)
    let myID who
    if ((firm-free-slots > 0) and (not empty? connectionCandidates)) [
;can I connect? and is there someone I would like to connect to?
      let otherID first connectionCandidates
      if (is-list? otherID) [ set otherID first first connectionCandi-
dates ]
      let hasSpace space-for-connections otherID
      let conWishOther [ connectionCandidates ] of turtle otherID
      let wannaConnect false
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      let f-stratOther [ firm-strategy ] of turtle otherID
      ;show (word "my firm Wishlist: " map first connectionCandidates
" other firm's wishlist: " map first conWishOther)
      ;show (word "I (" firm-free-slots") asked otherID (" [ firm-
free-slots ] of turtle otherID ") to connect.")

      ifelse ( hasSpace ) [                     ; If other firm has
free slot it always considers the request directly
        ifelse (f-stratOther = DESPAIRING)
        [ set wannaConnect true
          ;show (word "asking firm: " otherID " who is desperate so
yes we will connect")
           ]
        [ ifelse (member? myID map first conWishOther)  ;on the con-
nection-wish-list of the other firm? both satisficing & optimising
will connect
          [ set wannaConnect true
            ;show (word "asking firm: " otherID " and I am also on its
wishlist - yay! - we will connect")
          ]
          [ if (f-stratOther = SATISFICING) [     ;if not on the wish-
list, calculate attraction
              let myAttractionToOther calc-attractiveness otherID
myID ; the other firm is evaluating my attractiveness
              if (myAttractionToOther > MIN-ATTRACTION)
              [ set wannaConnect true
                ;show (word "asking firm: " otherID ", I am not on its
wishlist but I am attractive enough (other is a satisficer)- we will
connect")
              ]]
            if (f-stratOther = OPTIMISING) and (more-attractive
otherID myID > -1) [ ;; FUTURE consideration. also check the wishlist?
              set wannaConnect true
              ;show (word "asking firm: " otherID ", I am not on its
wishlist,  but more attractive than its connections (other is a maxi-
miser)- we will connect")
        ]]]
        if wannaConnect [ connect-firms myID otherID ]
      ]
      [ ;; other has no freeslots, but the maximiser would always re-
consider its current connections
        ifelse (f-stratOther = OPTIMISING)[
          set notLooking false
          let switch more-attractive otherID myID
          if ( switch > -1 ) [
            switch-connection otherID myID switch
          ]]
        [ ;show (word "asking firm: " otherID ", he is not interested
- he has no space for me :(")
        ]
      ]
   ]]
end

;Report whether agent1 wants to connect with agent2 by evaluating
;the attraction of agent 2 in comparison to the connections agent 1
has.
;Report -1:  If agent2 is not better than any of the connections
;Report turtleID of agent that is going to be replaced with agent2
to-report more-attractive [ agent1 agent2 ]
  let attraction_agent2 calc-attractiveness agent1 agent2
  let lowestAttraction attraction_agent2
  let replaceMe -1
  ask turtle agent1 [
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    foreach [who] of link-neighbors [ [?1] ->
      let attraction calc-attractiveness agent1 ?1
      if lowestAttraction > attraction [
        set lowestAttraction attraction
        set replaceMe ?1
  ] ]]
  report replaceMe
end

;Reports whether a firm has space for new connections
;i.e., it has free slots and hasn't made MAX-NEW-CONNECTIONS during
this tick
to-report space-for-connections [ firmID ]
  let free-slots [ firm-free-slots ] of turtle firmID
  let maxConnection [ max-new-connections ] of turtle firmID
  let nr-new-connections [ firm-new-connections ] of turtle firmID
  ;show ("space-for-connections" )
  ifelse (free-slots > 0) and (nr-new-connections < maxConnection)
    [ report true ]
    [ report false ]
end

; connects or maintains two firms by creating or maintaining a
tie/link and updating the corresponding variables (e.g. num-free-
slots, numConnections, new-links)
; if one connects to a member of an alliance, one also becomes a mem-
ber of an alliance (if one can connect to an alliance)
to connect-firms [ myID otherID ]
  ;show( "in connect firms")
  let allies false
  let allianceMembershipOther [firm-alliance-membership] of turtle
otherID
  let myAllianceMembership [firm-alliance-membership] of turtle myID
  let overlapMembership []

  ask turtle myID [
    ifelse ( link-neighbor? turtle otherID)
    [ ask link myID otherID [
        set maintain true
        set maintain-cnt maintain-cnt + 1
          set project-time getProjectDuration
          set link-duration link-age + project-time ]
    ]
    [ create-link-with turtle otherID
      [ set link-age 0
        set project-time getProjectDuration
        set link-duration link-age + project-time
        set maintain false ]
      set new-links new-links + 1
      set firm-numConnections firm-numConnections + 1
      set firm-free-slots firm-free-slots - 1
      set firm-new-connections firm-new-connections + 1
      set overlapMembership intersection firm-alliance-membership al-
lianceMembershipOther

      set allies not empty? overlapMembership
      ;let memWish not empty? myAllianceWish
      if (not allies and random 10 < 2) [  ;no overlapping membership
- take up one of the memberships
        if (space-for-alliance-membership myID and not empty? alli-
anceMembershipOther) [ ;I have space for new alliances and the other
has alliances they are connected to
          let new-alliance one-of allianceMembershipOther
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          set firm-alliance-membership lput new-alliance firm-alli-
ance-membership
          ;show (sentence "added a new alliance " new-alliance " to
memberhships" firm-alliance-membership)
          set overlapMembership lput new-alliance overlapMembership
          add-to-alliance myID new-alliance
          check-alliance-numbers myID new-alliance
          set allies true
        ]]
      ask turtle otherID [
        set firm-numConnections firm-numConnections + 1
        set firm-free-slots firm-free-slots - 1
        set firm-new-connections firm-new-connections + 1
        ;let memWish not empty? otherAllianceWish
        if (not allies and random 10 < 2) [  ;no overlapping member-
ship - take up one of the memberships
          if (space-for-alliance-membership otherID and not empty? my-
AllianceMembership) [ ;space for new alliances and the other has alli-
ances they are connected to
            let new-alliance one-of myAllianceMembership
            set firm-alliance-membership lput new-alliance firm-alli-
ance-membership
            ;show (sentence "added a new alliance " new-alliance " to
memberhships" firm-alliance-membership)
            set overlapMembership lput new-alliance overlapMembership
            add-to-alliance otherID new-alliance
            check-alliance-numbers otherID new-alliance ]]]

        ;;add memberships to the link properties
        ask link myID otherID [
          set allianceLNK1 false
          set allianceLNK2 false
          set allianceLNK3 false
          set allianceLNK4 false
          set allianceLNK5 false

          foreach overlapMembership [ [?1] -> ;#what about the alli-
ance entry count?
            if (?1 = 1) [ set allianceLNK1 true ]
            if (?1 = 2) [ set allianceLNK2 true ]
            if (?1 = 3) [ set allianceLNK3 true ]
            if (?1 = 4) [ set allianceLNK4 true ]
            if (?1 = 5) [ set allianceLNK5 true ]
          ]
        ]
    ]
    set connectionCandidates remove otherID connectionCandidates ; re-
move the partnerfirm from the partners-firm list
    ask turtle otherID [
      set connectionCandidates remove myID connectionCandidates ; re-
move the firm the partners-firm list
    ]]

   remove-duplicates-in-alliances
end

; Switch connections by ending the engagement with one firm and con-
nect with the other
to switch-connection [ myID otherID replaceID ]
  let connection 0
  ask link myID replaceID [
      ask both-ends [
        set firm-numConnections firm-numConnections - 1
        set firm-free-slots firm-free-slots + 1
```

```
        let idOther [ who ] of other-end
        set maintain-options remove idOther maintain-options
      ]
      set num-broken-links num-broken-links + 1
      die
    ]
  ;set maintain-options remove replaceID maintain-options
  connect-firms myID otherID
end

; reportr whetehr there is still space to become an alliance memeber
to-report space-for-alliance-membership [ f-id ]
 let maxNr [ max-alliances ] of turtle f-id
 let len length [ firm-alliance-membership ] of turtle f-id
 report len < maxNr
end

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;; INITIALISATION FUNCTIONS ;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

;setup initialisations
to init-constants
  set TWOYEARS 104 ; tick ~ week
  set INDIVIDUAL-PREF "fully_individual_orientated"
  set NETWORK-PREF "network-pref"
  set INC-NETWORK-PREF "inc-network-pref"
  set OPTIMISING "maximise"
  set SATISFICING "satisficing"
  set DESPAIRING "desparing"
  set BOTH "both"

  set YOUNG 52         ; 1 year (max value of a young firm)
  set MEDIUM-AGE 156   ; 3 years (max value of a medium aged firm)
  set OLD-AGE 364      ; 7 years (max value for initialisation of old
firms)

  set SMALL-FIRM  333  ; max value of a small firm in terms of size
and resource
  set MEDIUM-FIRM 666  ; max value of a medium firm in terms of size
and resource
  set LARGE-FIRM 999   ; max value of a large firm in terms of size
and resource

  set MAX-SIZE 1000
  set MAX-RESOURCE 1000
  set MAX-SLOTS 10

  set resize false
  set-default-shape turtles "circle"   ;makes the firms round shapes.

end

to init-dyn-vars
  set alliance1 []
  set alliance2 []
  set alliance3 []
  set alliance4 []
  set alliance5 []

  set allianceStability1 0
  set allianceStability2 0
  set allianceStability3 0
  set allianceStability4 0
```

```
  set allianceStability5 0

  set alliance-density1 0
  set alliance-density2 0
  set alliance-density3 0
  set alliance-density4 0
  set alliance-density5 0

  set allianceDominance1 0
  set allianceDominance2 0
  set allianceDominance3 0
  set allianceDominance4 0
  set allianceDominance5 0

  set timeOfCollapse -1
  set numFirms init-num-firms
  set numLargeFirms 0;

  set aware-nr min(list awareness-range (numFirms - 1))

  ;response variables
  set cnt-resource-small 0
  set cnt-resource-medium 0
  set cnt-resource-high 0
  set deadFirms 0
  set num-broken-links 0
  set maintain-cnt 0
  set lock-in false
  set time-to-lockIn 0
  set stableCnt 0
  set alliance-dec 0
  set alliance-inc 0
  set allianceCnt 0
  set alliance-entries 0
  set alliance-exits 0
end

; used for creating and intialising a new firm (network node)
to make-firm
  crt 1 [
    set color red
   ;setxy random-xcor random-ycor
    set notLooking true
    set maintain-options []

    ;; Initialise the individual constants: firm-reach, firm-no-tie-
history, max-new-connections-per-tick
    set firm-no-tie-history 0
    if (firm-reach-distribution = "none")  [ set firm-reach 0 ]
    if (firm-reach-distribution = "all_2")  [ set firm-reach 2 ]
    if (firm-reach-distribution = "all_3")  [ set firm-reach 3 ]

    ;; Initialise firm-age
    if  (firm-age-distribution = "all_new") [ set firm-age 1 ]
    if  (firm-age-distribution = "all_young") [ set firm-age (random
YOUNG) + 1]                          ; uniform random value [1,52] -
0-1 year
    if  (firm-age-distribution = "all_medium") [ set firm-age (random
MEDIUM-AGE - YOUNG) + 1 + YOUNG]    ; uniform random value [52,156] -
1-3 years
    if  (firm-age-distribution = "all_old") [ set firm-age (random
OLD-AGE - MEDIUM-AGE) + 1 + MEDIUM-AGE]; uniform random value
[157,364] - 3-7 years
```

```
    if  (firm-age-distribution = "fully_random") [ set firm-age (ran-
dom 1000) + 1 ]
    if  (firm-age-distribution = "normal_distribution") [ set firm-age
(random-normal MEDIUM-AGE YOUNG) ]

     ;; Initialise firm-size
    if  (firm-size-distribution = "all_small") [ set firm-size (random
SMALL-FIRM) + 1 ]             ; uniform random value [1,333]
    if  (firm-size-distribution = "all_medium")[ set firm-size (random
SMALL-FIRM) + 1 + SMALL-FIRM]  ; uniform random value [334,666]
    if  (firm-size-distribution = "all_large") [ set firm-size (random
SMALL-FIRM) + 1 + MEDIUM-FIRM] ; uniform random value [667,999]
    if  (firm-size-distribution = "fully_random") [ set firm-size
(random 1000) + 1 ]
    if  (firm-size-distribution = "normal_distribution") [ set firm-
size (random-normal MEDIUM-FIRM (0.5 * SMALL-FIRM)) ]
    if (firm-size >= MEDIUM-FIRM) [
      set numLargeFirms numLargeFirms + 1 ]

    ;; Initialise firm-resource
    if  (firm-resource-distribution = "all_low")    [ set firm-re-
source (random SMALL-FIRM) + 1 ]   ; uniform random value [1,333]
    if  (firm-resource-distribution = "all_medium") [ set firm-re-
source (random SMALL-FIRM) + 1 + SMALL-FIRM]  ; uniform random value
[334,666]
    if  (firm-resource-distribution = "all_high")   [ set firm-re-
source (random SMALL-FIRM) + 1 + MEDIUM-FIRM] ; uniform random value
[667,999]
    if (firm-resource-distribution = "fully_random") [ set firm-re-
source (random 1000) + 1 ]
    if  (firm-resource-distribution = "normal_distribution") [ set
firm-resource (random-normal MEDIUM-FIRM (0.5 * SMALL-FIRM)) ]

;    ;; Initialise firm-slots
    set firm-slots ceiling (firm-size * 0.1)
    set firm-free-slots firm-slots
    set firm-numConnections 0

    ;;init maximum new connections MAX-NEW-CONNECTIONS-PER-TICK
    set max-new-connections ceiling(firm-size * 0.01)
    if max-new-connections > 5 [ set max-new-connections 5 ]

    ;; Initialise firm-benefits-preference
    if firm-benefits-preference = "fully_network_orientated"      [
set firm-preference NETWORK-PREF ]
    if firm-benefits-preference = "fully_individual_orientated"   [
set firm-preference INDIVIDUAL-PREF ]
    if firm-benefits-preference = "increasingly_network_oriented" [
set firm-preference INC-NETWORK-PREF ]
    if firm-benefits-preference = "both"                          [
set firm-preference BOTH ]    ;; both network and individual are im-
portant
    if firm-benefits-preference = "fully_random_orientated"       [
      let rnd random 4
      if rnd = 0  [ set firm-preference NETWORK-PREF ]
      if rnd = 1  [ set firm-preference INDIVIDUAL-PREF ]
      if rnd = 2  [ set firm-preference INC-NETWORK-PREF ]
      if rnd = 3  [ set firm-preference BOTH ]
    ]

    ;; Initialise firm-strategy
    if (firm-strategy-distribution = "maximise") [ set firm-strategy
OPTIMISING ]
    if (firm-strategy-distribution = "satisfice") [ set firm-strategy
```

```
SATISFICING ]
    if (firm-strategy-distribution = "desperate") [ set firm-strategy
DESPAIRING ]
    if (firm-strategy-distribution = "random" ) [
      let rnd random 3
      ifelse (rnd = 0)
      [ set firm-strategy OPTIMISING ]
      [ ifelse (rnd = 1)
        [ set firm-strategy SATISFICING ]
        [ set firm-strategy DESPAIRING ]]]

    if max-alliance-membership = "1" [ set max-alliances 1 ]
    if max-alliance-membership = "2" [ set max-alliances 2 ]
    if max-alliance-membership = "3" [ set max-alliances 3 ]
    if max-alliance-membership = "4" [ set max-alliances 4 ]
    if max-alliance-membership = "5" [ set max-alliances 5 ]
    if max-alliance-membership = "random1-5" [ set max-alliances (ran-
dom 5) + 1 ]
    if max-alliance-membership = "big5-med2-small1" [
      ifelse firm-size > LARGE-FIRM [
        set max-alliances 5 ]
      [ ifelse firm-size < SMALL-FIRM [
        set max-alliances 1 ]
      [ set max-alliances 2 ]]]  ;medium firms

     ; initialise time the firm can exist without links
     ifelse (linkless-lifetime = "5") [
       set lifetime-without-links 5 ]
     [ ifelse (linkless-lifetime = "normalDistr(104,52)") [
       set lifetime-without-links max(list 0 round(random-normal 104
26)) ]
     [ ifelse (linkless-lifetime = "uniformDistr(26-156)") [
       set lifetime-without-links getRnd 26 156 ]
     [ print "linkless-lifetime has the wrong format!" ]]]

    ;; Initialise variables that are derived from others
    set firm-alliance-membership []
    set connectionCandidates []
  ]
end

;initalises the alliances based on the interface settings
;none = each alliances is initialised with 1 member - members are the
biggest firms
;oneAlliance = 1 alliance with 20 random members, the rest of the al-
liances are intialised as in none
;twoAlliancesEqual and Unequal = two alliances with either (10 - 10)
or (15-5) random members, the rest is initialised as in none
to init-alliances
  ifelse (init-network-scenarios = "none")
  [ init-minimal-alliance-membership ]
  [ ifelse (init-network-scenarios = "oneAlliance")
    [ init-alliance-and-members 1 num-init-allianceMembers
      set allianceCnt allianceCnt + 1
      init-minimal-alliance-membership ]
    [ ifelse (init-network-scenarios = "twoAlliancesEqual")
      [ let nr round (num-init-allianceMembers * 0.5)
        init-alliance-and-members 1 nr
        init-alliance-and-members 2 nr ]
      [ if (init-network-scenarios = "twoAlliancesUnequal") [
        let nr round (num-init-allianceMembers * 0.75)
        init-alliance-and-members 1 nr
        init-alliance-and-members 2 (num-init-allianceMembers - nr) ]]
      set allianceCnt allianceCnt + 2
```

```
      init-minimal-alliance-membership ]]
end

;; Creates an alliance with random nrMembers of members that each have
one connection random in the alliance1
to init-alliance-and-members [ allianceNr nrMembers ]
  let allianceMembers n-of nrMembers turtles
  ;show  [who] of allianceMembers
  if (count allianceMembers > 1) [
    ask allianceMembers [
      let me who
      set firm-alliance-membership lput allianceNr firm-alliance-mem-
bership
      add-to-alliance who allianceNr
      let newConnection one-of allianceMembers with [ who != me]
      ;show (sentence "newConnnection" newConnection " alliancemem-
bers: " [who] of allianceMembers)
      create-link-with newConnection
    ]]
end

;; Initialises the alliance membership in the simulation
;; Most firms have no membership, only X biggest firms are initialised
with a membership, representing the starting points of the memberships
to init-minimal-alliance-membership
  let biggestFirms max-n-of max-avail-alliances (turtles with [ firm-
alliance-membership = []]) [ firm-size ] ; get the X biggest firms
  ask biggestFirms [
    if (allianceCnt < max-avail-alliances) [
      set allianceCnt allianceCnt + 1
      ;show (word "I am going to initiate alliance nr: " allianceCnt)
      set firm-alliance-membership lput allianceCnt firm-alliance-mem-
bership
      add-to-alliance who allianceCnt
  ]]
end

to add-to-alliance [ id f-alliance ]
  set alliance-entries alliance-entries + 1
  set alliance-inc alliance-inc + 1

  ifelse (f-alliance = 1) [
    set alliance1 lput id alliance1
    set allianceNumMem1 length alliance1 ]
;    show (word "turtle " id " added to alliance 1")]
      [ ifelse (f-alliance = 2) [
          set alliance2 lput id alliance2
          set allianceNumMem2 length alliance2]
         ; show (word "turtle " id " added to alliance 2") ]
          [ ifelse (f-alliance = 3) [
              set alliance3 lput id alliance3
              set allianceNumMem3 length alliance3 ]
;             show (word "turtle " id " added to alliance 3")]
              [ ifelse (f-alliance = 4) [
                  set alliance4 lput id alliance4
                  set allianceNumMem4 length alliance4 ]
 ;                show (word "turtle " id " added to alliance 4")]
                  [ ifelse (f-alliance = 5) [
                      set alliance5 lput id alliance5
                      set allianceNumMem5 length alliance5]
;                        show (word "turtle " id " added to alliance
5")]
          [ show (word "Syst.err: add-to-alliance is not possible " f-
alliance " is not one of the 1-5 alliances on can be member of")
```

```
          ]]]]]

end

to remove-alliance-membership [ id ]
  set alliance1 remove id alliance1
  set alliance2 remove id alliance2
  set alliance3 remove id alliance3
  set alliance4 remove id alliance4
  set alliance5 remove id alliance5
end

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;; Outcome variables for logging ;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

;; updates the variables representing the patterns of interest for
this study
;; Lock-in: Alliance stability on system level (little-no change in 2
years)
to update-outcome-vars
;; alliances
  calcAllianceStability
  calcAllianceDensities    ;this order is important, used the updates
settings used in calcAllianceStability
  calcAllianceDominance

  ifelse (alliance-entries > 5 AND alliance-inc < 5 AND alliance-dec <
5)
  [ set stableCnt stableCnt + 1 ]
  [ set stableCnt 0 ]

  if (not lock-in and stableCnt > TWOYEARS)[
    set lock-in true
    set time-to-lockIn ticks - TWOYEARS
  ]
end

;Calculates whether the alliance is stable, i.e. didn't change it num-
ber of members for STABLE_ALLIANCE ticks
;if the membership of the alliance didn't change the counter goes up
to calcAllianceStability
  let membersLastTick allianceNumMem1
  set allianceNumMem1 length alliance1
  ;let membershipDiff1 allianceNumMem1 - membersLastTick
  ifelse (allianceNumMem1 = membersLastTick)
  [ set stableCnt1 stableCnt1 + 1 ]
  [ set stableCnt1 0 ]
  set allianceStability1 (stableCnt1 > STABLE_ALLIANCE)

  set membersLastTick allianceNumMem2
  set allianceNumMem2 length alliance2
 ;let membershipDiff2 allianceNumMem2 - membersLastTick
  ifelse (allianceNumMem2 = membersLastTick)
  [ set stableCnt2 stableCnt2 + 1 ]
  [ set stableCnt2 0 ]
  set allianceStability2 (stableCnt2 > STABLE_ALLIANCE)

  set membersLastTick allianceNumMem3
  set allianceNumMem3 length alliance3
  ;let membershipDiff3 allianceNumMem3 - membersLastTick
  ifelse (allianceNumMem3 = membersLastTick)
  [ set stableCnt3 stableCnt3 + 1 ]
  [ set stableCnt3 0 ]
```

```
  set allianceStability3 (stableCnt3 > STABLE_ALLIANCE)

  set membersLastTick allianceNumMem4
  set allianceNumMem4 length alliance4
  ;let membershipDiff4 allianceNumMem4 - membersLastTick
  ifelse (allianceNumMem4 = membersLastTick)
  [ set stableCnt4 stableCnt4 + 1 ]
  [ set stableCnt4 0 ]
  set allianceStability4 (stableCnt4 > STABLE_ALLIANCE)

  set membersLastTick allianceNumMem5
  set allianceNumMem5 length alliance5
  ;let membershipDiff5 allianceNumMem5 - membersLastTick
  ifelse (allianceNumMem5 = membersLastTick)
  [ set stableCnt5 stableCnt5 + 1 ]
  [ set stableCnt5 0 ]
  set allianceStability5 (stableCnt5 > STABLE_ALLIANCE)
end

;Calculates the density of each alliance
; number of connections that exist within an alliance / max possible
connections in an alliance
to calcAllianceDensities
  ifelse(allianceNumMem1 > 0) [
    let linksAlliance1 links with [ allianceLNK1 = true ]
    let numConn count linksAlliance1
    set alliance-density1 calcAllianceDensity numConn allianceNumMem1
  ] [ set alliance-density1 0 ]

  ifelse(allianceNumMem2 > 0) [
    let linksAlliance2 links with [ allianceLNK2 = true ]
    let numConn count linksAlliance2
    set alliance-density2 calcAllianceDensity numConn allianceNumMem2
  ] [ set alliance-density2 0 ]

  ifelse(allianceNumMem3 > 0) [
    let linksAlliance3 links with [ allianceLNK3 = true ]
    let numConn count linksAlliance3
    set alliance-density3 calcAllianceDensity numConn allianceNumMem3
  ] [ set alliance-density3 0 ]

  ifelse(allianceNumMem4 > 0) [
    let linksAlliance4 links with [ allianceLNK4 = true ]
    let numConn count linksAlliance4
    set alliance-density4 calcAllianceDensity numConn allianceNumMem4
  ] [ set alliance-density4 0 ]

  ifelse(allianceNumMem5 > 0) [
    let linksAlliance5 links with [ allianceLNK5 = true ]
    let numConn count linksAlliance5
    set alliance-density5 calcAllianceDensity numConn allianceNumMem5
  ] [ set alliance-density5 0 ]
end

;Calculates the dominance of the alliances based on the
;number of members divided by the number of firms
to calcAllianceDominance
  ifelse (numFirms > 0) [
  set allianceDominance1 allianceNumMem1 / numFirms
  set allianceDominance2 allianceNumMem2 / numFirms
  set allianceDominance3 allianceNumMem3 / numFirms
  set allianceDominance4 allianceNumMem4 / numFirms
  set allianceDominance5 allianceNumMem5 / numFirms
  ]
```

```
  [ set allianceDominance1 0
    set allianceDominance2 0
    set allianceDominance3 0
    set allianceDominance4 0
    set allianceDominance5 0 ]
end

;; Checks whether the firm membership is reflected by
;; being connnected with minimally one other person in the alliance.
;; if not the membership is withdrawn
to-report checkMembership [ id memberships myLinks ]
  let mmbr memberships
  foreach memberships [ [?1] ->
    if (?1 = 1) [
      let lnks1 myLinks with [ allianceLNK1 = true ]
      if (count lnks1 < 1 )  [
        set alliance-exits alliance-exits + 1
        set alliance-dec alliance-dec + 1
        set mmbr remove ?1 mmbr
        set alliance1 remove id alliance1 ]]
    if (?1 = 2) [
      let lnks2 myLinks with [ allianceLNK2 = true ]
      if (count lnks2 < 1 ) [
        set alliance-exits alliance-exits + 1
        set alliance-dec alliance-dec + 1
        set mmbr remove ?1 mmbr
        set alliance2 remove id alliance2 ]]
    if (?1 = 3) [
      let lnks3 myLinks with [ allianceLNK3 = true ]
      if (count lnks3 < 1 ) [
        set alliance-exits alliance-exits + 1
        set alliance-dec alliance-dec + 1
        set mmbr remove ?1 mmbr
        set alliance2 remove id alliance2 ]]
    if (?1 = 4) [
      let lnks4 myLinks with [ allianceLNK4 = true ]
      if (count lnks4 < 1 ) [
        set alliance-exits alliance-exits + 1
        set alliance-dec alliance-dec + 1
        set mmbr remove ?1 mmbr
        set alliance4 remove id alliance4 ]]
    if (?1 = 5) [
      let lnks5 myLinks with [ allianceLNK5 = true ]
      if (count lnks5 < 1 ) [
        set alliance-exits alliance-exits + 1
        set alliance-dec alliance-dec + 1
        set mmbr remove ?1 mmbr
        set alliance5 remove id alliance5 ]]
  ]
 report mmbr
end

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;; support - handy - misc ;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

to-report calcAllianceDensity [ numConnections numMembers ]
;to-report maxLinks [ numConnections numMembers ]
  let maxConn (numMembers * (numMembers - 1)) / 2
  ifelse (maxConn > 0)
  [ report numConnections / maxConn ]
  [ report 0 ]
end
```

```
; Reports the elements that are both in list 1 and 2, i.e. the inter-
section of two list
to-report intersection [ list1 list2 ]
  let intsec []
  foreach list1 [ [?1] ->
    if  member? ?1 list2 [ set intsec fput ?1 intsec ]
  ]
  report intsec
end

;;used for identifying the five oldest links, enables displaying them
in yellow.
to-report five-links
  let amount-of-links count links
  ifelse amount-of-links < 5
  [ report amount-of-links]
  [ report 5 ]
end

;Reports a random integer greater than or equal to rangeVal1 and
smaller or equal to rangeVal2
to-report getRnd [ rangeVal1 rangeVal2 ]
  let rnd random rangeVal2 - rangeVal1 + 1
  report rnd + rangeVal1
end

; Reports a project duration based on the settings in the interface
; uniformDistr = a random number from a uniform distribution
to-report getProjectDuration
 ifelse (project-duration = "uniformDistr(8-104)")
 [ report getRnd 8 104 ]
 [ print "Syst.err: link-duration is not set to a proper project dura-
tion"
   report -1 ]
end

;checks whether the memberships are properly reflected globally and
internally
to check-alliance-numbers [ myID new-alliance ]
  let membership [ firm-alliance-membership ] of turtle myID
  let allia []
  if (new-alliance = 1) [ set allia alliance1 ]
  if (new-alliance = 2) [ set allia alliance2 ]
  if (new-alliance = 3) [ set allia alliance3 ]
  if (new-alliance = 4) [ set allia alliance4 ]
  if (new-alliance = 5) [ set allia alliance5 ]

  if not member? myID allia [ print (sentence myID "is not member of
alliance" new-alliance " " allia) ]
  if not member? new-alliance membership [ print (sentence new-alli-
ance "is not member of internal membership " membership) ]
end

to remove-duplicates-in-alliances
  set alliance1 remove-duplicates alliance1
  set alliance2 remove-duplicates alliance2
  set alliance3 remove-duplicates alliance3
  set alliance4 remove-duplicates alliance4
  set alliance5 remove-duplicates alliance5
end
```

Appendix D: Guiding questions for case study interviews

The questions below informed the semi-structured interviews conducted for the case study in the smartphone industry (Section 3).

Empirical category	Question(s)
Introduction	Open entry conversation.
	What is your role in your organisation?
	How long have you/your organisation worked in the smartphone sector or been interested in it?
	How would you characterise the recent developments of this industry around {alliance(s)} (market, community, industry)?
Brokerage and entry	When did your organisation join {alliance(s)}?
	Why has your organisation chosen to become a member of {alliance(s)}?
	Whose initiative was it to join {alliance(s)}?
	How did your organisation become a member of {alliance(s)}?
	Did {lead organisation} play any role in this process, and how?
Alliance activities	Have you/your organisation created new business relations through your membership?
	Have you/your organisation gained access to new resources/opportunities/contacts through your membership?"
	Which other organisation(s) have you/your organisation created business relations with within {alliance}?
	Which other members did you/your organisation already have business relations with before joining {alliance(s)}?
	What kinds of activities occur within the alliance? And how often?
Closure, steering and control	What share of your/your organisation's activities are mainly alliance-related?
	How stable/regular) are these business relations/activities?
	(How) does your organisation invest in these relations/activities?
	(How) does {lead organisation} influence the activities of {alliance}?
	Do you/your organisation have any rights or obligations within {alliance}?
	Who decides about contributions to the shared {alliance} software code?
	With which organisations outside {alliance(s)} do you/your organisation have strong business relations?
	(How) do other {alliance} members react to your outside activities?
	Do you/your organisation identify as an {alliance} member?
Lock-in / exit	Have you considered the option of leaving {alliance}?
	What would be reasons for leaving/staying in {alliance}?
Conclusion	Is there anything else you would like to share?

Table 38: Guiding interview questions

Appendix E: Publications and conference contributions related to this thesis

Stöppler, Frithjof (2011): Industrial cliques: Agent-based modelling of the development of structural rigidity in interorganisational networks. In 6th SimSoc@work workshop. Rijskuniversiteit Groningen, Netherlands, 19-21 Apr 2011.

Stöppler, Frithjof (2011): Interorganisational networks and platform competition: A path dependence perspective on social capital and evidence from smartphone operating systems. In 2nd International Conference on Path Dependence. Freie Universität Berlin, Germany, 3-4 Mar 2011.

Stöppler, Frithjof; Meyer, Tobias (2010): Inter-organizational networks and platform competition. A path dependence perspective on social capital and evidence from the smartphone operating systems market. In 26th EGOS Colloquium of the European Group of Organizational Studies, subtheme Imprints of the Past: Organizational Path Dependencies. Universidade Nova de Lisboa, Portugal, 28 June – 3 July 2010.

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Appendix F: Co-authorship and declarations

Co-authorship

The description and context information for the empirical case (Section 3. 2. 2) and the history of mobile communications (Appendix A) was written in cooperation with my colleague and friend Tobias Meyer and some of the interviews were conducted together. It is the result of our joint empirical research on the smartphone industry over the three years 2008-2011 and also forms part of his PhD thesis (Meyer 2012). This cooperation took place in context of the Pfadkolleg Research Centre and has been approved by all our supervisors in advance and subsequently.

EIDESSTATTLICHE ERKLÄRUNG

Hiermit erkläre ich, Frithjof Stöppler, die vorliegende Dissertation selbstständig und unter ausschließlicher Verwendung und auf Basis der angegebenen Literatur, Hilfsmittel und Hilfen (siehe „Bibliography") verfasst zu haben. Alle Stellen, die wörtlich oder sinngemäß veröffentlichtem oder unveröffentlichtem Schrifttum entnommen sind, habe ich als solche kenntlich gemacht. Alle in Forschungskooperation entstandenen Bestandteile der Dissertation sind als solche gekennzeichnet. Weiterhin erkläre ich, dass ich mich bisher noch keinem Promotionsverfahren unterzogen oder an einer anderen Hochschule um Zulassung zu einem solchen beworben habe. Die Dissertation wurde bisher in gleicher, ähnlicher oder anderer Form oder Fassung keiner anderen Fakultät, anderen Hochschule oder deren Fachvertreter, anderen Prüfungsbehörde oder -ausschuss vorgelegt und auch nicht veröffentlicht.

Teile des Abschnitts 3.2.2. der Fallstudie („Contextualisation") und des Appendix A (History of mobile communications) wurden in **Kooperation** mit Dr. Tobias Meyer erarbeitet und Teile dieses Datenmaterials sind auch in seiner Dissertation (Meyer 2012) enthalten, dort jedoch mit grundsätzlich verschiedenem Fokus in der Datenanalyse.

Berlin, 2021-01-13 ____