# Essays in Industrial Organization: Regulation and Investments

INAUGURAL-DISSERTATION

zur Erlangung des akademischen Grades einer
Doktorin der Wirtschaftswissenschaft

eingereicht am
Fachbereich Wirtschaftswissenschaft
der Freien Universität Berlin

von

Juliane Fudickar
aus
Wuppertal

Berlin, 2017

**Erstgutachter:** Prof. Dr. Helmut Bester

**Zweitgutachter:** Prof. Dr. Roland Strausz (Humboldt Universität Berlin)

**Tag der Disputation:** 3. Mai 2017

## List of Papers and Publications

This thesis contains three papers. The third paper is joint work with my co-author Ružica Rakić:

**Chapter 1:** Revised version of: Fudickar, J. (2015). Net Neutrality, Vertical Integration and Competition between Content Providers. BDPEMS Working Paper Series 2015-14, Berlin Doctoral Program in Economics and Management Science (BDPEMS)

**Chapter 2:** Fudickar, J. (2016). Asymmetric Access Regulation and Broadband Investment of Competing Network Providers. unpublished working paper

**Chapter 3:** Based on: Fudickar, J. and Rakić, R. (2016). Cooperative and Noncooperative R&D in an Asymmetric Multiproduct Duopoly with Spillovers. BDPEMS Working Paper Series 2016-05, Berlin Doctoral Program in Economics and Management Science (BDPEMS)

Für Opi

# Acknowledgments

While working on this dissertation, I received support from many people, whom I would like to thank.

First of all, I would like to express my deepest gratitude to my supervisor Helmut Bester for his guidance in my research. My work greatly benefited from his advice and numerous suggestions. The support I have received is invaluable. I am also indebted to Roland Strausz for helpful comments and the co-supervision of this dissertation.

A special thank goes to my co-author Ružica Rakić for the great collaboration and becoming a good friend. I appreciated working with her and would not want to miss our chats, which made the past years much more enjoyable.

I am especially grateful to Philipp Dimakopoulos, Ružica Rakić, Slobodan Sudaric and Colin von Negenborn for valuable suggestions and careful proofreading. I also thank Pio Baake and Özlem Bedre-Defolie as well as numerous seminar participants for providing helpful comments.

I would also like to thank my colleagues at FU, in the BDPEMS program and in the RTG for providing not only research advice but also encouragement and motivation.

Last but not least, I am incredibly grateful to Johannes, my family and my closest friends for believing in me and providing ongoing support and encouragement on this long journey. Thank you!

# Contents

# List of Figures

# Introduction

This thesis contains three essays in Industrial Organization with a focus on the interplay between regulation and investments. Innovation and investments are critical drivers of a country's competitiveness as well as its economic growth and development. Therefore, each country needs to create an environment in which the economic, social, institutional and regulatory factors are conducive to research and development. For example, the European Commission launched its Europe 2020 Strategy to create the conditions for smart, sustainable and inclusive growth. The main objective is to form a single market with the aim of stimulating competition, increasing efficiency and raising innovation and investments (European Commission, 2010b).

Regulation is one of the activities that governments can engage into, which can exert a profound impact on the level and direction of innovation, both in specific sectors and in the economy as a whole. The economic literature has also recognized that regulation can be a powerful tool for innovation and investment (Ashford et al., 1985; Porter and van der Linde, 1995). Regulatory interventions change the degree of competition and therefore also affect the incentives of firms to invest or innovate. Economic theory suggests ambiguous effects of competition on investment incentives. On the one hand, competition increases the incentives for firms to invest as they seek to gain a competitive advantage over their rivals (e.g. Arrow, 1959). On the contrary, competition implies lower profits which in turn decreases the incentives to innovate. Hence, firms in concentrated markets have higher investment incentives as they are better in maintaining the resulting returns (Schumpeter, 1943). Aghion et al. (2005) combine both views and find an inverted U-shape relationship between competition and innovation, which implies that the optimal degree of competition to spur investment is intermediate. In network industries, such as energy, transport, and communication, significant investments in infrastructure are necessary. Alesina et al. (2005) show that regulatory reforms that enhance competition also promote investment. In the telecommunication industry, regulation has increased retail competition substantially due to local loop unbundling. Nonetheless, there is a negative relationship between regulation and infrastructure investment (e.g. Grajek and Röller, 2012).

Hence, to reach its innovation objectives, the European Commission can set the path with the right regulatory policy. The question arises which policy instruments are best suited to achieve these goals. The purpose of this thesis is to address different regulatory interventions and analyze their effects on investment activities, competition and welfare with the help of microeconomic models. Chapters 1 and 2 focus on the regulation of telecommunication networks, while Chapter 3 is concerned with cooperative investment behaviour.

Chapter 1 explores the economic consequences of network neutrality on competition and investments. Network neutrality refers to the principle that all data packets on the internet are to be treated equally, such that there is no discrimination in price and quality. It prevents last mile internet service providers from speeding up, slowing down or blocking traffic based on its source or content. We consider a situation, in which a monopoly internet service provider is vertically integrated with one of the content providers. Without regulation, the vertically integrated firm prioritizes the delivery of its content. In contrast to the existing literature, in which content providers derive profits solely from advertising, we assume price competition so that the unaffiliated content providers may adjust its prices due to non-neutral behaviour by the internet service provider.

We find that the integrated internet service provider and consumers as a whole are better off without net neutrality. The competing content providers might also be better off without net neutrality if the congestion intensity is high. From a social welfare perspective, no regulation is also desirable unless product differentiation and congestion intensity are low. Contrary to some claims by internet service providers, we find that investment incentives are not always higher without net neutrality regulation, especially when the degree of product differentiation is small.

Chapter 2 deals with broadband access regulation in the presence of network competition due to digital convergence. Digital convergence refers to "the ability of different network platforms to carry essentially similar kinds of services" (European Commission, 1997). As a result, cable companies and telecom firms compete heavily in the broadband market. However, current access regulation does not recognize this trend and only regulates telecom companies. Therefore, we present a model with asymmetric access regulation, in which an incumbent telecommunication operator, a cable operator and a retail entrant compete in the broadband market. Asymmetric access regulation implies that the incumbent operator is obliged to provide access to its network, whereas the cable operator is excluded from this rule. Incorporating this asymmetric set-up, the model assumes that the cable operator never provides access to its network. Different regulatory alternatives are analyzed regarding firms' investment incentives and social welfare.

Results show that the cable operator invests more than the incumbent with access regulation while the incumbent invests more than the cable operator without access regulation. Contrary to a monopolistic setting, we find that without regulation the incumbent never forecloses the service-based entrant from the market as this generates access revenues. With investment sharing the incumbent and the entrant invest more than the cable operator. Moreover, we show that co-investment leads to the highest social welfare as it provides relatively high investment incentives and intense retail market competition.

Moving away from the analysis of telecommunication markets to a more general market environment, Chapter 3 (joint work with Ružica Rakić) focuses on cooperation at the investment level. Several studies [1] show that joint R&D efforts trigger investments and generate welfare benefits. Consequently, collaborations between competitors at the investment level should be treated differently to anticompetitive agreements, like cartels or market-sharing, which are prohibited by Article 101 of the Treaty of the European Union (European Commission, 2012). Therefore, the European Commission (2010a) issued a "block exemptions" regulation which provides an automatic exemption from competition law for certain types of R&D agreements. To evaluate the effect of this block exemption, we analyse whether investment incentives are higher under R&D cooperation or competition in an asymmetric setting. New market environments, in which established goods are in competition with innovative goods, may lead to asymmetries between firms.

[1] See, among others, D'Aspremont and Jacquemin (1988) and Kamien et al. (1992).

Therefore, contrary to the existing literature, we consider R&D investment with spillovers in a market where a multi-product firm competes with a single-product firm.

We find that investments with R&D cooperation are lower than with R&D competition when the established good and the innovative good are close substitutes even if the spillover is substantial. More specifically, R&D investment of the single-product firm is only higher under cooperation than under competition if the spillover is high and product differentiation is low. The multi-product firm invests less under R&D cooperation if the spillover is low for any degree of product differentiation. Moreover, for medium spillovers and low product differentiation, the multi-product firm also invests less under R&D cooperation.

# Chapter 1

# Net Neutrality, Vertical Integration and Competition between Content Providers

This chapter is based on Fudickar (2015).

## 1.1 Introduction

Net neutrality refers to the principle that all data packets on the internet are to be treated equally, such that there is no discrimination in price and quality. It prevents last mile internet service providers from speeding up, slowing down or blocking traffic based on its source or content. While the net neutrality debate has many aspects, in this paper we focus on discriminatory behaviour by an integrated internet service provider. Ever since Madison River Communications, a small internet service provider, blocked VoIP[1] services that competed with its own voice services, net neutrality has been subject to a fierce debate not only in the United States but also around Europe. The question arises whether and how net neutrality should be enforced. In 2015, the Federal Communications Commission (2015) in the US and the European Commission (2015) for the European Union adopted net neutrality rules. These rules prohibit internet service providers from discriminating

[1]Voice over Internet Protocol

in favour of their own services.

With the boom of broadband internet, many innovative online content services have emerged. These content services stimulate the use of broadband to the benefit of internet service providers. The relationship between content services and internet service providers is not unproblematic, especially when there is competition between an internet service provider's own content and "over-the-top" content. The concern arises that vertically integrated internet service providers might have an incentive to favour their own content over unaffiliated rival services.

Another key aspect of the net neutrality debate concerns the investment in the next generation network. Investments in the network are critical not only for innovation of online services but also for overall economic growth. Internet service providers, however, claim that net neutrality makes the network less profitable and therefore discourages investment in the internet infrastructure [2]. For policy makers, it is, therefore, important to assess the economic consequences of a net neutrality regulation with respect to competition and investments.

We add to this debate by developing a theoretical model that explores the competition and welfare effects of net neutrality versus prioritisation. Moreover, we analyse the incentives of the internet service provider to invest in the network capacity. Our contribution to the literature is twofold: First, our focus is on vertical integration as a monopolistic internet service provider is integrated with one of the two competing content providers. We concentrate on potential discriminatory behaviour. Without a net neutrality regulation, the internet service provider might use its network to discriminate the unaffiliated content provider. Second, we introduce direct payments by consumers to content providers because, for example, online video service providers like Netflix charge consumers a monthly subscription fee to access their content. This set-up contrasts most of the existing literature, in which content providers derive profits solely from advertising. Directly competing in prices allows unaffiliated content providers to react better to non-neutral behaviour by the internet service provider and adjust their prices accordingly.

Waiting time is explicitly modelled, and consumers' utility decreases in waiting time. Under net neutrality, all consumers, no matter which content they consume, face the same waiting time. In the absence of net neutrality, the internet service

[2] http://www.washingtonpost.com/wp-dyn/content/article/2006/02/06/AR2006020601624.html

provider prioritises the delivery of its own content. This action leads to increased waiting times for consumers of the provider with less favourable treatment and reduced waiting times for consumers of the affiliated content. The affiliated content provider then obtains a quality of service advantage.

Comparing the two regulatory outcomes, we find that the internet service provider is always better off when it can prioritise its content. In the content market, profit of the integrated firm increases because it can offer a higher quality and thereby can raise its price. In the internet access market, it has to charge lower internet subscription fees as consumers of the competing content have a lower willingness to pay due to lower quality. This loss in the internet access market is, however, more than offset by the gains in the content market.

Surprisingly, prioritisation is not always detrimental to the competing content provider although it has a quality disadvantage. Whether the competing content provider is worse off depends on the congestion intensity and the degree of content differentiation. Under low congestion intensity, the profit of the unaffiliated content provider is always less. However, when congestion intensity is high, profits may also be higher than under net neutrality. The reason is that the integrated content provider faces a trade-off between demand and waiting time. As demand increases, waiting time for its consumers also increases. To balance this trade-off, it further increases the price of its content so that demand and waiting time are reduced. Due to the strategic complementarity of the pricing strategies, prices of the unaffiliated content provider might then rise considerably compared to the drop in demand; hence, higher profits under prioritisation.

Consumers as a whole gain from a prioritisation because more consumers benefit from prioritised delivery of their content. The effect of prioritisation on social welfare compared to net neutrality depends on the congestion intensity and the degree of content differentiation. Social welfare is higher under prioritisation if the differentiation between the contents is sufficiently large.

Finally, by analysing the effect of a net neutrality regulation on the internet service provider's incentive to invest in its network, we find that - contrary to recent claims - internet service providers do not necessarily have higher incentives to invest under prioritisation.

The remainder of this paper is organised as follows. Section 1.2 is devoted to the related literature. Section 1.3 presents the theoretical model, that is then solved in Section 1.4. We consider both net neutrality and prioritisation. In Section 1.5 we compare these two different regimes and derive welfare effects. Section 1.6 identifies the investment incentives of the internet service provider under the two scenarios. Section 1.7 concludes. The proofs of all formal results are relegated to Appendix 1.8. In Appendix 1.9 we develop waiting times in a system based on the queueing theory.

## 1.2 Related Literature

The present paper contributes to the growing economic literature on net neutrality, which is surveyed by Schuett (2010) and more recently by Krämer et al. (2013). Net neutrality is often studied in the framework of a two-sided market (see Armstrong, 2006), in which internet service providers are platforms that connect content providers on one side with internet consumers on the other side. Consumers and content providers generate positive network effects for each other. Net neutrality is then discussed in the context of either a zero-price rule (Economides and Tag, 2012; Musacchio et al., 2009; D'Annunzio and Russo, 2015; Kourandi et al., 2015) or a non-discrimination rule (Krämer and Wiewiorra, 2012; Choi and Kim, 2010; Cheng et al., 2011).

The zero-price rule implies that, under net neutrality, internet service providers cannot charge content providers for terminating their traffic to the consumers. Economides and Tag (2012) find that net neutrality can be welfare enhancing if content providers value additional consumers more than consumers value additional content providers. Consumers are clearly worse off under net neutrality because of the one-sided pricing by the internet service provider. Musacchio et al. (2009) analyse a similar issue but also allow investment in network quality.

We abstract from the possibility of paying termination fees and focus on net neutrality in the context of a non-discrimination rule. Under this rule, net neutrality corresponds to a situation in which internet service providers cannot offer different priority lanes and, at the same time, cannot charge content providers for prioritised delivery of their traffic. Many opponents of net neutrality argue that net neutrality neglects the importance of quality of service. Some content services desire a reliable transmission of information that is time critical. For example, video on demand and email services have different quality of service requirements. From a welfare perspective, discriminatory traffic management creates the potential for allocating bandwidth in a more efficient way, thereby maximising welfare for all users of the network (Hermalin and Katz, 2007; Krämer and Wiewiorra, 2012; Peitz and Schuett, 2016). To demonstrate this, Krämer and Wiewiorra (2012) consider a continuum of non-competing congestion sensitive content providers and consumers that connect to all content providers on the network. The number of content providers that choose to join the network in equilibrium is determined endogenously. They find that a discriminatory scheme is more profitable for the internet service providers and is welfare-enhancing as long as enough content providers benefit from prioritisation. Bourreau et al. (2015) extend their framework by introducing competition between internet service providers as competition might mitigate the problems associated with discriminatory traffic management (Hahn and Wallsten, 2006). They show that prioritisation leads to more investment because internet service provider can extract more revenue from content providers and more content providers with a high congestion sensitivity enter the market. Prioritisation is, therefore, welfare superior to net neutrality. Economides and Hermalin (2012) use a screening model to analyse the incentives of an internet service provider to provide priority lanes. Consumers adjust their behaviour based on actual transmission speeds. They conclude that net neutrality is often welfare maximising because discrimination can lead to bandwidth inefficiencies. Specifically, discrimination increases demand for content services with priority so that these services generate more traffic than under net neutrality, which in turn then re-congests the network. These papers differ from our model in that they consider a continuum of independent content providers that do not compete.

We are interested in priority given to one content provider in competition with another content provider offering content with the same congestion sensitivity. Without net neutrality, the internet service provider could give priority to some content providers and thereby harm competing content providers (Economides, 2007; van Schewick, 2015). The models by Choi and Kim (2010) and Cheng et al. (2011) are conceptually the closest to ours as they also consider a monopolistic internet service provider, two content providers and consumers who only consume one content. Based on queuing theory (Kleinrock, 1975, 1976), they set up a Hotelling model of competition between content providers. The main difference between the two papers is the treatment in selling priorities to the content providers. Choi and Kim (2010) only allow one content provider to acquire the priority right, while Cheng et al. (2011) allow both content providers to pay for priority. Contrary to our model, content providers derive profits solely from advertising and waiting time reduces utility linearly. We introduce direct payments between content providers and consumers because such a revenue model becomes increasingly popular with subscription-based content. Competing in prices allows the content providers to act strategically. Non-linear waiting times imply that prioritisation always enhances total quality of service.

Under prioritisation, Choi and Kim (2010) demonstrate that for the internet service provider the loss in subscription fees is offset by the gain in revenue from selling priority when advertising margins are high. While the profit of the content provider which pays for priority might increase, the profit of the non-prioritised content provider is always lower than under net neutrality. Due to the quality disadvantage, it loses market share and hence, advertising revenue. In contrast to our model, content providers do not have a decision variable to react strategically. Welfare effects of imposing net neutrality depend on how advertising margins related to transportation costs. Our results are driven by the difference in total perceived quality of service and transportation costs because waiting time is non-linear in our utility specification. Regarding investment incentives, the relative value of priority becomes relatively small for higher levels of capacity. As a result, investment incentives are higher under net neutrality in which such rent extraction effects do not exist. Similarly, Cheng et al. (2011) find in their setting that the internet service provider always gains from prioritisation and content providers are left in a worse position. Consumers who consume prioritised content are better off while other consumers are worse off. Total welfare and consumer surplus increase when only one content provider pays for priority but is unchanged when both content providers pay. They further show that the investment incentives are lower under prioritisation because the revenue contributions from content providers decrease in capacity expansion.

In a similar framework, Guo et al. (2010) incorporate vertical integration. They find that prioritisation increases or decreases social welfare depending on whether the internet service provider is integrated with the more or less efficient content provider. Moreover, they argue that the integrated internet service provider may even have incentives to prioritise the competing content provider provided that it is more efficient in generating advertising revenue so that the internet service provider can extract more rent.

Brito et al. (2013) and Gans (2015) are the first to our knowledge to introduce direct payments from consumers to content providers. Gans (2015) thereby focuses on net neutrality regulation in the context of different types of price regulation. The framework in Brito et al. (2013) is similar to ours, but the key differences are that they consider competition between internet service providers, and that they do not explicitly model congestion. They translate the quality of network service into the gross utility function for consumers. Contrary to our model, quality of service does not depend on demand. The prioritised content provider, therefore, does not have to trade off quality of service with the demand. As a result, the discriminated content provider is always worse off under prioritisation. They also find that internet service providers are better off under prioritisation. Investment and welfare are higher under prioritisation when internet service providers are symmetric and can allocate the level of quality of network services among the content providers freely.

Finally, by introducing vertical integration, our work is also related to the extensive literature on discrimination and foreclosure [3]. Net neutrality implies that a vertically integrated internet service provider is not allowed to degrade or foreclose competing content artificially. The Chicago School (e.g. Bowman, 1957; Posner, 1976; Bork, 1978) argues that there are no incentives to vertically foreclose a competitor when the goods are essential complements because there is only one profit to be extracted. Firms could use their upstream market power to extract the rent from the downstream competitors. Moreover, the monopolist even benefits from competition in the complementary market (Whinston, 1990).

Relating vertical foreclose to the net neutrality debate, Chen and Nalebuff (2006) show that a monopolistic upstream firm has no incentives to degrade the quality of service of its downstream competitors by offering its own competitive

[3] see Rey and Tirole (2007)

good for free and charging a higher price for the upstream product. It is further shown by Broos and Gautier (2015) that a monopolistic internet service provider never finds it profitable to exclude a competing content. The competing content creates additional value to the consumers so that the internet service provider can increase the price of the complementary internet service. Contrary, Dewenter and Rösch (2014) find that a vertically integrated internet service provider may foreclose competitors in the content market if content providers are close substitutes. Consumers give little value to additional content, and therefore, the internet service provider cannot set a higher price for the complementary good. Economides (1998) shows that it might be beneficial to an upstream monopolist to raise its rivals' cost by quality degradation. This result is also reflected in our paper. By prioritising affiliated content, the monopoly input supplier artificially degrades the quality of content of its competitor in the content market. The profit of the vertically integrated firm increases.

## 1.3 The Model

We study net neutrality regulation of the internet in a market with a single internet service provider and two content providers. The internet service provider owns an internet network and provides consumers access to it. Content providers are firms that create content for the consumers on the internet. Internet access is, therefore, essential to the consumption of these content services. Examples of such content services are email, news, music and video services. In our scenario consider content providers as being video service providers.

We consider a situation where the monopoly internet service provider is vertically integrated with one of the content providers and, therefore, effectively constitutes a single firm $A$. The other content provider, firm $B$, sells its content to consumers over the network of firm $A$. Consumers regard the products of the two content providers as horizontally differentiated. Adopting the Hotelling (1929) framework, consumers of mass one are uniformly distributed along the unit interval, while locations of the content providers are fixed. Firm $A$ is located at point 0 and firm $B$ is located at point 1. A consumer's location is equivalent to his taste parameter $x \in [0, 1]$. He faces total "transportation cost" of $tx$ when buying content from firm $A$ and $t(1-x)$ when buying from firm $B$, where the “transportation cost” parameter $t > 0$ indicates the degree of product differentiation. To consume content on the internet, each consumer first must buy internet access from firm $A$ at a price $p_I$ and then chooses to purchase either content $A$ at a price $p_A$ or content $B$ at a price $p_B$. A consumer who purchases content from firm $i \in \{A, B\}$ thus has to pay $p_I + p_i$ in total for internet access and content. A consumer with characteristic $x$ derives utility $U_i(x, p_i, p_I, w_i)$ from consuming internet access and content $i$, where

$$\begin{aligned} U_A(x, p_A, p_I, w_A) &\equiv u + \frac{v}{w_A} - tx - p_A - p_I \\ U_B(x, p_B, p_I, w_B) &\equiv u + \frac{v}{w_B} - t(1-x) - p_B - p_I \end{aligned} \tag{1.1}$$

The parameter $u$ is defined as $u = u_I + u_C$ such that each consumer derives a fixed utility of $u_I > 0$ for internet access and $u_C > 0$ for content consumption. The parameter $v > 0$ measures consumers’ preference for the speed of the internet connection for content consumption and $w_i$ is the waiting time until the content arrives. Therefore, $1/w_i$ represents the speed of the internet connection so that the second component, $v/w_i$, indicates the perceived quality of service. Perceived quality of service is decreasing in waiting time, which in turn depends on network capacity, demand and prioritisation. This formulation of perceived quality is new in the literature and is chosen for the following reasons. First, it is intuitive that the marginal disutility from waiting is decreasing. Second, it is convenient in terms of tractability of the calculations.

We assume for simplicity that (i) fixed utility from content consumption, $u_C$, is high enough so that all consumers obtain a positive net utility from content consumption, and (ii) the utility from internet access, $u_I$, is sufficiently high compared to the consumer surplus in the content market. Under this assumption, it is not profitable for the internet service provider to exclude some consumers from the market.

### Waiting Time and Congestion

The internet service provider owns the network infrastructure with a capacity of $\mu > 0$. Internet capacity, also called bandwidth, is the amount of data that can be transmitted over the network from content providers to consumers in a given period of time. This capacity is shared between all subscribers of the internet connection. As the size of the network is fixed, congestion arises. If data requests are increasing, more capacity will be used up at that time, so that it will take longer until content is transmitted to the consumers. The greater the capacity, the faster data can be carried over the network.

Under net neutrality, content is transmitted on a best-effort basis over the network to the consumers. More specifically, the internet service provider treats all content the same and is not allowed to differentiate between the transmission of its content and the unaffiliated one. Congestion, and the resulting waiting time until the content arrives, is, therefore, the same for all consumers no matter which content they consume. Without a net neutrality regulation, however, the internet service provider can prioritise its content, thereby reducing waiting time for consumers who buy the integrated content, while waiting time increases for consumers of content $B$.

As it is common in the net neutrality literature, the framework of the $M/M/1$ queuing system (e.g. Kleinrock (1975, 1976)) is adopted in order to model congestion[4]. Congestion is measured by the waiting time $w_i$ for consumers when they request content from one of the two content providers. Waiting time depends on network capacity, total traffic in the network as well as on data prioritisation.

We assume that the content request rate of each consumer follows a Poisson process with content request rate $\lambda > 0$ corresponding to the demand intensity. Total capacity demand equals content request rate times the total number of consumers. Given full market coverage, the waiting time for a consumer to obtain the requested content under net neutrality is therefore

$$w_i^N = \frac{1}{\mu - \lambda}. \tag{1.2}$$

Traffic intensity $\rho$ is defined by the ratio of arrival rate to capacity and measures congestion in the system:

$$\rho = \frac{\lambda}{\mu} \tag{1.3}$$

[4]see Appendix B for details

As traffic intensity goes up, the level of congestion increases and thereby consumers have longer waiting times in the system. For a stable system, we need to assume that available capacity is larger than the content request rate. Otherwise, the queue will grow indefinitely long, and the system will not have a stationary distribution.

**Assumption 1.1** $\mu > \lambda$.

Without net neutrality, the internet service provider can offer a priority lane for consumers who buy their own integrated content and a non-priority lane for consumers who buy the competing content, thereby offering different qualities of services. Let $x_A^P$ denote the market share of content provider $A$ under priority. Then, given full market coverage, the waiting time for consumers of content $A$, who are in the priority lane, is given by

$$w_A^P = \frac{1}{\mu - \lambda x_A^P} \tag{1.4}$$

whereas the waiting time for consumers of content $B$, who are in the non-priority lane, is given by

$$w_B^P = \frac{\mu}{(\mu - \lambda)(\mu - \lambda x_A^P)} \tag{1.5}$$

Consumers buying non-prioritised content face higher waiting times since the relative ratio of $w_B^P$ to $w_A^P$ is greater than one, i.e. $w_B^P / w_A^P = \mu/(\mu - \lambda) > 1$. As a consequence, $w_B^P > w_i^N > w_A^P$ for $\mu > \lambda$.

The perceived quality of service is decreasing in waiting time indicating that consumers suffer from congestion. More specifically, waiting time is decreasing in capacity $\mu$ and increasing in content request rate $\lambda$. Under prioritisation, waiting times are defined by equations (1.4) and (1.5). Priority consumers exert negative externalities on consumers of both priority lanes. The larger the market share of content provider $A$, the higher the waiting time for everyone. Moreover, this functional form exhibits a diminishing marginal disutility of waiting. The marginal negative impact of waiting on consumers' utility decreases as the waiting time increases so that there is a much greater loss in marginal utility with short waiting times.

Demand for internet access equals one since full market coverage is assumed for tractability. The market shares of content providers $A$ and $B$ are given by $x_A(p_A, p_B)$ and $x_B(p_A, p_B) = 1 - x_A(p_A, p_B)$, respectively. Moreover, neither content provision nor access provision involves any cost so that both firms have identical marginal costs equal to zero. Hence, firm $A$'s profit is the sum of the profits from internet access, $\Pi_{AI}$, and content services, $\Pi_{AC}$, that is

$$\Pi_A = \Pi_{AI} + \Pi_{AC} = p_I + p_A x_A(p_A, p_B).$$

Content provider $B$ makes profit only from content services, that is

$$\Pi_B = p_B x_B(p_A, p_B).$$

Competition then proceeds as follows:

Stage 1: In the absence of net neutrality regulation, the internet service provider chooses whether to prioritise its own content. Under net neutrality, there is no stage 1.

Stage 2: The internet service provider sets the subscription fee $p_I$ for internet access.

Stage 3: Content providers compete simultaneously in the content market by setting prices $p_A$ and $p_B$ and consumers decide whether to subscribe to the internet and choose which content to buy.

## 1.4 Equilibrium Outcomes

We next solve for the equilibria under net neutrality and under prioritisation by backward induction.

### 1.4.1 Network Neutrality

Under net neutrality, all content has to be treated equally. The internet service provider, therefore, cannot prioritise its content; hence, waiting times are the same for all consumers no matter which content is consumed. Provided that all consumers buy internet access, waiting times are given by (1.2) and hence,

$$w_A^N = w_B^N = \frac{1}{\mu - \lambda}.$$

Each consumer chooses whether to buy content from firm $A$ or firm $B$. The consumer indifferent between the two firms, denoted by $\hat{x}$, is defined by $U_A(\hat{x}, p_A, p_I, w^N) = U_B(\hat{x}, p_B, p_I, w^N)$. This yields

$$\hat{x}(p_A, p_B) = \frac{1}{2} + \frac{p_B - p_A}{2t} \tag{1.6}$$

Since we assume that the market for content is covered, the market shares for content provider $A$ and content provider $B$ are $x_A^N(p_A, p_B) = \hat{x}(p_A, p_B)$ and $x_B^N(p_A, p_B) = 1 - \hat{x}(p_A, p_B)$, respectively. The content providers compete by setting prices to the consumers. Firm $A$ maximises its profit from content services, $\Pi_{AC}^N(p_A, p_B)$, and content provider $B$ maximises its profit, $\Pi_B^N(p_A, p_B)$. From the first-order conditions $\partial\Pi_{AC}^N(p_A, p_B)/\partial p_A = 0$ and $\partial\Pi_B^N(p_A, p_B)/\partial p_B = 0$ we obtain the equilibrium prices

$$p_A^N = p_B^N = t. \tag{1.7}$$

By substituting (1.7) into (1.6), we obtain the equilibrium market shares of the content providers

$$x_A^N = x_B^N = \frac{1}{2}. \tag{1.8}$$

Because waiting times under net neutrality are the same for all consumers independent of the content they consume, content providers are symmetric and therefore share the market equally.

As internet access is essential to the consumption of content services, the internet service provider can exploit its market power in the access market and extract some of the surplus consumers gain in the content market. The subscription fee $p_I$ is set so that all consumers connect to the internet and the indifferent consumer receives zero overall utility:

$$\max_{p_I} \Pi_{AI} = p_I \text{ s.t. } U_A(\hat{x}(p_A^N, p_B^N), p_A^N, p_I, w^N) \geq 0$$

which leads to equilibrium access fee

$$p_I^N = u + v(\mu - \lambda) - \frac{3t}{2}. \tag{1.9}$$

The above analysis implies that the integrated firm A's overall profit, $\Pi_A = \Pi_{AC} + \Pi_{AI}$, in the content and internet access market is given by

$$\Pi_A^N = u + v(\mu - \lambda) - t \tag{1.10}$$

and firm B's profit by

$$\Pi_B^N = \frac{t}{2}. \tag{1.11}$$

Under net neutrality, profits in the content market are independent of capacity and content request rate because of the equal treatment of consumers of both content provider. However, an increase in network capacity increases firm $A$'s profit in the internet access market as it can charge a higher subscription fee to consumers because congestion is reduced. Thereby, consumers' waiting time is reduced which increases their willingness to pay. Moreover, because internet access is essential to the consumption of content, firm $A$ can extract all this surplus. On the contrary, when there is an increase in the content request rate, congestion is increased so that the willingness to pay decreases and firm $A$'s profit will be smaller.

### 1.4.2 Prioritisation

Without net neutrality regulation, the integrated internet service provider can offer priority and non-priority lanes for content transmission. The internet service provider, therefore, prioritises transmission for consumers who have bought the integrated content $A$. Consequently, consumers face a different waiting time depending on the choice of content service. By (1.4) and (1.5), waiting time in the system for consumers buying content $A$ is

$$w_A^P = \frac{1}{\mu - \lambda x_A}$$

and for consumers of content $B$

$$w_B^P = \frac{\mu}{\mu - \lambda} \frac{1}{\mu - \lambda x_A}.$$

The consumer $\tilde{x}$, who is indifferent between the two content providers, is defined by $U_A(\tilde{x}, p_A, p_I, w^P) = U_B(\tilde{x}, p_B, p_I, w^{NP})$. We assume consumers' expectations regarding the demand for content $A$ is fulfilled, so that $\tilde{x} = x_A(p_A, p_B)$. From the indifference condition we then obtain

$$\tilde{x}(p_A, p_B) = \frac{\mu(t + v\lambda + p_B - p_A)}{2t\mu + v\lambda^2}. \tag{1.12}$$

As before, the market for content is covered so that the market shares of content provider $A$ and content provider $B$ are given by $x_A^P(p_A, p_B) = \tilde{x}(p_A, p_B)$ and $x_B^P(p_A, p_B) = 1 - \tilde{x}(p_A, p_B)$, respectively. The content providers compete in prices. Profit from content services for firm $A$ is $\Pi_{AC}^P(p_A, p_B)$ and profit for content provider $B$ is $\Pi_B^P(p_A, p_B)$.

Solving the first-order conditions, $\partial\Pi_{AC}^P(p_A, p_B)/\partial p_A = 0$ and $\partial\Pi_B^P(p_A, p_B)/\partial p_B = 0$, yields the equilibrium prices

$$p_A^P = t + \frac{v\lambda}{3\mu}(\mu + \lambda) \tag{1.13}$$

$$p_B^P = t - \frac{v\lambda}{3\mu}(\mu - 2\lambda). \tag{1.14}$$

Substituting these equilibrium prices into the demand functions, we obtain the market shares for the content providers

$$\begin{aligned} x_A^P &= \frac{3\mu t + v\lambda(\mu + \lambda)}{6\mu t + 3v\lambda^2} \\ x_B^P &= 1 - x_A^P \end{aligned} \tag{1.15}$$

When the internet service provider prioritises its content, perceived quality for consumers of content $A$ is higher than perceived quality of content $B$. As a result firm $A$ always obtains a larger market share than firm $B$.

**Proposition 1.1** *Under prioritisation content provider $A$ always covers more than half of the market, that is $x_A^P > 1/2$ and therefore also has a larger market share than content provider $B$, that is $x_A^P > x_B^P$.*

To ensure an interior solution in which both firms sell strictly positive quantities of their services, one needs $x_i^P \in (0, 1)$. Therefore, we assume in what follows that the differentiation parameter $t$ is high enough.

**Assumption 1.2** $t > \underline{t} \equiv [v\lambda(\mu - 2\lambda)]/(3\mu)$

Differentiation is high enough so that even with prioritisation of its own content, firm $A$ cannot attract the entire market for content.

Anticipating the prices that will be set in the content market, the internet service provider sets the access fee $p_I$ such that all consumers subscribe to the internet. It extracts all utility from the indifferent consumer:

$$\max_{p_I} \Pi_{AI} = p_I \text{ s.t. } U_A(\tilde{x}(p_A^P, p_B^P), p_A^P, p_I, w^P) \geq 0$$

This yields the equilibrium access fee

$$p_I^P = u + \frac{6vt\mu(\mu^2 - \lambda\mu - \lambda^2) + v^2\lambda^2(2\mu^2 - 2\lambda\mu - \lambda^2) - 9t^2\mu^2}{3\mu(2t\mu + v\lambda^2)}. \tag{1.16}$$

Using the results (1.13) – (1.16) we can calculate the profits of the firms. The profit of the integrated firm $A$ from sales of internet access as well as content services, $\Pi_A = \Pi_{AC} + \Pi_{AI}$, is

$$\Pi_A^P = u + \frac{6vt\mu(3\mu^2 - 2\lambda\mu - 2\lambda^2) + v^2\lambda^2(7\mu^2 - 4\lambda\mu - 2\lambda^2) - 18t^2\mu^2}{9\mu(2t\mu + v\lambda^2)} \tag{1.17}$$

and the profit of firm $B$ is

$$\Pi_B^P = \frac{(3t\mu + 2v\lambda^2 - v\lambda\mu)^2}{9\mu(2t\mu + v\lambda^2)}. \tag{1.18}$$

## 1.5 Network Neutrality vs Prioritisation

To study the impact of a net neutrality regulation, we now compare the two regulatory alternatives, net neutrality versus prioritisation, with respect to profits, consumer surplus and social welfare. We take the capacity level $\mu$ as constant.

First, we derive some properties regarding the waiting time and perceived quality of service under net neutrality and prioritisation.

**Lemma 1.1** *(i) The total waiting time in the system is the same under both net neutrality and prioritisation. (ii) Prioritisation always increases total perceived quality of service.*

The first result in Lemma 1.1 is a standard property of the $M/M/1$ queuing model. When total demand is fixed, a change from net neutrality to prioritisation only affects the order of service for the consumers. The second result states that prioritisation is efficiency-enhancing. As waiting time enters the perceived quality of service formulation in a non-linear way, total perceived quality of service in the system is always higher under prioritisation. This results is critical for the following analysis and stands in stark contrast with the existing literature. For example, in Choi and Kim (2010), waiting time enters utility linearly and therefore, by the first statement in Lemma 1.1, it has no effect on total utility and in Economides and Hermalin (2012), the formulation of bandwidth division tends to be efficiency-reducing.

**Lemma 1.2** *The demand for content $A$ is decreasing in the differentiation parameter, and therefore, the difference in perceived quality of service between the prioritised and non-prioritised delivery of content is increasing in the differentiation parameter.*

As product differentiation increases, consumers prefer buying the content service closer to their location because travelling becomes more costly. The demand for content $A$ decreases and the demand for content $B$ increases. This effect leads to a reduction in the waiting times and, thereby, increases the perceived quality of service. Consumers of $A$ gain more utility because the marginal utility gain of waiting is higher for shorter waiting times. Thus, the difference between the service qualities becomes larger.

### 1.5.1 Firms' Prices and Profits

We analyse the effects of prioritisation on the price-setting behaviour of the firms.

**Proposition 1.2** *(i) Under prioritisation, content prices of firm $A$ are always higher than prices of firm $B$, that is $p_A^P > p_B^P$.*
*(ii) Compared to net neutrality, under prioritisation the integrated firm $A$ always sets higher prices in the content market, that is $p_A^P > p_A^N$, and lower subscription fees in the internet service market, that is $p_I^P < p_I^N$.*
*(iii) The effect on firm $B$'s prices depends on traffic intensity:*
*(a) If $0 < \lambda < \mu/2$, then $p_B^P < p_B^N$.*

*(b) If $\mu/2 < \lambda < \mu$, then $p_B^P > p_B^N$.*

Intuitively, this result can be explained as follows. First, by implementing priority, firm $A$ has a perceived quality of service advantage in content relative to content provider $B$ due to lower waiting times. This competitive advantage allows content provider $A$ to charge a higher price for its content than content provider $B$. Despite charging a higher price than its competitor, firm $A$ also has a larger market share in content provision (see Proposition 1.1). Moreover, for the same reason, firm $A$'s content price and also its market share in content provision is higher under prioritisation than under net neutrality.

Depending on traffic intensity, the price charged by content provider $B$ under prioritisation is higher or lower than its price under net neutrality. Prioritisation only has an 'intrinsic' value if there is a certain level of congestion. When $0 < \lambda < \mu/2$, traffic intensity is low. Congestion is negligible, and prioritisation does not provide much added value. As a result, content provider $B$ competes fiercely with content provider $A$ by setting a lower price compared to net neutrality and, thereby, compensates its consumers for the marginal quality of service disadvantage.

Contrary, when $\mu/2 < \lambda < \mu$, the price of content $B$ is higher compared to net neutrality. The intuition is at follows. We observe that both content prices are increasing in the traffic intensity at an increasing rate. When traffic intensity increases, congestion becomes a crucial issue. Prioritisation of content $A$ stimulates the demand for the prioritised content because consumers prefer to consume content with the quality of service advantage. However, consumers of content $A$ exhibit a negative network effect not only on themselves but also on consumers of content $B$ so that the waiting time for priority also increases. Hence, there is a trade-off for firm $A$ between demand and waiting time and it has an incentive to counterbalance the increase in waiting time for its consumers by increasing its price further. Doing so, firm $A$ takes into account that a lower market share increases the utility of its consumers through the perceived quality of service. As content providers' pricing strategies are strategic complements, a price increase of one firm leads to a price increase of the competitor. It is, therefore, optimal for content provider $B$ to charge a higher price, the higher the price of the competitor even though its consumers have a lower perceived quality of service. As a result, the price of content $B$ is higher compared to net neutrality when traffic intensity is high.

The subscription fee is always lower under prioritisation than under net neutrality. By implementing priority, waiting time for consumers of content $B$ increases, thereby reducing their willingness to pay for internet access. The internet provider reduces the price it charges to consumers for access because it can extract more profit through the content price.

We next compare firms' profits between prioritisation and net neutrality.

**Proposition 1.3** *(i) The integrated firm A always has higher profit under prioritisation compared to net neutrality, that is* $\Pi_A^P > \Pi_A^N$.
*(ii) The effect on firm B's profit depends on traffic intensity and product differentiation:*

*(a) If* $0 < \lambda < \mu/2$, *then* $\Pi_B^P < \Pi_B^N$ *for all* $t > \underline{t}$.

*(b) If* $\mu/2 < \lambda < 4\mu/5$, *then there exists a critical value* $t_1^*$, *with* $t_1^* > \underline{t}$ *such that* $\Pi_B^P > \Pi_B^N$ *only if* $t < t_1^*$.

*(c) If* $4\mu/5 < \lambda < \mu$, *then* $\Pi_B^P > \Pi_B^N$ *for all* $t > \underline{t}$.

Prioritisation of traffic involves a trade-off for the vertically integrated firm. By Propositions 1.1 and 1.2, firm $A$ clearly has smaller subscription fees from internet access but higher prices and more sales from content services. The analysis shows that firm $A$ can always compensate for losses in the access market by gains in the content market. If firm $A$ has the choice, it will always choose to prioritise its content over the rival content.

The effect of prioritisation on firm $B$'s profit is not clear-cut. With price competition between content providers, the non-prioritised content provider might be better off under prioritisation as it can react to the non-neutral behaviour by the internet service provider and adjust its prices accordingly. In particular, it depends on the traffic intensity and the differentiation parameter. When congestion intensity is low, that is $0 < \lambda < \mu/2$, it follows immediately from Propositions 1.1 and 1.2 that profit of firm $B$ is lower under prioritisation. When traffic intensity is high, such that $\mu/2 < \lambda < \mu$, the price, that the content provider $B$ charges, is higher but its market share is lower than under net neutrality. Decomposing the difference in firm $B$'s profit under prioritisation and net neutrality, we can identify two opposing effects.

$$\begin{aligned}
\Pi_N^P - \Pi_B^N &= p_B^P x_B^P - p_B^N x_B^N \\
&= (p_B^N - \frac{v\lambda}{3\mu}(\mu - 2\lambda))x_B^P - p_B^N x_B^N \\
&= \underbrace{\overset{+}{\frac{v\lambda}{3\mu}(2\lambda - \mu)x_B^P}}_{\text{Gain in profit because of charging a higher price}} - \underbrace{\overset{+}{p_B^N(x_B^N - x_B^P)}}_{\text{Loss in profit if prices were constant due to reduced demand}}
\end{aligned} \tag{1.19}$$

On the one hand, there is an additional profit under prioritisation because firm $B$ can charge a higher price. On the other hand, if it were to charge the same price, there is a loss of profits because demand is lower under prioritisation due to lower quality of service. The overall effect on profit, therefore, depends on the relative magnitude of these two opposing effects.

The result in Proposition 1.3 (ii)-(b) is at first counter-intuitive because we would expect to see that profits under prioritisation are higher for higher values of the differentiation parameter. However, when $t$ increases, content services become more differentiated which implies that content providers obtain more market power. They can raise their prices, which, in turn, leads to higher profits. Yet, not only profits under prioritisation increase in $t$ but also profits under net neutrality. The effect of higher differentiation on the difference in profits is, therefore, ambiguous a priori.

When product differentiation increases, the profit of firm $B$ under net neutrality, $p_B^N x_B^N$, increases more than $p_B^N x_B^P$, which is the product of the price under net neutrality and the demand under prioritisation. Hence, the loss is increasing in $t$. From the first part of Lemma 1.2, we can conclude that the gain in profits is also increasing in $t$. Moreover, the gain is increasing and convex in the congestion intensity $\lambda$. This implies that the level of the gain is increasing in $\lambda$ at an increasing rate and thus, is more pronounced when congestion is substantial.

We can now distinguish the two cases. First, when $\mu/2 < \lambda < 4\mu/5$, traffic intensity is moderately high. From our analysis, it follows that when product differentiation $t \to 0$, then the loss $\to 0$. Hence, when t becomes small, the additional profit gain outweighs the loss of profits due to reduced demand. Additionally, it follows from Lemma 1.2 that the perceived quality of service advantage of $A$ is larger for higher values of the differentiation parameter. Then, even the increase in firm $B$'s price resulting in an additional profit gain cannot offset the loss in demand so that overall profit of firm $B$ is lower under prioritisation. Secondly, when $4\mu/5 < \lambda < \mu$, traffic intensity is extremely high, so that congestion matters a lot and all consumers have long waiting times. Nonetheless, the increase in the price $p_B^P$ is substantial so that the level of the profit gain is high enough for all parameter values to offset the loss in market share; hence higher profit for firm $B$.

### 1.5.2 Consumer Surplus and Total Welfare

For a policy maker who has to decide whether to allow the integrated internet service provider to prioritise its content or to implement a net neutrality rule, welfare effects are an important consideration. We now compare consumer surplus and social welfare under priority and net neutrality.

First, we determine consumer surplus. Adding up the net utilities of all consumers buying content $A$ and content $B$, we obtain the consumer surplus of the regulatory regime $j \in \{N, P\}$:

$$\begin{aligned} CS^j &= \int_0^{x_A^j} U_A(x, p_A^j, p_I^j, w_A^j)\mathrm{d}x + \int_{x_A^j}^1 U_B(x, p_B^j, p_I^j, w_B^j)\mathrm{d}x \\ &= \frac{t}{2} - t x_A^j + t(x_A^j)^2 \end{aligned} \tag{1.20}$$

Under both regimes, consumer surplus only depends on the differentiation parameter and the location of the consumer indifferent between the two content providers because the internet access price $p_I^j$ captures all the surplus from the indifferent consumer. All other consumers get the excess surplus that depends only on their location. Thus, consumer surplus is equivalent to total transportation costs. From (1.8) consumer surplus under net neutrality is

$$CS^N = \frac{t}{4} \tag{1.21}$$

and from (1.15) consumer surplus under prioritisation is

$$CS^P = \frac{t(18t\mu(t\mu + v\lambda^2) + v^2\lambda^2(5\lambda^2 - 2\lambda\mu + 2\mu^2))}{18(2\mu t + v\lambda^2)^2}. \tag{1.22}$$

**Proposition 1.4** *Consumers as a whole benefit from prioritisation, i.e.* $CS^P > CS^N$.

In this specific Hotelling framework, individual consumer surplus increases linearly with the distance of one's location from the marginal consumer who is indifferent between the two content providers. Under net neutrality, content providers are symmetric so that the location of the indifferent consumer is fixed in the middle of the Hotelling line. Under prioritisation, however, content providers are asymmetric. The strength of the asymmetry and also the location of the indifferent consumer depend on the congestion intensity and the differentiation parameter. As content $A$ is prioritised, consumers are redistributed towards this content provider with the quality advantage. Hence, the marginal consumer is located to the right of the middle. As a result, total transportation costs increase which implies that consumer surplus is higher.

To determine the overall effect of prioritisation by the integrated firm, we now look at the total welfare of the regulatory regime $j \in \{N, P\}$, which is defined as the sum of profits of both firms and consumer surplus.

$$\begin{aligned} TS^j &= \Pi_A^j + \Pi_B^j + CS^j && (1.23) \\ &= \int_0^{x_A^j} (u + \frac{v}{w_A^j} - tx)dx + \int_{x_A^j}^1 (u + \frac{v}{w_B^j} - t(1-x))dx && (1.24) \end{aligned}$$

Since prices are simple transfers from consumers to the firms, total welfare only depends on the utility and perceived quality of service of the content as well as transportation costs. From (1.10), (1.11) and (1.21) we obtain total welfare under net neutrality

$$TS^N = u + v(\mu - \lambda) - \frac{t}{4} \tag{1.25}$$

and from (1.17), (1.18) and (1.22), we derive total welfare under prioritisation

$$TS^P = u + \frac{1}{18\mu(2\mu t + v\lambda^2)^2}(-18t^3\mu^3 + 72vt^2\mu^3(\mu - \lambda) + v^2\lambda^2 t\mu(70\mu^2 - 70\lambda\mu + 13\lambda^2) + 4v^3\lambda^4(2\mu - \lambda)^2) \tag{1.26}$$

Since the fixed utility of content $u$ is the same under both regimes, the difference in total welfare is determined by the total perceived quality of service and the total transportation cost.

$$\begin{aligned}\Delta TS &= TS^P - TS^N \\ &= \underbrace{\overset{+}{\frac{v\lambda^2 x_A^P}{\mu}(1 - x_A^P)}}_{\substack{\text{Gain in total} \\ \text{quality of service}}} - \underbrace{\overset{+}{(\frac{t}{4} - tx_A^P + t(x_A^P)^2)}}_{\substack{\text{Loss in} \\ \text{transportation cost}}}\end{aligned} \tag{1.27}$$

First, as seen in Lemma 1.1, total perceived quality of service increases compared to net neutrality. Second, total transportation costs are minimised when the marginal consumer is located at the midpoint so that prioritisation with $\tilde{x} > 1/2$ is inefficient in terms of transportation cost minimisation. Hence, total transportation costs increase under prioritisation. Welfare effects, therefore, depend on the trade-off between the total gain in perceived quality of service and the total loss in transportation costs. If the gain in quality of service is large relative to the increase in transportation costs, prioritisation is preferred.

**Proposition 1.5** *The impact of prioritisation on total welfare depends on traffic intensity and product differentiation:*

*(a) If $0 < \lambda < \mu/2$, then there exists a critical value $t_2^*$ with $t_2^* > \underline{t}$ such that $TS^P > TS^N$ only if $t > t_2^*$*

*(b) If $\mu/2 < \lambda < \mu$, then $TS^P > TS^N$ for all $t$.*

From Lemma 1.2, we know that demand for content $A$ decreases in the differentiation parameter. As the gain in total quality of service decreases in $x_A^P$, an increase in $t$ leads to a larger quality of service gain under prioritisation. Moreover, loss in total transportation costs decreases for high values of $t$. Thus, if

$0 < \lambda < \mu/2$, total welfare is higher only for larger degrees of product differentiation. As the product differentiation parameter $t$ increases, the gain in the quality of service exceeds the additional costs. Furthermore, if $\mu/2 < \lambda < \mu$, congestion matters substantially and the level of the efficiency gain from prioritisation is high. This gain in quality of service always more than offsets the increase in transportation costs.

## 1.6 Investment Incentives

In a dynamic setting, the internet service provider can invest into the network capacity. Investment in capacity decreases congestion and increases the relative perceived quality differential of the content services. We denote by $C(\mu)$ the cost of investing in a network with capacity level $\mu$ with $C'(\mu) \geq 0$ and $C''(\mu) \geq 0$. The optimal investment level is determined at the point where the marginal profit (or benefit), $d\Pi_A(\mu)/d\mu$, equals the marginal cost of investment, $dC(\mu)/d\mu$ . The higher the marginal profit, the larger is the incentive to invest for the internet service provider. Profit under net neutrality is

$$\Pi_A^N = p_I^N(\mu) + p_A^N x_A^N \tag{1.28}$$

Using (1.10), firm $A$'s marginal profit of capacity investment under net neutrality is given by

$$\frac{d\Pi_A^N}{d\mu} = \frac{dp_I^N}{d\mu} = v \tag{1.29}$$

Under net neutrality perceived quality for all consumers is the same for all levels of capacity so that consumers' demand decisions in the content market and hence, equilibrium content prices and demand are independent of changes in capacity. Profits in the content market are, therefore, unaffected by investment. Yet investment in capacity speeds up the delivery of content for all consumers leading to an increase in their willingness to pay for internet access; hence the internet service provider can increase the subscription fee by $v$ per unit of additional capacity.

Profit under prioritisation is

$$\Pi_A^P = p_I^P(\mu) + p_A^P(\mu) x_A^P(\mu) \tag{1.30}$$

Using (1.17), the marginal profit of capacity investment under prioritisation is given by

$$\begin{aligned}\frac{d\Pi_A^P}{d\mu} &= \frac{dp_I^P}{d\mu} + \frac{d\Pi_{AC}^P}{d\mu} \\ &= [v(1-\lambda\frac{dx_A^P}{d\mu}) - t\frac{dx_A^P}{d\mu} - \frac{dp_A^P}{d\mu}] + [\frac{dp_A^P}{d\mu}x_A^P(\mu) + p_A^P(\mu)\frac{dx_A^P}{d\mu}] \qquad (1.31)\end{aligned}$$

We note that $dp_A^P/d\mu < 0$ and $dx_A^P/d\mu > 0$ due to the trade-off between demand and waiting time under prioritisation. As capacity increases, congestion becomes less important. Therefore, the negative externality of more consumers of content $A$ on waiting time is reduced. Under prioritisation perceived quality differs across consumers, so that an investment in capacity has not only an effect on the subscription fee but also on competition in the content market. The parameter $v$ measures the increase in the willingness to pay for access of a consumer buying prioritised content through the faster delivery of content, under the condition that demand is fixed. We next note that investment in capacity reduces congestion on the network. Less congestion increases the quality advantage of the content provider with priority, hence its demand increases which in turn increases congestion. Therefore, $-v\lambda(dx_A^P/d\mu)$ indicates the decrease in the willingness to pay of a consumer in the priority class due to increased congestion induced by additional demand. As investment changes the location of the marginal consumer, this investment in capacity increases the transportation cost of the marginal consumer who consumes prioritised content. This decreases the marginal consumer's willingness to pay for internet subscription, captured by $-t(dx_A^P/d\mu)$. Moreover, an increase in capacity leads to a decrease in the price of $A$ by the law of demand. This effect, denoted by $-(dp_A^P/d\mu)$ increases consumers' willingness to pay for access. The relative effect on investment in capacity on consumers' subscription fee depends on parameter values.

The second square bracket represents the effect of the capacity investment on firm $A$'s profit in the content market. There are two opposing effects. Capacity investment increases demand for content $A$ but at the same time decreases the price of content $A$. Therefore, the effect on profit depends on parameter values.

When evaluating whether incentives to invest in capacity are higher under prioritisation or under net neutrality, we consider the difference between them:

$$\begin{aligned}\Delta &= \frac{d\Pi_A^P}{d\mu} - \frac{d\Pi_A^N}{d\mu} \\ &= (p_A^P - v\lambda - t)\frac{dx_A^P}{d\mu} - (1 - x_A^P)\frac{dp_A^P}{d\mu}. \end{aligned} \tag{1.32}$$

**Proposition 1.6** *The impact of prioritisation on the investment incentives of the internet service provider depends on product differentiation: There exists a critical value $t_3^*$, with $t_3^* > \underline{t}$ such that $d\Pi_A^P/d\mu > d\Pi_A^N/d\mu$ only if $t > t_3^*$*

Whether the internet service provider has higher incentives to invest in capacity under prioritisation or net neutrality depends on the relative magnitudes of the indirect effect of investment through changes in market shares and the indirect effect of investment through changes in the price of content. When product differentiation $t$ is sufficiently high, the indirect effects through changes in market shares become negligible as $dx_A^P/d\mu$ is decreasing in $t$ and approaching zero. The contents become differentiated enough so that demand is not affected by an increase in capacity. Then investment incentives under prioritisation are higher than under net neutrality as the total indirect effect through changes in the content price is positive and large for high $t$.

## 1.7 Conclusion

This paper provides an economic analysis of a net neutrality regulation when the internet service provider is vertically integrated into content provision. We have investigated the effect of such a regulation on the price competition of content providers, on social welfare and on the internet service provider's incentive to invest in its network. We have considered a situation in which consumers pay directly to the content providers for content.

Compared to net neutrality, we find that prioritisation generally has positive short-run efficiency effects. The integrated internet service provider has an incentive to favour vertically affiliated content over unaffiliated rival services. This is, however, not always detrimental to the rival content provider. Consumer surplus is higher, while the effect on social welfare depends on congestion intensity and the degree of product differentiation. In the long run, prioritisation does not always guarantee dynamic efficiency, as investment incentives might be lower when the degree of product differentiation is small.

Future research can relax the assumption of full market coverage. The internet service provider might find it profitable to increase the subscription fee such that some consumers are excluded from the market. Further, one can look at asymmetries in the content market. It might be interesting to see how the results change depending on whether the integrated firm is more or less efficient. Another important extension is to explore the effects of net neutrality with competition in the internet service market. Competition is said to mitigate the problems associated with a violation of net neutrality.

## 1.8 Appendix A

**Proof of Proposition 1.1** By (1.8) and (1.15), the difference in equilibrium demands for content $A$ is given by

$$\Delta x_A = x_A^P - x_A^N = \frac{v\lambda(2\mu - \lambda)}{6(2\mu t + v\lambda^2)} > 0 \tag{1.33}$$

which always holds under Assumption 1.1. This implies that $x_A^P > 1/2$.

Since we assume that the content market is covered, by (1.33) it must also hold that

$$\Delta x_B = x_B^P - x_B^N < 0. \tag{1.34}$$

This proves that $x_B^P < x_B^N = 1/2 = x_A^N < x_A^P$. ■

**Proof of Lemma 1.1** We first show statement (i). As waiting time is the same for all consumers under net neutrality, total waiting time in the system, denoted by $W^N$, is

$$W^N = \frac{1}{\mu - \lambda}. \tag{1.35}$$

The total waiting time under prioritization, denoted by $W^P$, is

$$\begin{aligned}
W^P &= x_A^P w_A^P + (1 - x_A^P) w_B^P \\
&= x_A^P \frac{1}{\mu - \lambda x_A^P} + (1 - x_A^P) \frac{\mu}{(\mu - \lambda)(\mu - \lambda x_A^P)} \\
&= \frac{x_A^P(\mu - \lambda) + (1 - x_A^P)\mu}{(\mu - \lambda)(\mu - \lambda x_A^P)} \\
&= \frac{\mu - \lambda x_A^P}{(\mu - \lambda)(\mu - \lambda x_A^P)} \\
&= \frac{1}{\mu - \lambda} = W^N \qquad (1.36)
\end{aligned}$$

We next show statement (ii). Total perceived quality of service under net neutrality, denoted by $V^N$, is

$$\begin{aligned}
V^N &= x_A^N \frac{v}{w_A^N} + (1 - x_A^N) \frac{v}{w_B^N} \\
&= x_A^N v(\mu - \lambda) + (1 - x_A^N) v(\mu - \lambda) \\
&= v(\mu - \lambda). \qquad (1.37)
\end{aligned}$$

Total perceived quality of service under prioritization, denoted by $V^P$, is

$$\begin{aligned}
V^P &= x_A^P \frac{v}{w_A^P} + (1 - x_A^P) \frac{v}{w_B^P} \\
&= x_A^P v(\mu - \lambda x_A^P) + (1 - x_A^P) \frac{v(\mu - \lambda x_A^P)}{\mu} \\
&= \frac{v\mu^2 - v\lambda\mu + v\lambda^2 x_A^P - v\lambda^2 (x_A^P)^2}{\mu} \\
&= v(\mu - \lambda) + \frac{v\lambda^2 x_A^P}{\mu}(1 - x_A^P) \qquad (1.38)
\end{aligned}$$

From (1.37) and (1.38) we can easily derive that $V^P > V^N$ because $(1 - x_A^P) > 0$.
■

**Proof of Lemma 1.2** Demand of content $A$, $x_A^P$, is given by (1.15). Taking the derivative with respect to $t$, we obtain

$$\frac{\partial x_A^P}{\partial t} = -\frac{v\lambda\mu(2\mu - \lambda)}{3(2\mu t + \lambda^2 v)^2} < 0 \qquad (1.39)$$

Equation (1.39) is clearly negative for $\mu > \lambda$ so that demand for content $A$ is decreasing in $t$. From $x_B^P = 1 - x_A^P$, it follows directly that demand for content $B$ is increasing in $t$.

From (1.4) and (1.5), we derive the difference in perceived quality of service.

$$\begin{aligned} \Delta QoS &= \frac{v}{w_A^P} - \frac{v}{w_B^P} \\ &= v(\mu - \lambda x_A^P) - \frac{v(\mu - \lambda)(\mu - \lambda x_A^P)}{\mu} \\ &= \frac{v(\mu - \lambda x_A^P)}{\mu} \end{aligned} \tag{1.40}$$

Taking the derivative of (1.40) with respect to $x_A^P$, we obtain

$$\frac{\partial \Delta QoS}{\partial x_A^P} = -\frac{v\lambda^2}{\mu} < 0 \tag{1.41}$$

The difference in perceived quality of service is decreasing in the demand of content $A$. As $x_A^P$ is decreasing in the differentiation parameter, $t$, it follows from (1.41) that perceived quality of service is increasing in $t$. ■

**Proof of Proposition 1.2** First, we show that (i) holds. By (1.13) and (1.14), the difference in content prices under prioritisation is

$$\begin{aligned} \Delta p_{AB}^P &= p_A^P - p_B^P \\ &= \frac{v\lambda(2\mu - \lambda)}{3\mu} \end{aligned} \tag{1.42}$$

By Assumption 1.1, (1.42) is strictly positive.

Next, we show statements (ii) and (iii). By (1.9) and (1.16), the difference in internet subscription fees is given by

$$\begin{aligned} \Delta p_I &= p_I^P - p_I^N \\ &= -\frac{v\lambda^2(3\mu t + 2v\mu^2 + 2v\lambda^2 - 2v\lambda\mu)}{6\mu(2\mu t + v\lambda^2)} \end{aligned} \tag{1.43}$$

We now have to prove that $\Delta p_I < 0$. This is equivalent to

$$3\mu t + 2v\mu^2 + 2v\lambda^2 - 2v\lambda\mu = 3\mu t + 2v(\mu^2 + \lambda^2 - \lambda\mu) > 0. \tag{1.44}$$

Since $\mu^2 + \lambda^2 > \lambda\mu$, the inequality in (1.44) must hold, and therefore $\Delta p_I$ is always negative. This proves that $p_I^P < p_I^N$.

We consider the difference in equilibrium content prices to consumers of content $A$ and content $B$ as we move away from net neutrality to a prioritisation scheme. That is

$$\Delta p_A = p_A^P - p_A^N = \frac{v\lambda(\mu + \lambda)}{3\mu} \tag{1.45}$$

$$\Delta p_B = p_B^P - p_B^N = -\frac{v\lambda(\mu - 2\lambda)}{3\mu} \tag{1.46}$$

Equation (1.45) is always positive while equation (1.46) is negative for $0 < \lambda < \mu/2$ and positive for $\mu/2 < \lambda < \mu$. This proves that $p_A^P > p_A^N$. Moreover it shows that $p_B^P < p_B^N$ if $0 < \lambda < \mu/2$ and $p_B^P > p_B^N$ if $\mu/2 < \lambda < \mu$. This concludes the proof of Proposition 1.2. ■

**Proof of Proposition 1.3** We first prove statement (i). From Propositions 1.1 and 1.2, it follows directly that firm $A$'s profit in the content market is greater under prioritisation , that is $\Pi_{AC}^P > \Pi_{AC}^N$ and firm $A$'s profit from internet access is lower under prioritisation, hence $\Pi_{AI}^P < \Pi_{AI}^N$. The total impact on $A$'s profit, therefore, depends on the magnitude of these opposing effects.

By (1.10) and (1.17), the difference in total profits of firm $A$ is

$$\Delta \Pi_A = \Pi_A^P - \Pi_A^N = \frac{v\lambda(2\mu - \lambda)(3\mu t + 2v\lambda^2 - v\lambda\mu)}{9\mu(2\mu t + v\lambda^2)} > 0 \tag{1.47}$$

Indeed this inequality must hold because $2\mu - \lambda > 0$ by Assumption 1.1 and $3\mu t + 2v\lambda^2 - v\lambda\mu > 0$ by Assumption 1.2. This proves that the profit for the integrated firm $A$ is higher under prioritisation; hence, $\Pi_A^P > \Pi_A^N$.

We now prove statement (ii). First, consider statement (a) if $\lambda \leq \mu/2$. It follows directly from Propositions 1.1 and 1.2 that the difference in profits for firm $B$ is negative because $p_B^P < p_B^N$ and $x_B^P < x_B^N$.

Considering next $\mu/2 < \lambda < \mu$, it depends on the relative magnitudes of $p_B^P$ and $x_B^P$ whether profit is higher or lower under prioritisation. From (1.11) and (1.18), the difference in equilibrium profits of firm $B$ is

$$\Delta \Pi_B = \Pi_B^P - \Pi_B^N = \frac{v\lambda(-12\mu^2 t + 8v\lambda^3 - 8v\lambda^2\mu + \lambda\mu(15t + 2v\mu))}{18\mu(2\mu t + v\lambda^2)} \tag{1.48}$$

For profit to be higher under prioritisation, the numerator in the RHS of equation (1.48) has to be greater than zero. This is the case if

$$\begin{aligned} -12\mu^2 t + 8v\lambda^3 - 8v\lambda^2\mu + \lambda\mu(15t + 2v\mu) &= \\ 2v\lambda(4\lambda^2 - 4\lambda\mu + \mu^2) + 3\mu t(5\lambda - 4\mu) &= \\ 2v\lambda(\mu - 2\lambda)^2 + 3\mu t(5\lambda - 4\mu) &> 0 \end{aligned} \tag{1.49}$$

The first term of the LHS of (1.49) is always positive. The second term of the LHS of (1.49) is positive if $(5\lambda - 4\mu) > 0$. This is true for $4\mu/5 < \lambda < \mu$. Under this condition, the profit of firm $B$ is higher under prioritisation. This proves statement (c).

It remains to consider statement (b) if $\mu/2 < \lambda < 4\mu/5$. Thus, $5\lambda - 4\mu$ is now negative. Rearranging the LHS of (1.49) we obtain the critical value $t_1^*$ for which the LHS of (1.49) is negative:

$$t < t_1^* \equiv -\frac{2v\lambda(\mu - 2\lambda)^2}{3\mu(5\lambda - 4\mu)}. \tag{1.50}$$

To be a feasible solution $t_1^*$ has to be greater than $\underline{t}$; otherwise profit under prioritisation is always smaller if $\mu/2 < \lambda < 4\mu/5$. Therefore, we have to check that $t_1^* > \underline{t}$, that is

$$t_1^* = -\frac{2v\lambda(\mu - 2\lambda)^2}{3\mu(5\lambda - 4\mu)} > \underline{t} \tag{1.51}$$

which is true under Assumption 1.1. Hence, there are some values of $t$ such that $t_1^* > \underline{t}$ and profit is higher under prioritisation in the given parameter range. This then concludes the proof of Proposition 1.3. ■

**Proof of Proposition 1.4** From (1.20), we derive

$$\frac{\partial CS^j}{\partial x_A^j} = 2tx_A^j - t = t(2x_A^j - 1), \tag{1.52}$$

which is positive for $x_A^j > 1/2$. Therefore, consumer surplus is increasing in $x_A^j$ if $x_A^j > 1/2$. As $x_A^P > x_A^N = 1/2$, consumer surplus is higher under prioritisation, that is $CS^P > CS^N$. ■

**Proof of Proposition 1.5** Given (2.92) and (1.26), we derive the difference in total welfare under the two alternatives:

$$\begin{aligned}\Delta TS &= TS^P - TS^N \\ &= \frac{v^2\lambda^2(-4v\mu^3 t + 8v^2\lambda^4 + v\lambda^2\mu(35t + 4v\lambda) + 4\mu^2(9t^2 + v\lambda t - v^2\lambda^2))}{36\mu(2\mu t + v\lambda^2)^2}\end{aligned} \tag{1.53}$$

For total welfare to be higher under prioritisation we look at the sign of the large bracket in numerator of the RHS of equation (1.53). Rearranging this term yields

$$\phi_1(t) \equiv 36\mu^2 t^2 + v\mu t(-2\mu + 7\lambda)(2\mu + 5\lambda) + 4v^2\lambda^2(2\lambda - \mu)(\lambda + \mu) \tag{1.54}$$

For this to be positive for sure, both $(-2\mu + 7\lambda)$ and $(2\lambda - \mu)$ have to be positive. This is satisfied if $\mu/2 \leq \lambda < \mu$. This proves statement (b).

Next we prove statement (a) if $\lambda < \mu/2$. By collecting terms in $t$, $\phi_1(t)$ is a quadratic function of $t$. First, we determine the sign of $\phi_1(\underline{t})$, which is

$$\phi_1(\underline{t}) = \frac{v^2\lambda(\lambda - 2\mu)^2(2\lambda - \mu)}{3} < 0 \tag{1.55}$$

for $\lambda < \mu/2$. Total welfare is lower under prioritisation if $t = \underline{t}$. Therefore, we now look at the derivatives $\phi_1'(t)$ and $\phi_1''(t)$ to determine the shape of the function $\phi_1(t)$.

$$\phi_1'(t) = 72\mu^2 t + v\lambda(7\lambda - 2\mu)(5\lambda + 2\mu) \tag{1.56}$$

$$\phi_1''(t) = 72\mu^2 > 0 \tag{1.57}$$

Since $\phi_1(t)$ is a quadratic and convex function and $\phi_1(\underline{t}) < 0$, there exists a unique $t_2^*$ such that $\phi_1(t_2^*) = 0$. If $t < t_2^*$, then $\phi_1(t) < 0$ and if $t > t_2^*$, then $\phi_1(t) > 0$. The sign of expression(1.54) and hence the effect of prioritisation on total welfare is positive under the condition $\lambda < \mu/2$ provided that $t$ is large enough, that is $t > t_2^*$. This then concludes the proof of Proposition 1.5. ■

**Proof of Proposition 1.6** From (2.92) and (1.26) we obtain the difference in the marginal benefits

$$\Delta = \frac{d\Pi_A^P}{d\mu} - \frac{d\Pi_A^N}{d\mu}$$
$$= (p_A^P - v\lambda - t)\frac{dx_A^P}{d\mu} - (1 - x_A^P)\frac{dp_A^P}{d\mu}. \tag{1.58}$$

Next we derive the signs of the derivatives $(dx_A^P/d\mu)$ and $(dp_A^P/d\mu)$:

$$\frac{dx_A^P}{d\mu} = \frac{v\lambda^2(t+v\lambda)}{3(2\mu t + v\lambda^2)^2} > 0 \tag{1.59}$$

$$\frac{dp_A^P}{d\mu} = -\frac{v\lambda^2}{3\mu^2} < 0 \tag{1.60}$$

It is easy to see that $(dx_A^P/d\mu) > 0$ and $(dp_A^P/d\mu) < 0$. Using (1.13) as well as the LHS of (1.59) and(1.60) we can write the difference in (1.58) as

$$\Delta = \frac{2v\lambda^2(3\mu^2t^2 + 2v\lambda\mu t(2\lambda - \mu) + v^2\lambda^2(\lambda^2 - \mu^2))}{9\mu^2(2\mu t + v\lambda^2)^2} \tag{1.61}$$

For investment incentives to be higher under prioritisation we look at the sign of the large bracket in numerator of the RHS of (1.53). Let us define

$$\phi_2(t) = 3\mu^2t^2 + 2v\lambda\mu t(2\lambda - \mu) + v^2\lambda^2(\lambda^2 - \mu^2) \tag{1.62}$$

which is a quadratic function in $t$. We first determine the sign of $\phi_2(\underline{t})$, which is

$$\phi_2(\underline{t}) = -\frac{v^2\lambda^2(\lambda - 2\mu)^2}{3} < 0 \tag{1.63}$$

by Assumption 1.1. Investment incentives are lower under prioritisation if $t = \underline{t}$. We now look at the derivatives $\phi_2'(t)$ and $\phi_2''(t)$ to determine the shape of the function $\phi_2(t)$.

$$\phi_2'(t) = 6\mu^2t + 2v\lambda\mu(2\lambda - \mu) \tag{1.64}$$

$$\phi_2''(t) = 6\mu^2 > 0 \tag{1.65}$$

Under Assumption 1.1, $\phi_2'(t) >$ for all $\lambda$. Since $\phi_2(t)$ is a quadratic and convex function and $\phi_2(\underline{t}) < 0$, there exists a unique $t_3^* > \underline{t}$ such that $\phi_2(t_3^*) = 0$. If $t < t_3^*$, then $\phi_2(t) < 0$ and if $t > t_3^*$, then $\phi_2(t) > 0$. The sign of expression (1.62) and hence the effect of prioritisation on the investment incentives is positive provided that $t$ is large enough, that is $t > t_3^*$. This then concludes the proof of Proposition 1.6. ■

## 1.9 Appendix B: Queuing Theory - Waiting Time in a System

Queueing theory is the mathematical way of studying waiting times in a system. The M/M/1 queuing model has a single server and both the arrival rate ($\lambda$) and the service rate ($\mu$) are exponentially distributed. Arrival and service rates are independent and identically distributed. More specifically, consumers arrive according to a Possion process at an average rate of $\lambda$ per time period. On average one consumer appears every $1/\lambda$ time periods. Moreover, there is a single server with an exponential service rate of $\mu$ consumers per time period. To ensure that the queue will not grow infinitely, it must be $\lambda < \mu$.

Related to the transmission of data packets in the internet, $\lambda$ refers to the rate of packets that arriver per time period and measures the expected capacity demand. $\mu$ packets is the available service capacity, i.e. bandwidth, that the server can serve per time period.

Traffic intensity $\rho$ is defined by the ratio of arrival rate to service rate, hence

$$\rho = \frac{\text{capacity demand}}{\text{available capacity}} = \frac{\lambda}{\mu}.$$

It measures congestion in the system. As the traffic intensity increases the amount of congestion increases and thereby consumers have longer waiting times in the system.

Consumers move from the queue into service on a first-come- first- served principle. The consumer that has been waiting the longest is served first. The expected number of consumers in the entire system is

$$L = \frac{\rho}{(1-\rho)} = \frac{\lambda}{\mu - \lambda}.$$

By Little's law (1961) the average number of consumers in the system $L$ is the effective arrival rate $\lambda$ times the average time that a consumer spends in the system $W$; put simply $L = \lambda W$. As a result, waiting time spent in the entire system is

$$W = \frac{1}{\mu - \lambda}.$$

Under a priority scheme, consumers with priority are served first. We consider preemptive queues where a job in service without priority can be interrupted by one with priority. Hence, the priority class has absolute priority over the non-priority class. Therefore, for consumers with priority the consumers without priority do not exist. Hence we immediately have the expected waiting time of the priority class

$$W_P = \frac{1}{\mu - \lambda_P}$$

given an arrival rate of $\lambda_P$ for the priority consumers. Once there are no more consumers with priority in the system, the server proceeds with serving the non-priority consumers. Expected waiting time without priority is given by

$$W_{NP} = \frac{\mu}{\mu - \lambda} W_P = \frac{\mu}{(\mu - \lambda)(\mu - \lambda_P)}$$

where $\lambda$ is the sum of the arrival rates from priority and non-priority consumers.

# Chapter 2

# Asymmetric Access Regulation and Broadband Investment of Competing Network Providers

## 2.1 Introduction

High-speed internet is a crucial driver of a country's competitiveness and its economic development. The European Commission has recognized the significance of broadband development and its importance to economic growth. Therefore, significant investments are required to reap the benefits and keep up with international markets. By 2020 all European households should have access to such Next Generation Access (NGA) networks. Despite these ambitious political objectives, the willing to invest is still very low among network operators. For example, in Germany, the share of fiber connections is just around 1% of all broadband connections (European Commission, 2015). Hence, the targets are unlikely to be met unless there is substantial investment in infrastructure in the near future. The question arises which regulatory environment encourages investment but also enables competition so that affordable high-speed internet is available for everyone.

The aim of this chapter is to investigate the role of network competition in the promotion of broadband deployment. We develop a theoretical model that explores how asymmetric access regulation influences the incentives of infrastructure providers to invest in their networks. In contrast to most of the literature, we study a situation in which different access technologies co-exist. Namely, we consider an incumbent telecommunication network and a competing network provider, where only the incumbent telecom operator is subject to regulation. We then study competition and welfare effects as well as investment incentives under different regulatory regimes and analyze how an additional, but unregulated, network provider influences the outcome.

Nowadays, competition is not only driven by retail entry due to access regulation but also by alternative network operators due to technological convergence. Different physical transmission channels provide essentially the same kind of services and therefore stand in competition with each other. It is, for example, possible to access broadband internet not only via incumbent telecommunication networks but also via cable TV networks. Under current access regulation, there exists a regulatory asymmetry between these firms. The incumbent telecom operator is required to provide access to its network at a regulated price, whereas a competing, alternative network operator is not subject to such an access regulation. For example, in many European countries, only Digital Subscriber Line (DSL) providers must provide access to their network, whereas cable operators remain unregulated. It is, therefore, interesting to theoretically assess whether the presence of a competitive access infrastructure provides sufficient investment incentives.

We compare three regulatory approaches, which are supported by the European Commission, in terms of investment incentives and from a welfare perspective. First, we consider access regulation, where the regulator commits to an access charge before investment takes place. Second, we analyze regulatory holiday such that ex-ante access obligations are at least temporarily removed for the incumbent operator and thus, there is no regulation. Third, we also consider investment sharing between the incumbent and the access-seeking entrant. In all these scenarios we assume that the competing vertically integrated broadband provider cannot sell access to retail competitors due to technical constraints.

Comparing the investment incentives of the network operators, we find that the incumbent invests more than the cable operator without access regulation, while the cable operator invests more than the incumbent with access regulation.

Moreover, with investment sharing the incumbent and the entrant invest more than the cable operator. Indeed, when the incumbent is mandated to provide access to its network, its quality investments also benefits the entrant that uses its network. As a consequence, it has lower incentives to invest in quality. On the contrary, when the incumbent is not regulated and therefore free to choose the access price, we find that, in contrast to Foros (2004), the incumbent never forecloses the entrant in the retail market. Even though the entrant benefits from its investment, the incumbent has higher incentives to invest because it can obtain sacrifice some retail revenue in return for additional access revenue. Investment sharing with the entrant can even improve the investment incentives of the incumbent.

Regarding consumer surplus and social welfare, the results show that investment sharing dominates regulation and no regulation. Consumers as a whole gain from investment sharing because more consumers benefit from higher network quality and the retail market is more competitive. Regulation is better than no regulation from a consumer perspective, but also from a total welfare perspective for a large range of the cost parameter. No regulation provides overall the highest investment incentives but leads to the least competitive retail market outcome. Thus, investment sharing can be an effective means of relaxing ex-ante regulation.

The remainder of this chapter is organized as follows. Section 2.2 presents the related literature. Section 2.3 presents the theoretical model. Sections 2.4, 2.5 and 2.6 identify the equilibria and investment incentives for the three alternative regulatory schemes, namely access regulation, no regulation and co-investment. In Section 2.7 we compare these different regimes and derive welfare effects. Section 2.8 concludes. The proofs of all formal results are relegated to Appendix 2.9.

## 2.2 Related Literature

The present chapter contributes to the extensive economic literature on the effects of access regulation on investment incentives, which is reviewed by Cambini and Jiang (2009). A central question is whether and how to regulate infrastructure bottlenecks in order to secure retail competition as well as to promote infrastructure investment. Traditionally, telecommunication networks have been viewed as natural monopolies. Therefore, in contrast to our setting, access regulation has often been studied in the framework of a single, vertically integrated, infrastructure provider and a potential entrant. In the theoretical literature, different duopoly model are considered in which either only the incumbent invests (e.g. Brito et al. (2010), Foros (2004), Nitsche and Wiethaus (2011), Cambini and Silvestri (2012)), or only the entrant invests (Avenali et al. (2010)), or both have the option to invest (e.g. Manenti and Sciala (2013), Brito et al. (2012)). Access regulation is successful in encouraging service-based competition at the retail level, but it is claimed that this approach does not promote infrastructure investment (e.g. Bourreau et al. (2012), Brito et al. (2012)). These findings are also supported by the empirical literature (e.g. Grajek and Röller (2012),Briglauer (2015)).

Our model builds upon several papers that have critically discussed different regulatory alternatives in the context of static and dynamic efficiency when only the incumbent invests. Foros (2004) examines the effect of access regulation on the investment incentives of the incumbent and to foreclose the entrant. He uses a very similar set-up to ours and shows that access regulation with no commitment by the regulator leads to lower investment than without regulation. Moreover, without regulation, the incumbent accommodates the entrant only if the entrant has a higher ability to use the improved quality. In contrast, we show that with network competition foreclosure never occurs.

Given an access monopoly, Nitsche and Wiethaus (2011) compare investment incentives and competition for different regulatory regimes under demand uncertainty. They support the hypothesis that cost-based regulation leads to the smallest extent of quality investment and consumer welfare. In addition, co-investment leads to the highest consumer welfare even though regulatory holidays and access charges based on fully distributed costs lead to more investment than co-investment. Compared to stand-alone investment under cost-based access regulation, co-investment is claimed to stimulate investment in quality and finally promote social welfare (Nitsche and Wiethaus (2011), Cambini and Silvestri (2013)). Cambini and Silvestri (2012) use a similar model to Nitsche and Wiethaus (2011), but analyze a dynamic framework with vertically differentiated firms. They find similar results regarding the benefits of co-investment agreements.

Cambini and Silvestri (2013) examine the broadband market under three different alternatives of investment; namely, no investment sharing with a cost-based access charge, investment sharing without side payments and joint investment with side payments. They find that joint investment with side payments leads to the greatest incentives to invest. Despite the highest level of quality, the joint venture may soften competition because the firms may collude to set above-cost side payments. As a result, the joint investment with collusion on side payments and the cost based access regulation regime with less investment incentives both yield lower consumer surplus and social welfare than the basic investment sharing.

All of these studies consider a monopolistic infrastructure provider and a potential entrant. However, nowadays there is a shift towards facility-based competition from different technologies. Therefore, we extend this strand of the literature by incorporating a competing network provider to describe how the presence of such an unregulated, facility-based competitor alters the implications of different regulatory scenarios. We thereby supplement the existing literature by showing that the general results depending on investment in regulated broadband markets hold even when there is competition between network operators.

Ordover and Shaffer (2007), Brito and Pereira (2010) as well as Bourreau et al. (2011) are among the first to model two competing, vertically integrated network operators and one potential retail entrant. They consider a setting without regulation and allow both network operators to decide whether to grant access to their networks voluntarily. They find that both firms want to provide access to their network and that competition between network providers may induce access being priced at marginal cost. In comparison to our model, they neither analyse investment incentives nor do they account for possible regulation of one or both network operators.

To our knowledge, there is only one relevant study that deals with two network operators, of which only one is mandated to provides access to an entrant and the other one deliberately does not grant access to its network. Kocsis (2013) analyses such a setting of asymmetric access regulation. She assumes that the cable operator initially has a higher quality of service. She then only allows the incumbent to invest in quality upgrades. She finds that access revenues compensates the incumbent for offering lower quality and therefore hamper its investment. A high access price forecloses the entrant from the market. In such a situation, the incumbent invests more to be more competitive towards the high quality competitor.

Another paper which is closely related to ours is that of Ribeiro (2016). Differently from our model, he considers three independent market operators, which can all invest in quality upgrades. His focus is thereby on investment sharing agreements between two or all three market participants.

## 2.3 The Model

We study broadband access regulation in a market with three firms. More specifically, we consider two firms, an incumbent telecom operator ($I$) and a cable operator ($C$), who own an internet infrastructure and also sell internet services. The internet infrastructure provides a necessary input for the retail service. The third firm, the retail entrant (E), can obtain access to the infrastructure of firm $I$. Using the network of firm $I$, the entrant can then compete with the integrated network operators for retail services.

The two vertically integrated network operators invest in their infrastructure to upgrade to next-generation access (NGA) networks. Deploying a NGA network of quality $x_i$ requires a quadratic investment cost $c(x_i) = kx_i^2/2$, with $i = I, E$ and $k > 0$. Hence, the cost function is assumed to be increasing and convex in the investment level. NGA investment is continuous where higher values of $x_i$ reflect a larger geographic coverage or closeness to the consumers' premises, which translates into faster broadband speeds.

The demand structure is adapted from Katz and Shapiro (1985). Consumers have a unit demand for a single subscription and can buy internet services at a price $p_i$ for $i \in \{I, C, E\}$. They differ in their willingness to pay for the basic service $\tau$, but value network quality the same. Hence, the utility of a consumer of type $\tau$ buying internet subscription from firm $i$ is

$$U_i = \tau + x_i - p_i, \tag{2.1}$$

where $\tau$ is uniformly distributed in $[\underline{v}, v]$ and $v > 0$. The parameter $\underline{v}$ is sufficiently small so that not all consumers enter the market. Without investments, consumers perceive the services as perfect substitutes. However, with investments, the valuation of the service increases for all consumers by $x_i$. As the entrant does not own a network, but either buys access from firm $I$ or shares the investment costs with firm $I$, we set $x_E = x_I$.

A consumer of type $\tau$ then buys from firm $i$ if $U_i > U_j$. All firms are active in the market as long as their quality-adjusted prices are the same:

$$p_I - x_I = p_C - x_C = p_E - x_E = P \tag{2.2}$$

Consumers with $\tau \geq P$ buy an internet subscription so that there are $v - P$ active consumers due to the uniform distribution. The three firms offer the total quantity $Q = q_I + q_C + q_E$, and prices must ensure that $Q = v - P$. Thus, the inverse demand functions are:

$$p_I = v + x_I - q_I - q_C - q_E \tag{2.3}$$

$$p_C = v + x_C - q_I - q_C - q_E \tag{2.4}$$

$$p_E = v + x_I - q_I - q_C - q_E \tag{2.5}$$

For simplicity, all firms have identical marginal costs equal to zero. To reflect the current situation in many European countries, where the cable operators do not open their networks to service-based competitors, we assume that there are either technical constraints or high sunk costs for the cable operator such that it never wants to grant access to its cable network. Thus, the incumbent's infrastructure is available to the retail entrant if the entrant pays an access fee $a$ per user to firm $I$. This study examines competition effects and investment incentives regarding different regulatory approaches. In the following, we thereby focus on three different cases: (i) regulation (R), (ii) no regulation (N) and (iii) co-investment (S). With regulation, the regulator sets the access fee, whereby without regulation, the access fee is freely chosen by the incumbent. The incumbent, in contrast to the cable operator, may derive revenues not only from selling subscriptions to consumers but also from wholesale access. However, the incumbent shares the benefits of its investment with the entrant but bears the whole cost of its investment alone.

Hence, profits under regulation and no regulation with the wholesale entrant are

$$\Pi_I = p_I q_I + a q_E - k x_I^2/2 \tag{2.6}$$
$$\Pi_C = p_C q_C - k x_C^2/2 \tag{2.7}$$
$$\Pi_E = (p_E - a) q_E. \tag{2.8}$$

Whenever the access fee is higher than an exclusionary level $\bar{a}$, i.e. $a \geq \bar{a}$, the entrant is foreclosed from the market, and the two network operators compete in a retail duopoly. In this duopoly equilibrium, the profits are

$$\Pi_I^f = p_I q_I - k x_I^2/2 \tag{2.9}$$
$$\Pi_C^f = p_C q_C - k x_C^2/2 \tag{2.10}$$
$$\Pi_E^f = 0, \tag{2.11}$$

where the superscript $f$ stands for an equilibrium with foreclosure.

In the case of co-investment, we assume that the incumbent and the entrant share the investment costs equally. In return for sharing the investment cost, the incumbent grants the entrant access to their network free of charge, i.e. $a = 0$. Profits are then

$$\Pi_I^S = p_I q_I - \frac{1}{2}\frac{k}{2} x_I^2 \tag{2.12}$$
$$\Pi_C^S = p_C q_C - \frac{k}{2} x_C^2 \tag{2.13}$$
$$\Pi_E^S = p_E q_E - \frac{1}{2}\frac{k}{2} x_I^2 \tag{2.14}$$

In all scenarios, consumer surplus is given by

$$CS = \frac{(q_I + q_C + q_E)^2}{2} \tag{2.15}$$

and social welfare is given by the sum of consumer surplus and profits

$$TS = CS + \Pi_I + \Pi_C + \Pi_E \tag{2.16}$$

The following assumptions are made for the model.

**Assumption 2.1** *(i)* $k > 2$*; (ii)* $a \geq 0$

The first assumption guarantees interior solutions for each profit maximizing investment problem as well as the regulator's welfare maximization problem; i.e. all profit functions and the welfare function are concave. Moreover, it also assures that investments by the firms are non-negative. We further assume that the access charge cannot be lower than the marginal cost of providing access, which we normalize to zero, to rule out the possibility of margin squeeze.

## 2.4 Regulation

We first characterize the equilibrium with access regulation. Under regulation, the incumbent network operator is required to provide access to the entrant at a fixed access fee set by the regulator. We assume that the regulator credibly commits to the access fee before investment takes place. Therefore, under regulation the regulator first sets the access charge, $a^R$, for the broadband network. Second, firms $I$ and $C$ invest in their infrastructure quality and finally, all active firms compete in the retail market. We solve for the equilibrium by backward induction.

**Retail competition:** In the last stage, all active firms compete simultaneously in the retail market given the infrastructure investment and the access fee. We first consider the situation when the entrant obtains access to the network of the incumbent. Then all three service providers, $I$, $C$, and $E$, compete for consumers in the retail market. Firms choose their retail quantities by maximizing their profits (2.6)-(2.7).

By solving the system of first-order conditions, we calculate the equilibrium retail quantities as functions of the access fee and the investment levels of the two network operators:

$$q_I^R(x_I, x_C, a) = \frac{1}{4}(v + a + 2x_I - x_C) \tag{2.17}$$

$$q_C^R(x_I, x_C, a) = \frac{1}{4}(v + a - 2x_I + 3x_C) \tag{2.18}$$

$$q_E^R(x_I, x_C, a) = \frac{1}{4}(v - 3a + 2x_I - x_C). \tag{2.19}$$

As we can see, the equilibrium is not symmetric. Both the access fee as well as the investments in infrastructure quality influence the retail market outcome.

As the access fee is a cost to the entrant, it reduces the competitiveness of the entrant and increases the competitiveness of the network operators. Therefore, the entrant's quantity is decreasing in the access fee, and the network operators' quantities are increasing in the access fee. The firms that provide broadband access with a higher quality can offer higher retail market quantities. The network operators' quantities increase in their own quality and decrease in the quality of their network competitor. As the entrant uses the incumbent's network, an increase in the incumbent's network quality also benefits the entrant, thus its quantity is also rising in the incumbent's investment and decreasing in the cable operator's investment.

This retail equilibrium will only prevail if the entrant wants to buy access from the incumbent and thereby obtains a non-negative profit. That is the case if $q_E^R(x_I, x_C, a) \geq 0$. The higher the access fee, the more likely that the entrant will be excluded from the market. Hence, the exclusionary level of the access fee is

$$\bar{a} \equiv \frac{1}{3}(v + 2x_I - x_C). \tag{2.20}$$

The exclusionary access fee is increasing in the incumbent's investment and decreasing in the cable operator's investment. The entrant enters the market as long as $a \leq \bar{a}$. Thus, if the access fee is higher than the exclusionary level, the two network operators compete in a retail duopoly. Then, the retail market quantities depend only on the investment in broadband quality

$$q_I^{Rf}(x_I, x_C) = \frac{1}{3}(v + 2x_I - x_C) \tag{2.21}$$

$$q_C^{Rf}(x_I, x_C) = \frac{1}{3}(v - x_I + 2x_C) \tag{2.22}$$

$$q_E^{Rf}(x_I, x_C) = 0. \tag{2.23}$$

Quantities are increasing in own investment levels and decreasing in competitor's investment. Moreover, we note that firms are symmetric when the entrant is foreclosed from the market.

Substituting the optimal retail quantities into the profit functions, we obtain profits as functions of the investment levels and the access fee with wholesale access

$$\Pi_I^R(x_I, x_C, a) = \frac{1}{16}((v + 2x_I - x_C)^2 + 6a(v + 2x_I - x_C) - 11a^2) - \frac{k}{2}x_I^2 \quad (2.24)$$
$$\Pi_C^R(x_I, x_C, a) = \frac{1}{16}(v + a - 2x_I + 3x_C)^2 - \frac{k}{2}x_C^2 \quad (2.25)$$
$$\Pi_E^R(x_I, x_C, a) = \frac{1}{16}(3a - v - 2x_I + x_C)^2 \quad (2.26)$$

and without wholesale access

$$\Pi_I^{Rf}(x_I, x_C) = \frac{1}{9}(v + 2x_I - x_C)^2 - \frac{k}{2}x_I^2 \quad (2.27)$$
$$\Pi_C^{Rf}(x_I, x_C) = \frac{1}{9}(v - x_I + 2x_C)^2 - \frac{k}{2}x_C^2 \quad (2.28)$$
$$\Pi_E^{Rf}(x_I, x_C) = 0 \quad (2.29)$$

**Investment decision:** Given the access fee set by the regulator, in the second stage, the network operators invest in network quality. Network operators maximize their profits, (2.24) and (2.25) with respect to their investment $x_i$. From the first-order conditions $\partial\Pi_i^R/\partial x_i = 0$ we obtain the best response functions:

$$R_I^R(x_C) = \frac{v + 3a - x_C}{2(2k - 1)} \quad (2.30)$$
$$R_C^R(x_I) = \frac{3(v + a - 2x_I)}{8k - 9} \quad (2.31)$$

Both reaction functions are downward sloping which implies that investments are strategic substitutes. An increase in competitor's investment leads to a decrease in one's investment.

By solving these best response functions, we obtain the optimal investment levels of the network operators as a function of the access fee:

$$x_I = \frac{3a(4k - 5) - 6v + 4kv}{6 + 2k(8k - 13)} \quad (2.32)$$
$$x_C = \frac{3(a(k - 2) + (k - 1)v)}{3 + k(8k - 13)} \quad (2.33)$$

Since the regulator credibly commits to the access fee ex-ante, firms' investment decisions depend on the access fee. We observe that the investment level is increasing in the access fee. A higher access fee, therefore, stimulates investment in network quality because it makes the entrant less competitive.

**Welfare maximization:** Taking into account the investment behavior and the outcome in the retail market, the regulator maximizes social welfare under the constraint that $a \geq 0$. The access fee should be non-negative to prevent margin squeeze from the incumbent. From the first-order condition $\partial TS(a)/\partial a = 0$[1] , we derive the optimal access fee.

**Proposition 2.1** *The optimal access fee under regulation is*

$$a^R = \begin{cases} \frac{2kv(69-2k(61+k(4k-31)))}{k(789+4k(-197+k(53+4k)))-216} & \textit{if } k < 5.08416 \\ 0 & \textit{if } k \geq 5.08416. \end{cases} \tag{2.34}$$

With access regulation all three firms are active in the retail market because $a^R \leq \bar{a}$. Thus, the regulator ensures sufficient competition in the retail market. Moreover, the access fee $a^R$ is decreasing in the cost of investment for all values of the cost parameter. The higher the cost of investment, the lower the access fee. When the cost of investment is small, the regulator compensates the incumbent with an above-cost access fee in order to spur investment. When the cost of investment is high, then it is better for the regulator to create a level playing field by setting the access fee to zero and thereby enhancing competition. This, however, might be at the detriment of investment.

In equilibrium, the investment levels of the two firms are

$$x_I^R = \begin{cases} \frac{2(108+k(-171+(71-4k)k))v}{k(789+4k(-197+k(53+4k)))-216} & \text{if } k < 5.08416 \\ \frac{v(2k-3)}{(3+k(8k-13))} & \text{if } k \geq 5.08416 \end{cases} \tag{2.35}$$

$$x_C^R = \begin{cases} \frac{3(72+k(-115+44k))v}{k(789+4k(-197+k(53+4k)))-216} & \text{if } k < 5.08416 \\ \frac{3v(k-1)}{3+k(8k-13)} & \text{if } k \geq 5.08416 \end{cases} \tag{2.36}$$

**Proposition 2.2** *Under access regulation, the investment by the incumbent is always smaller than the investment by the cable operator. That is $x_I^R < x_C^R$.*

[1]Social welfare formulation can be found in the Appendix and Assumption 1 ensures that social welfare is concave in $a$.

While the cable operator is the only one profiting from its investment, the incumbent has to share the benefits of its investment with the access-seeking entrant. However, as the incumbent has to bear most of the costs alone, it is less willing to help the entrant to gain market share through a higher network quality. Thus, the incumbent has fewer incentives to invest. Because investments are strategic substitutes, the cable operator reacts by increasing its investment level to enhance its network quality.

## 2.5 No Regulation

We next characterize the equilibrium when the incumbent network operator is granted a regulatory holiday such that there is no regulation. The incumbent decides whether it voluntarily wants to provide wholesale access to the entrant. Hence, without regulation, firms $I$ and $C$ first invest in their network and afterward the incumbent decides whether to provide access to the entrant and which access price to set. Then all participating retail service providers compete in the market.
**Retail competition:** When the incumbent grants access to its network and the entrant pays the access fee, all three service providers compete for consumers in the retail market. Then, as with regulation, the retail quantities as functions of the investments and the access fee, $q_i^N(x_I, x_C, a)$, are also given by equations (2.17)-(2.19) and profits, $\Pi_i^N(x_I, x_C, a)$, by equations (2.24) - (2.26). Whenever the incumbent decides to foreclose the entrant from the retail market, the network operators compete in a duopoly. Then, the retail quantities, $q_i^{Nf}(x_I, x_C)$ are given by equations (2.21)- (2.23) and profits, $\Pi_i^{Nf}(x_I, x_C, a)$, by equations (2.27)-(2.29).
**Access fee decision:** The incumbent decides whether to provide access to the entrant and which access fee to charge. Given the investment levels, the incumbent chooses the profit maximizing access fee, which is derived from the first-order condition $\partial\Pi_I^N(x_I, x_C, a)/\partial a = 0$:

$$a^N = \frac{3}{11}(v + 2x_I - x_C) \tag{2.37}$$

The optimal access fee increases with $x_I$ but decreases with $x_C$. The better the quality of the network of the incumbent, the better is also the quality of the entrant;

hence, the entrant has to pay more for a higher quality of service. However, the better the quality of the competing cable operator, the worse it is for the entrant; thus, it will pay less. If $a^N < \bar{a}$, the incumbent will grant access to the entrant and if $a^N \geq \bar{a}$, then the entrant is foreclosed from the market.

**Proposition 2.3** *Without regulation, the incumbent never forecloses the entrant and thus always grants access at an access fee $a^N$.*

The incumbent accommodates the entrant, which implies that there is more retail competition compared to foreclosure. It can, however, offset its losses in the product market with additional revenue from access provision. The incumbent then indirectly controls the entrant's retail market actions through its investment decision and the access charge. The cable operator is harmed due to more intense product market competition.

**Investment decision:** Taking into account that the incumbent always accommodates the entrant, we next examine the investment decisions of the network operators in the first stage. As the entrant is active in the retail market, the profits of the network operators are obtained by substituting the optimal quantities, (2.17)-(2.19), and the optimal access charge (2.37) into equations (2.24) and (2.25). Profits as functions of the investments are given by

$$\Pi_I^N(x_I, x_C, a^N(x_I, x_C)) = \frac{5}{44}(v + 2x_I - x_C)^2 - \frac{k}{2}x_I^2 \tag{2.38}$$

$$\Pi_C^N(x_I, x_C, a^N(x_I, x_C)) = \frac{1}{484}(7v - 8x_I + 15x_C)^2 - \frac{k}{2}x_C^2. \tag{2.39}$$

The network operators $I$ and $C$ then choose their investment level by maximizing their profit. From the first-order conditions $\partial\Pi_i^N(x_I, x_C, a^N(x_I, x_C))/\partial x_i = 0$, we obtain the investment levels

$$x_I^N = \frac{10v(11k - 15)}{150 + k(242k - 445)} \tag{2.40}$$

$$x_C^N = \frac{15v(7k - 10)}{150 + k(242k - 445)}. \tag{2.41}$$

Since the incumbent accommodates the entrant and $q_E^N(x_I^N, x_C^N, a^N) > 0$, these investment levels constitute the equilibrium outcome.

**Proposition 2.4** *Without regulation, investment by the incumbent is always larger than the investment by the cable operator. That is* $x_I^N > x_C^N$.

Investment of the incumbent benefits the entrant in the retail market and thereby increases the quantity provided by the entrant. In turn, the incumbent generates more access revenue because of higher sales of the entrant and a higher access fee. Therefore, the incumbent has stronger incentives to invest to be superior. Due to the strategic substitutability of investment, the significant investment by the incumbent decreases the marginal revenues of the cable operator giving this cable operator an incentive to invest less.

## 2.6 Co-Investment

Under co-investment, the incumbent and the entrant share the cost of the infrastructure investment. We assume that firms share the costs equally due to symmetry. After the investment took place, each of the two firms is entitled to use the network without having to pay an access fee, therefore $a = 0$. Hence, under co-investment, first firms $I$ and $E$ jointly and firm $C$ individually invest in broadband quality. Then all three providers compete in the retail market. Investment sharing can be seen as a lump-sum transfer from the entrant to the incumbent so that there is no interference in the retail market.

**Retail competition:** Under investment sharing, all three service providers are active in the retail market. As they all compete for consumers in the retail market, firms individually choose their retail quantities by maximizing their profits as in equations (2.12)-(2.14). Hence, retail quantities are

$$q_I^S(x_I, x_C) = \frac{1}{4}(v + 2x_I - x_C) \tag{2.42}$$

$$q_C^S(x_I, x_C) = \frac{1}{4}(v - 2x_I + 3x_C) \tag{2.43}$$

$$q_E^S(x_I, x_C) = \frac{1}{4}(v + 2x_I - x_C). \tag{2.44}$$

Since there are no side payments between the firms ($a = 0$) retail market competition is intensive. As the incumbent and the entrant share the infrastructure, they provide the same retail quantity. However, the cable operator offers a different output. Profits as functions of the investment levels are

$$\Pi_I^S(x_I, x_C) = \frac{1}{16}(v + 2x_I - x_C)^2 - \frac{1}{2}kx_I^2/2 \tag{2.45}$$

$$\Pi_C^S(x_I, x_C) = \frac{1}{16}(v - 2x_I + 3x_C)^2 - kx_C^2/2 \tag{2.46}$$

$$\Pi_E^S(x_I, x_C) = \frac{1}{16}(v + 2x_I - x_C)^2 - \frac{1}{2}kx_I^2/2 \tag{2.47}$$

**Investment decision:** In the investment stage, firms $I$ and $E$ jointly invest in the quality of service while firm $C$ invests on its own. The objective function of the co-investing firms is the sum of the individual profit of firms $I$ and $E$:

$$\max_{x_I} \Pi_I(x_I, x_C) + \Pi_E(x_I, x_C) \tag{2.48}$$

Differentiating equation (2.48) with respect to $x_I$ and equation (2.46) with respect to $x_C$, the corresponding investment levels are given by

$$x_I^S = \frac{2v(2k-3)}{6 + k(8k-17))} \tag{2.49}$$

$$x_C^S = \frac{3v(k-2)}{6 + k(8k-17))} \tag{2.50}$$

**Proposition 2.5** *Under co-investment, the co-investing firms $I$ and $E$ always invest more that firm $C$. That is $x_I^S > x_C^S$.*

Co-investment allows the incumbent and the entrant to share not only the benefits but also the costs of the investment. When choosing the optimal investment, the incumbent internalizes the positive effect of an improved quality on the profit of the entrant. Moreover, with investment sharing the incumbent and the entrant collude and attempt to weaken the cable operator's position. They, therefore, deploy a higher network quality not only to exploit mutual benefits but also to reduce the competitive pressure of the cable operator. Then the cable operator's output and profit margin fall, which reduce its investment incentives. In turn, the cable operator invests less.

## 2.7 Comparisons

The primary objectives of access regulation are to promote investment in network quality, to enhance competition in the retail market and to improve social welfare. For this reason, we compare the results obtained under the three regulatory alternatives with respect to output, investments, and welfare.

### 2.7.1 Investment Incentives and Competition

We first examine the effects of the different regulatory schemes on the competitive intensity in the retail market.

**Proposition 2.6** *Equilibrium retail output is the highest under co-investment and the lowest without any regulation. That is* $Q^S > Q^R > Q^N$.

Industry output is highest under co-investment. In contrast to regulation, we note that investment sharing does not involve the payment of an access fee between the incumbent and the entrant and therefore, leads to a more competitive retail market structure. Second, as seen in Proposition 2.7, the rivalry between the co-investing firms is mitigated under investment sharing. They heavily invest in network quality to gain market share from the cable operator with inferior quality. The large investment by the incumbent and the entrant leads to a reduction in the retail market quantity of the cable operator while the output of the incumbent and the entrant increase. The latter increase outweighs the former decrease such that industry output is higher under investment sharing than under regulation. Additionally, industry output is lower without regulation than with regulation. Because of a higher access fee, the retail market is less competitive, which clearly leads to a lower retail market outcome.

We next analyze the impact of the different regulatory schemes on the investment behavior of the two network operators.

**Proposition 2.7** *(i) Investment incentives of the incumbent are highest under co-investment and higher without regulation than with regulation. That is* $x_I^S > x_I^N > x_I^R$ *for all* $k$.

*(ii) Investment incentives of the cable operator are lowest under co-investment and higher (lower) without regulation than with regulation if the investment cost is large (small). That is* $x_C^N > x_C^R > x_C^S$ *if* $k > 3.77978$ *and* $x_C^R > x_C^N > x_C^S$ *otherwise.*
*(iii) Total investment is highest without regulation and higher (lower) with co-investment than with regulation if the investment cost is large (small). That is* $x_I^N + x_C^N > x_I^S + x_C^S > x_I^R + x_C^R$ *if* $k > 2.31416$ *and* $x_I^N + x_C^N > x_I^R + x_C^R > x_I^S + x_C^S$ *otherwise.*

Intuitively, this result can be explained as follows. The investment of the incumbent is always lower with regulation than without regulation. By leasing its network to the entrant, the incumbent captures some rent from the access fee. With regulation, the access fee is set by the regulator whereas the incumbent sets the access fee by itself without regulation. Thereby, it can indirectly control the entrant's retail market behavior. Investment of the incumbent not only increases the access fee but also has the potential to increase the retail output of the entrant. Primarily, this opportunity of a higher access revenue drives its incentives to invest. With regulation it cannot control the access fee and hence, its incentives to invest are dampened. Investment sharing between the incumbent and the entrant leads to the highest incentives to invest because the co-investing firms collude on the level of the network quality and thus try to weaken the cable operator's position by investing in network quality.

The investment of the cable operator depends on the investment cost parameter. When the investment cost is low, it has more incentives to invest with regulation than without regulation. When investment costs are small, investment levels, in general, are higher. Thus, the impact of investments on the retail market is more pronounced. The result is then explained by the strategic substitutability of the investments and a more competitive market under regulation. When the incumbent and the entrant share the investment, they invest a lot thereby reducing the cable operator's position. As the cable operator is put in a disadvantageous position, it has the lowest incentives to invest.

### 2.7.2 Consumer Surplus and Social Welfare

Regulators usually use consumer and social welfare standards to evaluate different regulatory schemes. Therefore, we compare consumer surplus and social welfare with and without regulation and under investment sharing.

**Proposition 2.8** *(i) Consumer surplus is the highest under co-investment and the lowest without any regulation. That is* $CS^S > CS^R > CS^N$.

*(ii) Social welfare is the highest under co-investment and higher (lower) with regulation than without regulation if the investment cost is large (small). That is* $TS^S > TS^R > TS^N$ *if* $k > 2.09084$ *and* $TS^S > TS^N > TS^R$ *otherwise.*

The previous analysis revealed that co-investment induces the highest level of competition and the largest investment of the access provider. Therefore, co-investment leads to the highest consumer surplus because consumers not only benefit from intense retail market competition but might also benefit from the best network quality. Even though investment incentives are larger without regulation than with regulation for higher investment costs, consumer surplus is always higher with regulation than without. Thus, we observe that the competition intensity is more important in determining consumer welfare than the network quality investment.

Under co-investment compared to regulation, the gain in consumer surplus outweighs any potential loss in producer surplus, especially for the cable operator. Thus, social welfare is strictly higher under investment sharing. Comparing regulation to no regulation, we find that even though access regulation enhances consumer surplus it does not always improve social welfare. When the cost of investment is small, social welfare is greater without regulation than with regulation. Then the gain in producer surplus outweighs the loss in consumer surplus because the incumbent has high incentives to invest and gains access revenue.

## 2.8 Conclusion

This chapter provides an economic analysis of investment incentives when only the incumbent is mandated to grant access to their competitors. We have examined the effect of different access regimes on firms' investment incentives and its effect on retail competition. We show that the incumbent has the highest incentives to invest with investment sharing and that investment for the incumbent is greater without regulation than with regulation. On the contrary, the competing network operator has the lowest investment incentives when the incumbent shares the investment cost with the entrant, and it may have higher investment incentives with regulation than without. Overall, co-investment can impede more competition and more investment than a strict ex-ante regulation. From a policy perspective we conclude that if investment sharing works smoothly, it allows for welfare improvements. Therefore, relaxing ex-ante regulation in favor of co-investment can be an effective choice for regulatory authorities. Investment sharing protects competition in the retail market, enhances welfare and increases investment incentives.

We have analyzed an asymmetric setting, in which the competing cable provider is not regulated and never provides access to its network. However, in the near future cable operators may also become significant market players, which might be able to provide access to their networks. Future research should take this into account and look at symmetric regulation and investment incentives.

## 2.9 Appendix

To simplify notations in the proofs, we define the following functions of the parameter $k$:

$$A(k) \equiv 150 + k(242k - 445) \tag{2.51}$$

$$B(k) \equiv k(789 + 4k(-197 + k(53 + 4k))) - 216 \tag{2.52}$$

$$C(k) \equiv 3 + k(8k - 13) \tag{2.53}$$

$$D(k) \equiv 6 + k(8k - 17) \tag{2.54}$$

Under assumption 1, that is $k > 2$, $A(k), B(k), C(k), D(k) > 0$. We further define $k_1 \equiv 5.08416$, which is the critical value for a "zero" access fee under regulation.

**Proof of Proposition 2.1** Substituting (2.32) and (2.33) into (2.17)-(2.19) and into (2.24)-(2.26), we derive total welfare as a function of the access fee from (2.16).

$$TS^R(a) = \frac{1}{8(3+k(-13+8k))^2}(a^2(216-789k+788k^2-212k^3-16k^4) + 4ak(69-122k+62k^2-8k^3)v + 4k(-18+138k-173k^2+60k^3)v^2) \tag{2.55}$$

The first- and second-order conditions with respect to the access fee $a$ are

$$\frac{\partial TS^R(a)}{\partial a} = \frac{1}{4(3+k(-13+8k))^2}(a(216-789k+788k^2-212k^3-16k^4) + 2vk(69-122k+62k^2-8k^3)) \tag{2.56}$$

$$\frac{\partial^2 TS^R(a)}{\partial a^2} = \frac{(216-789k+788k^2-212k^3-16k^4)}{4(3+k(-13+8k))^2} < 0. \tag{2.57}$$

The numerator of (2.57) is decreasing in $k$ and negative for $k > 2$. Hence, social welfare is a concave function in $a$ for $k > 2$.

From the first-order condition $\partial TS^R(a)/\partial a = 0$, the optimal access fee is

$$a^R = \frac{2kv(69-2k(61+k(4k-31)))}{k(789+4k(-197+k(53+4k)))-216}, \tag{2.58}$$

which is positive only if $k < 5.08416$. Moreover, $a^R < \bar{a}$ for all k. As the access fee must be non-negative, the result obtained in the Proposition holds. ■

**Proof of Proposition 2.2** By (2.35) and (2.36), the difference in equilibrium investments under regulation is given by

$$\Delta x^R = x_I^R - x_C^R = \begin{cases} \frac{kv(3+2k(5-4k))}{B(k)} & \text{if } k < k_1 \\ \frac{-kv}{C(k)} & \text{if } k \geq k_1 \end{cases} \tag{2.59}$$

We have to show the sign of $\Delta x^R$. The denominators of equation (2.59) are always positive for $k > 2$. Hence, it remains to show the sign of the numerators. When $k < k_1$, we first find the roots of $3+2k(5-4k)$, which are $k = -1/4$ and $k = 3/2$. Since we assume $k > 2$, we find that for any $k > 2$ the numerator is negative. Hence, $\Delta x^R < 0$ for $k < k_1$. It follows directly from (2.59) that also $\Delta x^R < 0$ when $k \geq k_1$. Hence, $x_I^R < x_C^R$ for all $k > 2$. ■

**Proof of Proposition 2.3** Foreclosure only occurs if $a^N \geq \bar{a}$, which is only true if $v + 2x_I - x_C < 0$. Given the investments and $v + 2x_I - x_C < 0$, the incumbent and the cable operator compete in a retail duopoly, in which the optimal quantities are defined by $q_I^{Nf}$ and $q^{Nf}$ as in (2.21) and (2.22), respectively. These optimal retail quantities are, however, negative for $v + 2x_I - x_C < 0$. Thus, they cannot constitute an equilibrium.

Moreover, if foreclosure would occur in an equilibrium, the optimal investments were obtained from $\partial \Pi_i^{Nf} / \partial x_i = 0$, which leads to

$$x_I^{Nf} = \frac{4v}{9k - 4} \tag{2.60}$$

$$x_C^{Nf} = \frac{4v}{9k - 4}. \tag{2.61}$$

As firms are symmetric under foreclosure they invest the same amount. Then clearly $v + 2x_I - x_C > 0$ and $a^N(x_I^{Nf}, x_C^{Nf}) < \bar{a}$. This result implies that with duopoly investment levels in the first stage, the incumbent always wants to provide access to the entrant in the second stage. But under entrant accommodation, they are not optimal. Therefore, given network competition, we conclude that the incumbent never forecloses the entrant without regulation. ■

**Proof of Proposition 2.4** By (2.40) and (2.41), the difference in equilibrium investments without regulation is given by

$$\Delta x^N = x_I^N - x_C^N = \frac{5kv}{A(k)} \tag{2.62}$$

Since the denominator of equation (2.62) is always positive, it is clear that $\Delta x^N > 0$. Hence, $x_I^N > x_C^N$ for all $k > 2$. ■

**Proof of Proposition 2.5** By (2.49) and (2.50), the difference in equilibrium investments under co-investment is given by

$$\Delta x^S = x_I^S - x_C^S = \frac{kv}{D(k)} \tag{2.63}$$

Since the denominator of equation (2.63) is always positive, it is clear that $\Delta x^S > 0$. Hence, $x_I^S > x_C^S$ for all $k > 2$. ■

**Proof of Proposition 2.6** To determine the industry output with regulation,

$Q^R$, we substitute the optimal access fee (2.34) and the optimal investment levels (2.35) and (2.36) into (2.17)-(2.19). Thus,

$$q_I^R = \begin{cases} \frac{k(147+20k(-11+4k))v}{B(k)} & \text{if } k < k_1 \\ \frac{k(2k-3)v}{C(k)} & \text{if } k \geq k_1 \end{cases} \tag{2.64}$$

$$q_C^R = \begin{cases} \frac{2k(72+k(-115+44k))v}{B(k)} & \text{if } k < k_1 \\ \frac{2(k-1)kv}{C(k)} & \text{if } k \geq k_1 \end{cases} \tag{2.65}$$

$$q_E^R = \begin{cases} \frac{(3-2k)^2k(1+4k)v}{B(k)} & \text{if } k < k_1 \\ \frac{k(2k-3)v}{C(k)} & \text{if } k \geq k_1 \end{cases} \tag{2.66}$$

$$\begin{aligned} Q^R &= q_I^R + q_C^R + q_E^R \\ &= \begin{cases} \frac{2k(150+k(-213+62k+8k^2))v}{B(k)} & \text{if } k < k_1 \\ \frac{2k(3k-4)v}{C(k)} & \text{if } k \geq k_1 \end{cases} \end{aligned} \tag{2.67}$$

To determine the industry output without regulation, $Q^N$, we substitute the optimal access fee (2.37) and the optimal investment levels (2.40) and (2.41) into (2.17)-(2.19). Thus,

$$q_I^N = \frac{7k(-15+11k)v}{A(k)} \tag{2.68}$$

$$q_C^N = \frac{11k(-10+7k)v}{A(k)} \tag{2.69}$$

$$q_E^N = \frac{k(-15+11k)v}{A(k)} \tag{2.70}$$

$$\begin{aligned} Q^N &= q_I^N + q_C^N + q_E^N \\ &= \frac{5k(-46+33k)v}{A(k)} \end{aligned} \tag{2.71}$$

To determine the industry output under co-investment, $Q^S$, we substitute optimal investment levels (2.49) and (2.50) into (2.42)-(2.44). Thus,

$$q_I^S = \frac{k(-3+2k)v}{D(k)} \tag{2.72}$$

$$q_C^S = \frac{2(-2+k)kv}{D(k)} \tag{2.73}$$

$$q_E^S = \frac{k(k(-3+2k)v}{D(k)} \tag{2.74}$$

$$\begin{aligned} Q^S &= q_I^S + q_C^S + q_E^S \\ &= \frac{2k(-5+3k)v}{D(k)} \end{aligned} \tag{2.75}$$

By (2.67) and (2.71), the difference in industry output with and without regulation is

$$\begin{aligned} \Delta Q^1 &= Q^R - Q^N \\ &= \begin{cases} \frac{vk(-4680+k(19710+k(-30655+4k(5727+k(-2103+308k)))))}{A(k)B(k)} & \text{if } k < k_1 \\ \frac{vk(-510+3k(325+k(-207+44k)))}{A(k)C(k)} & \text{if } k \geq k_1 \end{cases} \end{aligned} \tag{2.76}$$

We find that the expression in the numerator of the upper element of equation (2.76) has no roots in the interval $k \in (2, k_1)$. Substituting $2 < k < k_1$ into that expression yields a positive value. Hence, the overall value of the upper element of (2.76) is positive. Similarly, the expression in the numerator of the lower element of equation (2.76) has no roots for $k > k_1$. Substituting $k > k_1$ into that expression also yields a positive value. Thus, $\Delta Q^1 > 0$ for all $k > 2$.

By (2.67) and (2.75), the difference in industry output under regulation and co-investment is

$$\begin{aligned} \Delta Q^2 &= Q^R - Q^S \\ &= \begin{cases} \frac{2vk(-3+2k)(60+k(-215+2(-6+k)k(-19+4k)))}{B(k)D(k)} & \text{if } k < k_1 \\ \frac{-2vk(3-2k)^2}{C(k)D(k)} & \text{if } k \geq k_1 \end{cases} \end{aligned} \tag{2.77}$$

We first consider the expression in the numerator of the upper element of equation (2.77). The first two terms $2vk$ and $(2k-3)$ are clearly positive for $k > 2$. Moreover, the third component has no roots in the interval $k \in (2, k_1)$. Substituting $2 < k < k_16$ into that third component yields a negative value. Considering the lower element of (2.77),it clearly is always negative for any k. Thus, $\Delta Q^2 < 0$ for all $k > 2$.

By (2.71) and (2.75), the difference in industry output without regulation and co-investment is

$$\begin{aligned}\Delta Q^3 &= Q^N - Q^S \\ &= \frac{120 + k(-450 + (445 - 132k)k)}{A(k)D(k)}\end{aligned} \tag{2.78}$$

The numerator of expression (2.78) has not roots for $k > 2$. Substituting any $k > 2$ into this expression yields a negative value. Hence, $\Delta Q^3 < 0$ for all k.

We can therefore conclude that $Q^S > Q^R > Q^N$ for all k. ■

**Proof of Proposition 2.7** We first prove statement (i). By (2.32) and (2.40), the difference in equilibrium investments of the incumbent with and without regulation is given by

$$\begin{aligned}\Delta x_I^1 &= x_I^R - x_I^N \\ &= \begin{cases} \frac{-6kv(616k^4 - 2834k^3 + 4779k^2 - 3462k + 885)}{A(k)B(k)} & \text{if } k < k_1 \\ \frac{-3kv(215 + 2k(-169 + 66k))}{A(k)C(k)} & \text{if } k \geq k_1 \end{cases}\end{aligned} \tag{2.79}$$

We first consider the upper element of equation (2.79) when $k < k_1$. We determine the sign of the bracket in the numerator. The function in the bracket has roots at $k = 0.58499$ and at $k = 1.52164$. Substituting any $k > 2$ into the bracket, we find that the value is positive. Hence, the overall value of the upper element of (2.79) is negative and $\Delta x_I^1 < 0$ for $k < k_1$.

We next consider the second element of equation (2.79). Since the denominator is always positive, we need to determine the sign of the numerator when $k \geq k_1$. We first find the roots of $215 + 2k(66k - 169)$, which are $k = \frac{1}{132}(169 \pm \sqrt{181}) < 2$. Therefore, we substitute any $k \geq k_1$ into $215 + 2k(66k - 169)$ and find that the value is always positive. Hence, $\Delta x_I^1 < 0$ for any $k \geq k_1$. We can therefore conclude that $x_I^R < x_I^N$ for all $k > 2$.

By (2.32) and (2.49), the difference in equilibrium investments of the incumbent under regulation and co-investment is given by

$$
\begin{aligned}
\Delta x_I^2 &= x_I^R - x_I^S \\
&= \begin{cases} \frac{-2kv(4k-3)(-21+k(57+k(-53+16k)))}{B(k)D(k)} & \text{if } k < k_1 \\ v(2k-3)\frac{k(9-8k)}{C(k)D(k)} & \text{if } k \geq k_1 \end{cases}
\end{aligned}
\tag{2.80}
$$

We first consider the upper element, i.e. the case when $k < k_1$. By the assumption $k > 2$, the denominator is always positive. It remains to show the sign of the numerator. We split the numerator into three components. The first component, $-2kv$, is always negative. The second component, $4k-3$, is positive for all $k > 2$. The sign of the third component, $(-21+k(57+k(-53+16k)))$ is more cumbersome, since we cannot find the roots of this component. We therefore substitute $k = 2$ and find that the value of the third component is positive. Moreover, we note that the derivative of the third component with respect to $k$ is increasing for $k \geq 2$. Hence, the value becomes more positive for increasing values of $k$. Thus, we can conclude that the upper element is always negative, that is $\Delta x_I^2 < 0$ for $k < k_1$.

We now consider the lower element of equation (2.80). Since $v(2k-3)$ is positive for all values of $k$ and $k(9-8k)$ is negative for all $k > 2$, $\Delta x_I^2 < 0$ for any $k \geq k_1$. We can therefore conclude that $x_I^R < x_I^S$ for all $k > 2$.

By (2.40) and (2.49), the difference in equilibrium investments of the incumbent under no regulation and co-investment is given by

$$
\begin{aligned}
\Delta x_I^3 &= x_I^H - x_I^S \\
&= \frac{-2kv(30+k(44k-81))}{A(k)D(k)}
\end{aligned}
\tag{2.81}
$$

The denominator of equation (2.81) is positive for all $k$. The component, $-2kv$ is negative. We next consider the component in the brackets, $30+k(44k-81)$, and find its roots $k = \frac{1}{88}(81 \pm \sqrt{1281}) < 2$. Therefore, we substitute any $k \geq 2$ into $30+k(44k-81)$ and find that the value is always positive. Hence, $\Delta x_I^3 < 0$ for any $k \geq k_1$. We can therefore conclude that $x_I^H < x_I^S$ for all $k > 2$. By transitivity, this proves that $x_I^S > x_I^H > x_I^R$.

We next consider statement (ii). By (2.33) and (2.41), the difference in equilibrium investments of the cable operator with and without regulation is given by

$$\Delta x_C^1 = x_C^R - x_C^N$$
$$= \begin{cases} \frac{-6kv(280k^4-2014k^3+4615k^2-4092k+1140)}{A(k)B(k)} & \text{if } k < k_1 \\ \frac{-6kv(80+k(-84+19k))}{A(k)C(k)} & \text{if } k \geq k_1 \end{cases} \tag{2.82}$$

We first consider the upper element of equation (2.82) when $k < k_1$. We determine the sign of the bracket in the numerator. The function in the bracket has three roots at $k < 2$ and one root at $k = 3.77978$. Substituting $2 < k < 3.77978$ into the bracket, we find that the value is negative, while substituting $k > 3.77978$ into the bracket, we find that the value is positive. Hence, the overall value of ((2.82)) is positive if $2 < k < 3.77978$ and negative if $k > 3.77978$. Thus, $\Delta x_C^1 > 0$ for $k < 3.77978$ and $\Delta x_C^1 < 0$ for $3.77978 < k < k_1$.

We next consider the second element of equation (2.82). Since the denominator is always positive, we need to determine the sign of the numerator when $k \geq k_1$. We first find the roots of $80 + k(-84 + 19k)$, which are $k = \pm\frac{2}{\sqrt{181}} < 2$. Therefore, we substitute any $k \geq k_1$ into $80 + k(-84 + 19k)$ and find that the value is always positive. Hence, $\Delta x_C^1 < 0$ for any $k \geq k_1$. We can therefore conclude that $x_C^R > x_C^N$ for $k < 3.77978$ and $x_C^R < x_C^N$ for all $k > 3.77978$.

By (2.33) and (2.50), the difference in equilibrium investments of the cable operator under regulation and co-investment is given by

$$\Delta x_C^2 = x_C^R - x_C^S$$
$$= \begin{cases} \frac{-6kv(8k^4-86k^3+213k^2-215k+60)}{B(k)D(k)} & \text{if } k < k_1 \\ \frac{6kv(2k-3)}{C(k)D(k)} & \text{if } k \geq k_1 \end{cases} \tag{2.83}$$

We first consider the upper element of equation (2.83) when $k < k_1$. We determine the sign of the bracket in the numerator. The function in the bracket has no roots in the interval $k \in (2, k_1)$. Substituting $2 < k < k_1$ into the bracket, we find that the value is negative. Thus, $\Delta x_C^2 > 0$ for $k < k_1$.

We now consider the lower element of equation (2.83). Since the denominator is positive and $v(2k-3)$ is also positive for all values of $k$, $\Delta x_C^2 > 0$ for any $k \geq k_1$. We can therefore conclude that $x_C^R > x_C^S$ for all $k > 2$.

By (2.41) and (2.50), the difference in equilibrium investments of the cable operator without regulation and under co-investment is given by

$$\begin{aligned}\Delta x_C^3 &= x_C^N - x_C^S \\ &= \frac{6kv(10 + k(19k - 33))}{A(k)D(k)}\end{aligned} \tag{2.84}$$

The denominator of equation (2.84) is positive for all $k$. The component, $6kv$ is positive. We next consider the component in the brackets, $10 + k(19k - 33)$. Since $(19k - 33)$ is also positive for any $k > 2$, the numerator is always positive. We can therefore conclude that $x_C^N > x_C^S$ for all $k > 2$. By transitivity, we conclude that $x_C^R > x_C^N > x_C^S$ if $k < k_C$ and $x_C^N > x_C^R > x_C^S$ if $k > k_C$.

We next consider statement (iii). Industry investment, $x = x_I + x_C$, in the three regulatory alternatives is

$$x^R = \begin{cases} \frac{v(432+k(-687+274k-8k^2))}{B(k)} & \text{if } k < k_1 \\ \frac{v(5k-6)}{C(k)} & \text{if } k \geq k_1 \end{cases} \tag{2.85}$$

$$x^N = \frac{5v(43k - 60)}{A(k)} \tag{2.86}$$

$$x^S = \frac{v(7k - 12)}{D(k)} \tag{2.87}$$

By (2.85) and (2.86), the difference in industry-wide investment with and without regulation is

$$\begin{aligned}\Delta x^1 &= x^R - x^N \\ &= \begin{cases} \frac{-6vk(2025+2k(-3777+k(4697+8k(-303+56k))))}{A(k)B(k)} & \text{if } k < k_1 \\ \frac{-3vk(375+2k(-253+85k))}{A(k)C(k)} & \text{if } k \geq k_1 \end{cases}\end{aligned} \tag{2.88}$$

We first consider the expression in the numerator of the upper element of equation (2.88). The first term, $-6vk$ is negative and the term in the bracket has no roots in the interval $k \in (2, k_1)$. Substituting $2 < k < k_1$ into the term in the bracket yields a positive value. Hence, the overall value of the upper element of (2.88) is negative. Similarly, we consider the expression in the numerator of the lower element of equation (2.88). The first component, $-3vk$ is positive and the component in the bracket has no roots for $k > k_1$. Substituting $k > k_1$ into the component in the bracket yields a positive value. Thus, $\Delta x^1 < 0$ for all $k > 2$.

By (2.85) and (2.87), the difference in industry wide investment under regulation and co-investment is

$$\begin{aligned}\Delta x^2 &= x^R - x^S \\ &= \begin{cases} \frac{-2vk(2k-3)(-81+k(246+k(-193+44k)))}{B(k)D(k)} & \text{if } k < k_1 \\ \frac{vk(-45+2(27-8k)k)}{C(k)D(k)} & \text{if } k \geq k_1 \end{cases}\end{aligned} \tag{2.89}$$

We first consider the expression in the numerator of the upper element of equation (2.89). The first two terms $-2vk$ and $(2k-3)$ are negative and positive, respectively, for $k > 2$. Moreover, in the interval $k \in (2, k_1)$, the third component has one root at $k = 2.31416$. Substituting $2 < k < 2.31416$ into that third component yields a positive value. Considering the lower element of (2.89), it clearly is always negative for any $k \geq k_1$. Thus, $\Delta x^2 > 0$ for $2 < k < 2.31416$ and $\Delta x^2 < 0$ for $k > 2.31416$.

By (2.86) and (2.87), the difference in industry investment without regulation and co-investment is

$$\begin{aligned}\Delta x^3 &= x^N - x^S \\ &= \frac{2vk^2(13k-18)}{A(k)D(k)}\end{aligned} \tag{2.90}$$

The numerator of expression (2.90)is positive for $k > 2$. Hence, $\Delta x^3 > 0$ for all k.

We can therefore conclude that $x^N > x^S > x^R$ for $k > 2.31416$ and $x^N > x^R > x^S$ for $2 < k < 2.31416$.

■

**Proof of Proposition 2.8** We start to show statement (i). Since $CS = Q^2/2$, it follows directly from Proposition 2.6 that $CS^S > CS^R > CS^N$.

Next, we show statement (ii). Total welfare in the three regulatory alternatives is

$$TS^R = \begin{cases} \frac{(k(432+k(-617+16k(12+k)))v^2)}{2B(k)} & \text{if } k < k_1 \\ \frac{(k(-18+k(138+k(-173+60k)))v^2)}{(2C(k)^2)} & \text{if } k \geq k_1 \end{cases} \tag{2.91}$$

$$TS^N = \frac{(5k(-9000+k(33360+k(-33973+10527k)))v^2)}{(2A(k)^2)} \tag{2.92}$$

$$TS^S = \frac{(3k(-24+k(84+5k(-15+4k)))v^2)}{(2D(k)^2)} \tag{2.93}$$

By (2.91) and (2.92), the difference in social welfare with and without regulation is

$$\begin{aligned} \Delta TS^1 &= TS^R - TS^N \\ &= \begin{cases} \frac{k^2v^2}{2A(k)^2B(k)}(94864k^6 - 642572k^5 + 1662012k^4 \\ -2011127k^3 + 1079260k^2 - 156540k - 20700) & \text{if } k < k_1 \\ \frac{3k^2v^2}{2A(k)^2C(k)^2}(48400k^6 - 411644k^5 + 1383719k^4 \\ -2354694k^3 + 2129935k^2 - 960855k + 165600) & \text{if } k \geq k_1 \end{cases} \end{aligned} \tag{2.94}$$

We find that the expression in the numerator of the upper element of equation (2.94) has one root at $k = 2.09084$ in the interval $k \in (2, k_1)$. Substituting $2.09084 < k < k_1$ into that expression yields a positive value. Hence, the overall value of the upper element of (2.94) is positive for $k > 2.09084$ and negative for $k < 2.09084$. Similarly, the expression in the numerator of the lower element of equation (2.76) has no roots for $k > k_1$. Substituting $k > k_1$ into that expression also yields a positive value. Thus, $\Delta TS^1 < 0$ for $k < 2.09084$ and $\Delta TS^1 > 0$ for $k > 2.09084$.

By (2.91) and (2.93), the difference in social welfare under regulation and co-investment is

$$\begin{aligned} \Delta TS^2 &= TS^R - TS^S \\ &= \begin{cases} \frac{2v^2k^2(4k-3)(-75+k(322+k(-461+k(284+k(-71+4k)))))}{B(k)D(k)^2} & \text{if } k < k_1 \\ \frac{-v^2k^2(2k-3)(252+k(-1167+2k(899+8k(-71+16k))))}{2C(k)^2D(k)^2} & \text{if } k \geq k_1 \end{cases} \end{aligned} \tag{2.95}$$

We first consider the expression in the numerator of the upper element of equation

(2.95). The first two terms $2v^2k^2$ and $(4k-3)$ are clearly positive for $k > 2$. Moreover, the third component has no roots in the interval $k \in (2, k_1)$. Substituting $2 < k < k_1$ into that third component yields a negative value. Considering the lower element of (2.77),the first component $-v^2k^2$ is negative, the second component $(2k-3)$ is positive and the third component has not roots for $k > k_1$. Substituting any $k > k_1$ into that component yields a positive value. Hence, $\Delta TS^2 < 0$ for all $k > 2$.

By (2.92) and (2.93), the difference in social welfare without regulation and co-investment is

$$\begin{aligned}\Delta TS^3 &= TS^N - TS^S \\ &= \frac{v^2k^2}{2A(k)^2D(k)^2}(-97200 + 722160k - 2087040k^2 + 3007828k^3 \\ &\quad - 2313173k^4 + 911620k^5 - 145200k^6) \qquad (2.96)\end{aligned}$$

The numerator of expression (2.96) has not roots for $k > 2$. Substituting any $k > 2$ into this expression yields a negative value. Hence, $\Delta TS^3 < 0$ for all k.

We can therefore conclude that $TS^S > TS^R > TS^N$ for $k > 2.09084$ and $TS^S > TS^N > TS^R$ for $k < 2.09084$. ■

# Chapter 3

# Cooperative and Non-cooperative R&D in an Asymmetric Multi-Product Duopoly with Spillovers

This chapter is based on Fudickar and Rakic (2016).

## 3.1 Introduction

A firm investing in research and development (R&D) with spillovers usually imposes a positive externality on other companies which can then appropriate the results of this investment. D'Aspremont and Jacquemin (1988) show in a symmetric environment that encouraging firms to collaborate in R&D activities increases R&D investment and hence, social welfare by internalizing the externality. The European Commission (2010a) has recognized these benefits of joint R&D and has thus issued revised "block exemption" regulations in 2010 that provide an automatic exemption from competition law for certain types of joint R&D agreements.

We study R&D investment in a market where a multi-product firm produces an established and an innovative product and a single-product firm only produces an innovative product. Thereby, we extend the model of D'Aspremont and Jacquemin

(1988) by incorporating two additional aspects. First, we consider an asymmetric market environment where a multi-product firm competes with a single-product firm. Second, the innovative and the established goods are substitutes so that R&D investment in the innovative product might come at the expense of the sales of the established product. It is often assumed that innovative products are independent of any other products that the firms are producing. Such an assumption seems, however, rather restrictive. Hence, firms have to consider the impact of their R&D investments not only on the output decision of the innovative product but also on the established product.

The two extensions enable us to study asymmetric competition between multi-product and single-product firms as commonly observed in situations where "dirty" products compete with "clean", environmentally friendly products. An example of such a market is the automobile industry. Traditional car manufacturers compete with firms that specialize in the production of electric vehicles. For example, Tesla Motors produces exclusively electric cars and competes with more traditional businesses that produce both electric and gasoline cars. The most challenging issue related to the future development of electric vehicles is the battery charging. Companies invest in R&D to improve the loading time and reduce the size and cost of these batteries. Firms often cooperate in R&D investments to benefit from each other's know-how. One example of such a strategic relationship is the cooperation between Daimler and Tesla Motors, which started in 2009.

Investments in R&D are strategic as they influence product market outcomes. Hence, when firms compete in R&D, in addition to the *direct effect* by which firms benefit from cost reductions, there are two potential strategic effects. Through a *within-product competition effect*, a firm's investment decision indirectly affects its profit by its influence on its competitor's output decision of the innovative good. Depending on the level of the spillover, this effect can be negative or positive. Particular to our asymmetric set-up is the second strategic effect, the *cross-product competition effect*. It states that, in addition to changes in the output of the same product, the multi-product firm also modifies its output of the established good, which in turn benefits the single-product firm as it is able to steal some business.

In contrast to R&D competition, we obtain three additional effects under co-operation. When choosing an investment level to maximize joint profit, firms internalize the effect of their R&D investment on the competitor's profit. Because of the *spillover effect*, an increase in R&D investment benefits rival's profit by also decreasing its marginal cost; hence, R&D investment is stimulated. Moreover, through the *within-product cooperation effect*, by investing more, a firm gains a competitive advantage over its rival in the same product, which hurts the competitor. The third effect, *cross-product coordination effect*, is unique to our multi-product environment. When the multi-product firm increases its R&D expenditure, it reduces its output of the substitute good to mitigate within firm cannibalization. This output reduction has a positive impact on the single-product firm's profit and hence, increases investment incentives of the multi-product firm.

When the sum of these additional effects of cooperation is positive for a firm, its investment incentives under cooperation are higher than under competition because its investment then benefits the other firm. We find that the additional, positive, cross-product coordination effect of the multi-product firm together with the spillover effect counteracts the negative within-product coordination effect. Hence, the profit externality conferred on the profit of the single-product firm is positive for a greater range of values of the spillover level and the degree of product differentiation in comparison to the single-product firm.

Our central result states that when the established and the innovative products are close substitutes, total R&D investment under cooperation will be lower than under competition even if the spillover is substantial. More specifically, R&D investment of the single-product firm may be higher under competition than under cooperation even if the spillover is significant. Moreover, for medium spillovers and high product substitutability the multi-product firm also invests less under R&D cooperation. Thus, in contrast to standard results in D'Aspremont and Jacquemin (1988) which suggest that R&D investment under cooperation is higher than under competition when the spillover is high, we find that it not only depends on the technology spillover but also on the degree of product substitutability.

The remainder of this chapter is organized as follows. Section 3.2 gives the literature review. Section 3.3 presents the theoretical model. In section 3.4 we analyze the retail market equilibrium. Sections 3.5 and 3.6 identify the investment incentives under competition and cooperation, respectively. In Section 3.7 we compare R&D investment under competition and coordination. Section 3.8

concludes. The proofs of all formal results are relegated to the Appendix.

## 3.2 Related Literature

As mentioned before, the starting point of our analysis is the study by D'Aspremont and Jacquemin (1988), which also serves as our benchmark. They analyze firms' incentives to invest in R&D with spillovers under R&D competition and cooperation in a symmetric, homogeneous product duopoly. They show that cooperation increases R&D investment levels compared to competitive R&D only when the spillovers are sufficiently high. Kamien et al. (1992) extend their model by introducing heterogeneity among the firms. They show that the general results of D'Aspremont and Jacquemin (1988) still hold. The key intuition in that strand of the literature is that private incentives to conduct R&D are reduced when there are knowledge spillovers from one firm to another due to free-rider incentives.

Lin and Zhou (2013) analyze R&D investment incentives in a multi-product environment. They consider R&D investment in a two-product duopoly with differentiated goods, where each firm has an initial cost advantage in one of the products. They find that when a firm invests more in one particular good, its competitor will respond by investing more in the other good. When the goods become more substitutable, this effect will be stronger. Moreover, R&D coordination in R&D lowers investment. In contrast to Lin and Zhou (2013), we analyze an asymmetric setting without cost advantages, but instead, we allow for spillovers.

Kawasaki et al. (2014) also consider a multi-product model, in which firms engage in R&D investment. A multi-product firm has a monopoly in one market and competes with potential entrants in a second market. Contrary to our set-up, demands for the two products are independent and R&D efforts by the multi-market firm simultaneously reduce the marginal cost of both goods. They show that entry can stimulate investment in cost-reducing R&D.

None of those studies, however, considers the interaction between an asymmetric multi-product environment and the dynamics of R&D cooperation. Bulow et al. (1985) investigate strategic interaction in an asymmetric multi-market oligopoly. They find that a shock to a firm in one market also affects its competitor's strategy in a second market. This finding can be translated into our set-up as we consider

R&D investment as a strategic interaction. If a firm invests in the new technology product, the competitiveness of the substitute good is reduced. Therefore, the incumbent reduces its output of the established good.

## 3.3 The Model

We consider a market with two firms A and B. Firm A is the single producer of an established product (good 1), while both firms produce a substitute product (good 2), which is based on a new technology. The prices of the two products are given by the following linear inverse demand functions[1]:

$$p_1(q_{A1}, q_{A2}, q_{B2}) = a - q_{A1} - g(q_{A2} + q_{B2}) \tag{3.1}$$

$$p_2(q_{A1}, q_{A2}, q_{B2}) = a - (q_{A2} + q_{B2}) - gq_{A1} \tag{3.2}$$

where $a > 0$, quantity $q_{ji}$ is the output of good $i \in \{1, 2\}$ produced by firm $j \in \{A, B\}$ and $g \in [0, 1)$ represents the degree of product substitutability between goods 1 and 2. Therefore, the two products in the market are imperfect substitutes, while good 2 is homogeneous. This asymmetric market structure exists, for example, in the automobile industry, where traditional car manufacturers, producing gasoline and electric cars, compete with electric car manufacturers.

Focusing on R&D for the new technology good, we assume that the unit cost of producing the established good is fixed and equalize it to zero. Hence, only R&D investment in the new technology good is possible. The unit cost of producing the new technology good is $c > 0$, but each firm can invest some $x_j > 0$ in process R&D to reduce its unit cost[2]:

$$c_{j2} = c - x_j - \beta x_{-j}, \tag{3.3}$$

where the amount $x_j$ is the R&D investment of firm $j$, the amount $x_{-j}$ is the R&D investment of the rival, and $\beta \in [0, 1]$ is the spillover of the rival's R&D investment on firm $j$. Hence, firms benefit from their rival's R&D activity. We assume that

[1] Derived from the utility function of a representative consumer (Dixit, 1979): $U(q_{A1}, q_{A2}, q_{B2}) = a(q_{A1} + q_{A2} + q_{B2}) - 1/2(q_{A1}^2 + 2gq_{A1}(q_{A2} + q_{B2}) + (q_{A2} + q_{B2})^2)$

[2] We assume that $c$ is high enough, so the new technology is costlier than the established one.

the R&D cost is quadratic and given by $\gamma x_j^2$, where $\gamma > 0$. Thus, the profit of the multi-product firm A is

$$\begin{aligned}\Pi_A &= p_1(q_{A1}, q_{A2}, q_{B2})q_{A1} + \left[p_2(q_{A1}, q_{A2}, q_{B2}) - (c - x_A - \beta x_B)\right] q_{A2} - \gamma x_A^2 \\ &= \pi_A(q_{A1}, q_{A2}, q_{B2}, x_A, x_B) - \gamma x_A^2 \qquad (3.4)\end{aligned}$$

and the profit of the single-product firm B is

$$\begin{aligned}\Pi_B &= \left[p_2(q_{A1}, q_{A2}, q_{B2}) - (c - x_B - \beta x_A)\right] q_{B2} - \gamma x_B^2 \\ &= \pi_B(q_{A1}, q_{A2}, q_{B2}, x_A, x_B) - \gamma x_B^2 \qquad (3.5)\end{aligned}$$

where $\pi_j(q_{A1}, q_{A2}, q_{B2}, x_A, x_B)$, $j = A, B$, denotes the profit gross of R&D investment cost.

We consider the following two-stage game. In the first stage firms simultaneously choose their level of R&D investment $(x_A, x_B)$ to reduce marginal costs. We then examine R&D competition and cooperation. Based on their R&D choice, the firms compete in the second stage à la Cournot and set their production quantities simultaneously. We solve for the equilibria by backward induction.

## 3.4 Retail Market Outcomes

In the second stage, firms compete simultaneously in the product market given the R&D investment levels for the new technology good, $x_A$ and $x_B$. Firm A maximizes its profit $\pi_A$ by choosing quantities $q_{A1}$ and $q_{A2}$, while firm B maximizes its profit $\pi_B$ by only choosing quantity $q_{B2}$. From the first-order conditions $\partial\pi_A/\partial q_{A1} = \partial\pi_A/\partial q_{A2} = \partial\pi_B/\partial q_{B2} = 0$ we obtain the equilibrium quantities as functions of the R&D investments[3]:

$$
\begin{aligned}
q^*_{A1}(x_A, x_B) =& \frac{a(1-g) + g(c - x_A - \beta x_B)}{2(1-g^2)} && (3.6)\\
q^*_{A2}(x_A, x_B) =& \frac{1}{6(1-g^2)}(a(2-3g+g^2) - c(2+g^2) + (4+(2\beta-1)g^2 \\
& - 2\beta)x_A - (2-(2-\beta)g^2 - 4\beta)x_B) && (3.7)\\
q^*_{B2}(x_A, x_B) =& \frac{a - c + (2\beta - 1)x_A + (2-\beta)x_B}{3} && (3.8)
\end{aligned}
$$

To ensure positive output levels in the absence of R&D investments, we assume that $a > c(2+g^2)/(2-g(3-g))$. When there is no investment in R&D ($x_A = x_B = 0$), the multi-product firm produces more of its established good than of its new technology good because the established good has smaller marginal costs; hence, obtaining a competitive advantage. Moreover, firm B produces more of good 2 than firm A.

In the first stage, firms choose their R&D investment. We first examine how firms' R&D investments affect the market outcomes in the second stage by differentiating expressions (3.6)-(3.8) with respect to $x_A$ and $x_B$. By increasing its investment in the innovative product, a firm reduces its marginal cost of that product. Thereby, it always reacts with an increase in its own quantity of the innovative product,

$$\frac{\partial q^*_{i2}}{\partial x_i} > 0. \tag{3.9}$$

Due to the technology spillovers, an increase in a firm's R&D investment not only reduces its own marginal cost of the new technology good but also reduces its competitor's marginal cost of the same product. When $\beta$ is large, the spillover effect becomes strong so that the competitor also reacts with an increase in its

[3]The second-order conditions for a maximum are satisfied: $D(q_{A1}, q_{A2}) = (\partial^2\pi_A/\partial q^2_{A1})(\partial^2\pi_A/\partial q^2_{A2}) - (\partial^2\pi_A/(\partial q_{A2}\partial q_{A1}))^2 = 4 - 4g > 0$, $\partial^2\pi_A/\partial q^2_{A1} = -2 < 0$ and $\partial^2\pi_B/\partial q^2_{B2} = -2 < 0$.

quantity of the innovative product,

$$\frac{\partial q_{A2}^*}{\partial x_B} = -\frac{1}{3} + \frac{\beta(4-g^2)}{6(1-g^2)} = \begin{cases} > 0, & \text{if } \beta > \hat{\beta}_B \equiv \frac{2(1-g^2)}{4-g^2} \\ < 0, & \text{if } \beta < \hat{\beta}_B \equiv \frac{2(1-g^2)}{4-g^2} \end{cases} \tag{3.10}$$

and

$$\frac{\partial q_{B2}^*}{\partial x_A} = \frac{1}{3}(2\beta - 1) = \begin{cases} > 0, & \text{if } \beta > \hat{\beta}_A \equiv \frac{1}{2} \\ < 0, & \text{if } \beta < \hat{\beta}_A \equiv \frac{1}{2} \end{cases} \tag{3.11}$$

As the new technology products compete directly with the established product, there are also effects of R&D investment in the output of good 1. When R&D activity in the innovative product by either firm increases, firm A responds with a reduction in its output quantity of the traditional good:

$$\frac{\partial q_{A1}^*}{\partial x_i} < 0, \text{ for } g > 0. \tag{3.12}$$

Moreover, by taking the derivative of (3.12) with respect to $g$, it can be seen that the closer substitutes the goods are the more firm A suffers in the sales of its traditional product from investment in the new technology.

## 3.5 R&D Competition

In the first stage, firms invest in R&D taking into account the optimal output strategy in stage two. Both firms decide on their R&D investments to maximize their respective profit. Firm $i$ chooses $x_i$ to maximize its total profit

$$\Pi_i = \pi_i(x_i, x_j, q_{i1}^*(x_i, x_j), q_{i2}^*(x_i, x_j), q_{j2}^*(x_i, x_j)) - \gamma x_i^2 \tag{3.13}$$

where $i \in \{A, B\}$ and $j \neq i$. The first-order condition for maximizing firm $i$'s profit in expression (3.13) is

$$\frac{d\Pi_i}{dx_i} = \frac{d\pi_i}{dx_i} - 2\gamma x_i = 0. \tag{3.14}$$

In what follows we assume that $\gamma$ is large enough so that all second-order conditions are satisfied in order to have interior solutions.

**Assumption 3.1**

$$\gamma > \gamma_{min} \equiv \frac{11g^2 - 20 + \beta(1-g^2)(32-20\beta)(g^2-1)}{36(1-g^2)}$$

The relevant first-order conditions then lead to the R&D best-response functions $R_A^N(x_B)$ and $R_B^N(x_A)$ for firm A and B, respectively[4]. The reaction functions are downward sloping for low values of $\beta$ and upward sloping for higher values of $\beta$, as illustrated in Figure 3.1.

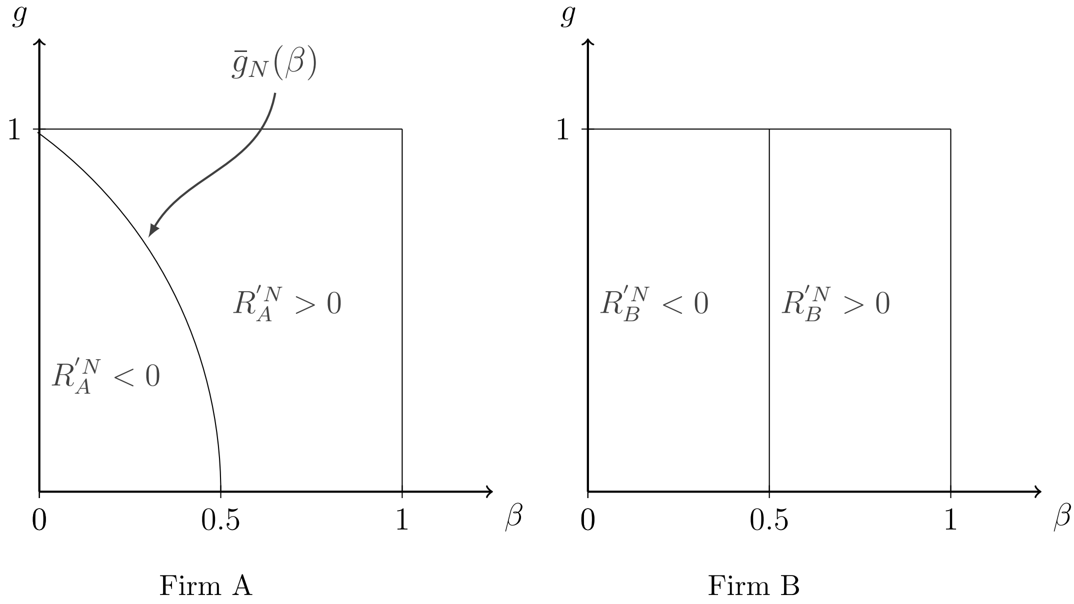



Figure 3.1: Signs of slopes of reaction functions

**Lemma 3.1** *The slope of*

**(i)** $R_A^N(x_B)$ *is negative if* $0 < \beta < 1/2$ *and* $0 < g < \bar{g}_N(\beta)$ *and positive elsewhere, where* $\bar{g}_N(\beta) \equiv \sqrt{4(\beta-2)(2\beta-1)/(8+\beta(8\beta-11))}$

**(ii)** $R_B^N(x_A)$ *is negative if* $0 < \beta < 1/2$ *and* $0 < g < 1$ *and positive elsewhere.*

[4]The closed forms are provided in the appendix by formulas (3.26) and (3.27).

Lemma 3.1 shows that R&D investments are strategic substitutes when spillovers are low. Intuitively, an increase in R&D investment by one firm leads to a decrease in the output of the competitor. R&D investments turn into strategic complements when spillovers intensify and products are more substitutable. An increase in R&D by one firm leads to a decrease in the competitor's marginal cost due to the technology spillover. This reduction in marginal cost has a positive impact on competitor's output decision and thereby increases its incentives to invest in R&D. To stay competitive with firm B, firm A may also increase its R&D investment when spillovers are low. This case happens when the products are closer substitutes.

We next derive the marginal benefit of investment for each firm and identify different strategic effects that arise under R&D competition.

By applying the Envelope Theorem to $d\pi_A/dx_A$ in (3.14) we obtain

$$\frac{d\pi_A}{dx_A} = \underbrace{\underset{+}{\frac{\partial \pi_A}{\partial x_A}}}_{\text{direct effect}} + \underbrace{\frac{\partial \pi_A}{\partial q_{A1}}\frac{\partial q^*_{A1}}{\partial x_A}}_{\substack{=0 \\ \text{(envelope theorem)}}} + \underbrace{\frac{\partial \pi_A}{\partial q_{A2}}\frac{\partial q^*_{A2}}{\partial x_A}}_{\substack{=0 \\ \text{(envelope theorem)}}} + \underbrace{\underset{-}{\frac{\partial \pi_A}{\partial q_{B2}}}\underset{-/+}{\frac{\partial q^*_{B2}}{\partial x_A}}}_{\substack{\text{within-product} \\ \text{competition effect}}} \tag{3.15}$$

Recall that $\partial\pi_A/\partial q_{Ai} = 0$ when evaluated in the optimum $q^*_{Ai}$, $i = 1, 2$, as a result of profit maximization in the second stage. By applying the Envelope Theorem to $d\pi_B/dx_B$ in (3.14) we obtain

$$\frac{d\pi_B}{dx_B} = \underbrace{\underset{+}{\frac{\partial \pi_B}{\partial x_B}}}_{\text{direct effect}} + \underbrace{\frac{\partial \pi_B}{\partial q_{B2}}\frac{\partial q^*_{B2}}{\partial x_B}}_{\substack{=0 \\ \text{(envelope theorem)}}} + \underbrace{\underset{-}{\frac{\partial \pi_B}{\partial q_{A2}}}\underset{-/+}{\frac{\partial q^*_{A2}}{\partial x_B}}}_{\substack{\text{within-product} \\ \text{competition effect}}} + \underbrace{\underset{-}{\frac{\partial \pi_B}{\partial q_{A1}}}\underset{-}{\frac{\partial q^*_{A1}}{\partial x_B}}}_{\substack{\text{cross-product} \\ \text{competition effect}}} \tag{3.16}$$

We also recall that $\partial\pi_B/\partial q_{B2} = 0$ when evaluated in the optimum $q^*_{B2}$ as a result of profit maximization in the second stage.

Each firm invests in R&D to reduce the costs of its innovative product. Those investments affect firms' profits in different ways. First of all, there is a *direct effect* of R&D investment, but additionally we identify two types of strategic effects:

(i) *within-product competition effect.* - A firm's investment decision indirectly affects its own profit through its influence on its competitor's output decision of the same product.

(ii) *cross-product competition effect.* - A firm's investment decision indirectly affects its own profit through its influence on its competitor's output decision of the substitute product.

We summarize the effects of R&D investments under R&D competition on the firms' gross profits (i.e. excluding R&D costs) in the following proposition.

**Proposition 3.1** *An increase in firm j's R&D investment $x_j$ affects its profits*

**(i)** *positively through the direct effect*

**(ii)** *positively for $0 \leq \beta < \hat{\beta}_j$ and negatively otherwise through the within-product competition effect.* [5]

*Additionally,*

**(iii)** *an increase in firm B's R&D investment also influences its own profit positively through the cross-product competition effect.*

Intuitively, the direct effect is always positive. This direct effect results from the fact that an increase in the level of R&D investment leads to a reduction in firm's marginal cost of the new technology good, which in turn leads to an increase in its profit.

Due to knowledge spillovers, an increase in a firm's R&D investment also reduces its rival's marginal cost. However, only when spillovers are significant, the competitor's marginal cost is reduced substantially so that it also reacts more aggressively and increases its output level. Then profit of the investing firm is reduced. Hence, the *within-product competition effect* increases R&D incentives of a firm when spillovers are low and decreases them for large spillovers. Only small spillovers create a real competitive advantage for an investing firm because large spillovers create greater potential for free-riding.

The *cross-product competition effect* is specific to the single-product firm. It only prevails in our asymmetric environment. As the multi-product firm produces two substitute goods, it influences the single-product firm's optimal R&D decision not only through its response regarding its output decision of the new technology product but also regarding its output decision of the traditional product.

[5] The critical spillover $\hat{\beta}_j$, $j \in \{A, B\}$ is defined by equations (3.10) and (3.11)

Clearly, the multi-product firm lowers its output of the traditional product because that good loses its competitive advantage. The single-product firm then benefits from that output reduction as its competitiveness towards the established good increases. The *cross-product competition effect*, therefore, always raises investment incentives for firm B.

The marginal benefit of firm A's cost-reducing investment depends only on the relative magnitudes of the direct effect and the within-product competition effect. Formally,

$$\frac{d\pi_A}{dx_A} = \frac{1}{3}g(1-2\beta)q_{A1} + \frac{2}{3}(2-\beta)q_{A2} \tag{3.17}$$

The overall marginal benefit of firm B's cost-reducing investment under R&D competition additionally depends on the cross-product competition effect. Hence, we obtain

$$\frac{d\pi_B}{dx_B} = \frac{2}{3}(2-\beta)q_{B2}. \tag{3.18}$$

As the latter is positive, firm B always has an incentive to invest in R&D. On the contrary, firm A's investment incentives can be negative if $\beta > 1/2$ and $g$ is very high. Under such a parameter constellation, firm A would not invest at all so that then $x_A = 0$.

## 3.6 R&D Cooperation

We next consider cooperation in R&D investment while the second stage remains competitive. In the first stage firms choose investment levels $x_A$ and $x_B$ by maximizing their joint profits given by (3.13):

$$\begin{aligned}\max_{x_A,x_B} \Pi_A + \Pi_B \\ &= \pi_A(x_A, x_B, q^*_{1A}(x_A,x_B), q^*_{2A}(x_A,x_B), q^*_{2B}(x_A,x_B)) \\ &+ \pi_B(x_A, x_B, q^*_{1A}(x_A,x_B), q^*_{2A}(x_A,x_B), q^*_{2B}(x_A,x_B)) \\ &- \gamma x_A^2 - \gamma x_B^2 \end{aligned} \tag{3.19}$$

The first-order condition for investment under joint profit maximization for firm $i$ in expression (3.19) is

$$\frac{d(\Pi_A + \Pi_B)}{dx_i} = \frac{d(\pi_A + \pi_B)}{dx_i} - 2\gamma x_i = 0 \tag{3.20}$$

where $d(\pi_A + \pi_B)/dx_A$ and $d(\pi_A + \pi_B)/dx_B$ are net marginal increases in the firms' joint profit. This then leads to

$$R_i^C(x_j) = arg\max_{x_i} \; [\Pi_A + \Pi_B]. \tag{3.21}$$

For convenience and abusing somewhat usual conventions we call $R_i^C(x_j)$, in what follows, reaction functions under cooperation[6].

**Lemma 3.2** *The slope of $R_i^C(x_j)$ under R&D cooperation is negative if $0 \leq \beta < 1/2$ and $0 \leq g \leq \bar{g}_C(\beta) \equiv \sqrt{8(\beta - 2)(2\beta - 1)/(16 + \beta(16\beta - 31))}$ and positive otherwise.*

Specifically, for the R&D investment level of firm A, by applying the Envelope Theorem, we obtain the following marginal benefit of joint profit maximization:

$$\begin{aligned} \frac{d(\pi_A + \pi_B)}{dx_A} &= \frac{d\pi_A}{dx_A} + \frac{d\pi_B}{dx_A} \\ &= \underbrace{\frac{d\pi_A}{dx_A}}_{\text{Prop. 3.1}} + \underbrace{\underset{+}{\frac{\partial \pi_B}{\partial x_A}}}_{\text{spillover effect}} + \underbrace{\underset{-}{\frac{\partial \pi_B}{\partial q_{A2}}} \underset{+}{\frac{\partial q^*_{A2}}{\partial x_A}}}_{\substack{\text{within-product} \\ \text{coordination effect}}} + \underbrace{\underset{-}{\frac{\partial \pi_B}{\partial q_{A1}}} \underset{-}{\frac{\partial q^*_{A1}}{\partial x_A}}}_{\substack{\text{cross-product} \\ \text{coordination effect}}} \end{aligned} \tag{3.22}$$

Similarly, we obtain the following result for firm B's investment:

$$\begin{aligned} \frac{d(\pi_A + \pi_B)}{dx_B} &= \frac{d\pi_B}{dx_B} + \frac{d\pi_A}{dx_B} \\ &= \underbrace{\frac{d\pi_B}{dx_B}}_{\text{Prop. 3.1}} + \underbrace{\underset{+}{\frac{\partial \pi_A}{\partial x_B}}}_{\text{spillover effect}} + \underbrace{\underset{-}{\frac{\partial \pi_A}{\partial q_{B2}}} \underset{+}{\frac{\partial q^*_{B2}}{\partial x_B}}}_{\substack{\text{within-product} \\ \text{coordination effect}}} \end{aligned} \tag{3.23}$$

Cooperation may increase the incentive to conduct R&D by internalizing spillovers across the firms. However, R&D investment makes firms tougher competitors;

[6]The closed forms are given in the Appendix by formulas (3.43) and (3.44).

hence, the effect of cooperation may be to reduce the incentive to conduct R&D.

The (strategic) effects of the first term, $d\pi_i/dx_i$, $i = A, B$, are derived and analyzed under R&D competition in Section 3.5 above. Under cooperation, each firm, also cares about how its choice of R&D investment affects the profit of its competitor. Hence, we identify a *spillover effect* and two further strategic effects under R&D cooperation:

(i) *within-product coordination effect.* - A firm's investment decision is influenced by the effect on its competitor's profit through changes in its own output decision of the same product.

(ii) *cross-product coordination effect.* - A firm's investment decision is influenced by the effect on its competitor's profit through its own output decision of the substitute product.

We summarize the additional effects of R&D investment due to cooperation on the firms' joint gross profit in the following proposition.

**Proposition 3.2** *When $x_i$ increases, firm j's profit is influenced*
**(i)** *positively through the spillover effect*

**(ii)** *negatively through the within-product coordination effect.*
*Additionally,*
**(iii)** *when firm A increases its R&D investment, it also influences firm B's profit positively through the cross-product cooperation effect.*

When R&D by one firm spills over to the other firm, private incentives to conduct R&D are reduced due to potential free-riding. If firms choose R&D investment levels cooperatively, then these spillover externalities are internalized, and R&D investment is stimulated. An increase in one firm's R&D investment reduces the other firm's cost due to the technology spillover; hence, lower costs increase rivals profit.

The *within-product coordination effect* decreases a firm's investment incentives as it also cares about its rival's profit under cooperation. When a firm invests more in the new technology, it increases its output of the innovative product, as seen in expression (3.9). As a result, the competitor faces a decline in its market share and suffers from a loss of its profit.

The *cross-product coordination effect* only exists for the multi-product firm in this asymmetric set-up as it internalizes its positive impact on the single-product firm's profit when it reduces its output of the traditional good to mitigate within-firm cannibalization. The *cross-product coordination effect* is always positive because the new technology good becomes more competitive towards the established good by approaching the cost level of the established good. This effect is strengthened if the products are closer substitutes because then the multi-product firm will lose a significant competitive advantage in the established good.

Within-product competition and cooperation effects indicate how R&D investment influence profits through the new technology good, whereas the cross-product competition and coordination effects indicated how R&D investment influence profits through the traditional good.

The overall marginal benefit of a firm's cost-reducing investment under R&D cooperation depends on the relative magnitudes of the direct and spillover effects and three strategic effects, where some of the strategic effects differ for the multi-product and the single-product firm.

## 3.7 R&D Competition vs. Cooperation

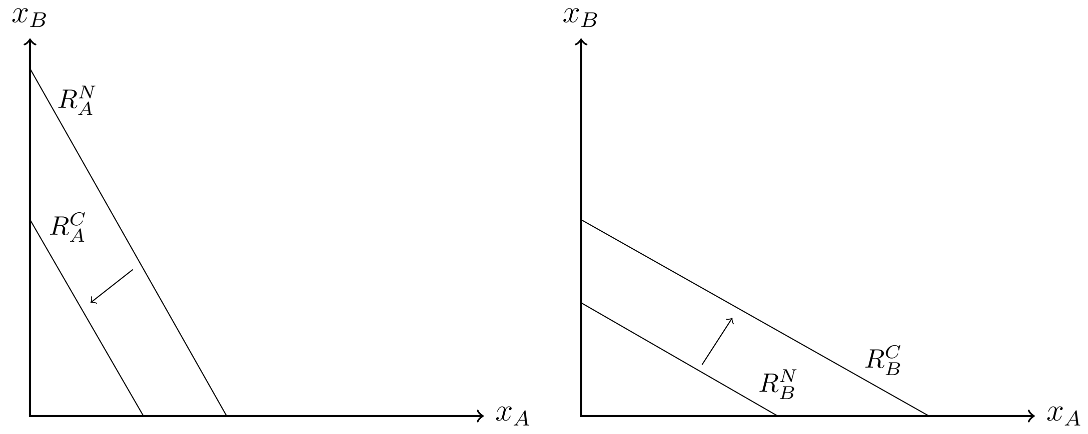
We next analyze the equilibrium R&D investment levels of each firm under competition and cooperation. In order to do so, we compare the reaction functions $R_i^C(x_j)$ and $R_i^N(x_j)$ in the $x_A - x_B$-diagram. Whether $R_i^C(x_j)$ under cooperation lies above or below $R_i^N(x_j)$ under competition depends only on the sign of the profit externality, $d\pi_j/dx_i$, in equations (3.22) and (3.23). If $R_i^C(x_j)$ is above (below) $R_i^N(x_j)$, a firm will respond with a higher (lower) investment level under cooperation than under competition.

By adding the spillover-, within-product coordination- and cross-product coordination-effects of expression (3.22), we obtain the profit externality conferred by A's R&D investment on the profit of firm B:

$$\frac{d\pi_B}{dx_A} = \frac{2}{3}(2\beta - 1)q_{B2} \tag{3.24}$$

Since $q_{B2}$ is always positive, the position of $R_A^C(x_B)$ depends only on the level of the spillovers.

**Lemma 3.3** *For all* $0 \leq g < 1$, $R_A^C(x_B)$ *lies below* $R_A^N(x_B)$ *if* $0 \leq \beta < 1/2$ *and above* $R_A^N(x_B)$ *if* $1/2 < \beta \leq 1$.




$R_A^C(x_B)$ below $R_A^N(x_B)$ $\qquad$ $R_B^C(x_A)$ above $R_B^N(x_A)$

Figure 3.2: Positions of reaction functions

The result follows from the fact that the negative within-product coordination effect outweighs the sum of the positive spillover- and cross-product cooperation effects when the spillover is small, as illustrated in Figure 3.2. However, when the spillover is large, the opposite is true.

From expression (3.23) we derive the profit externality of firm B's R&D investment on the profit of firm A:

$$\frac{d\pi_A}{dx_B} = \frac{2}{3}(2\beta - 1)q_{A2} - \frac{1}{3}g(2 - \beta)q_{A1} \tag{3.25}$$

The first term, $2(2\beta - 1)q_{A2}/3$, is positive if and only if $\beta > 1/2$, whereas the second term, $-g(2 - \beta)q_{A1}/3$, is always negative. Hence, the position of $R_B^C(x_A)$

of firm B under cooperation depends not only on the knowledge spillover but also on the degree of product differentiation between goods 1 and 2. The reaction function $R_B^C(x_A)$ lies above $R_B^N(x_A)$ whenever the second term is negligible; that is if $g$ approaches zero.

**Lemma 3.4** *There is an upward sloping function $g_B^C(\beta) : [1/2, 1] \rightarrow (0, 1)$ such that $R_B^C(x_A)$ lies above $R_B^N(x_A)$ if $1/2 < \beta \leq 1$ and $0 \leq g \leq g_B^C(\beta)$, and below otherwise.*

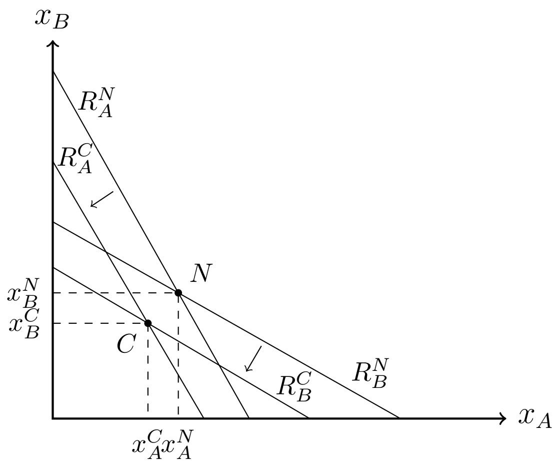
Firm B also internalizes the impact of its R&D on the other firm through cooperation. However, as firm B only produces the innovative good, the positive cross-product coordination effect on firm A's established product does not exist. Hence, there are only two opposing effects of R&D cooperation on the investment incentives of firm B. On one hand, if firms choose R&D investment levels cooperatively, then the spillover externalities are internalized, and R&D investment is stimulated. On the other hand, the within-product coordination effect counteracts this positive effect on R&D investment incentives and may even dominate it when spillovers are high and product substitutability is high. This case happens when firm A's loss in profit due to a decline in its market share in both products will not be offset by an increase in its profit due to reduced marginal cost. If the products are close substitutes firm A will lose significant market power in product 1 following R&D investment by firm B which cannot be offset by the spillover effect.

Having analyzed the effect of cooperation on the incentives to invest in R&D we are now able to determine the equilibrium R&D investment levels of both firms. The directions of the slopes of the reaction functions under R&D competition and under R&D cooperation are known from Lemmas 3.1 and 3.2, respectively. In addition, Lemmas 3.3 and 3.4 describe the positions of the respective reaction functions under R&D cooperation compared to R&D competition. We note that these functions are linear[7].

If spillovers are sufficiently low (i.e. $0 \leq \beta < 1/2$), we know from Lemmas 3.3 and 3.4 that both $R_A^C(x_B)$ and $R_B^C(x_A)$ are below the reaction functions under competition for all degrees of product substitutability. Hence, it follows directly

[7]This is easily seen from equations (3.26) - (3.27) and (3.43) - (3.44).

that, in this case, R&D investment levels under cooperation are lower than under R&D competition. Figure 3.3 illustrates this in the $x_A - x_B$-diagram.




$0 < \beta < 1/2$, $0 < g < \bar{g}_N(\beta)$

Figure 3.3: Optimal R&D investment levels under competition and cooperation

Similarly, if spillovers are sufficiently high (i.e. $1/2 \leq \beta \leq 1$) and at the same time, the degree of product substitutability is low (i.e. $0 \leq g < g_B^C(\beta)$), then both $R_A^C(x_B)$ and $R_B^C(x_A)$ lie above the reaction functions under competition. It is thus straightforward to see that then R&D investment levels under cooperation are higher for both firms.

When the positions are in the same direction, it is simple to determine the effect of cooperation on R&D levels. However, when this is not the case, it becomes more cumbersome. We illustrate all different cases subsequently.

Let us consider the case when $1/2 \leq \beta \leq 1$ and $g_B^C(\beta) < g < 1$, which is illustrated in Figure 3.4. By Lemmas 3.1 and 3.2, slopes of all reaction functions are upward sloping. By Lemma 3.3 $R_A^C(x_B)$ lies above $R_A^N(x_B)$ , while by Lemma 3.4 $R_B^C(x_A)$ lies below $R_B^C(x_A)$.

We observe two possible scenarios. First, the difference between $R_i^C(x_j)$ and $R_i^N(x_j)$ is of similar size and second, the difference between $R_B^C(x_A)$ and $R_B^N(x_A)$ is significantly larger than the difference between $R_A^C(x_B)$ and $R_A^N(x_B)$. The latter one occurs when the spillover approaches 1/2 and the degree of substitutability is positive. Then, we observe from equation (3.24) that the difference $(R_A^C(x_B) - R_A^N(x_B))$ is approaching zero. Additionally, the difference $(R_B^C(x_A) - R_B^N(x_A))$ is significant as the first term in equation (3.25) is negligible, while the second term increases as $g$ increases.

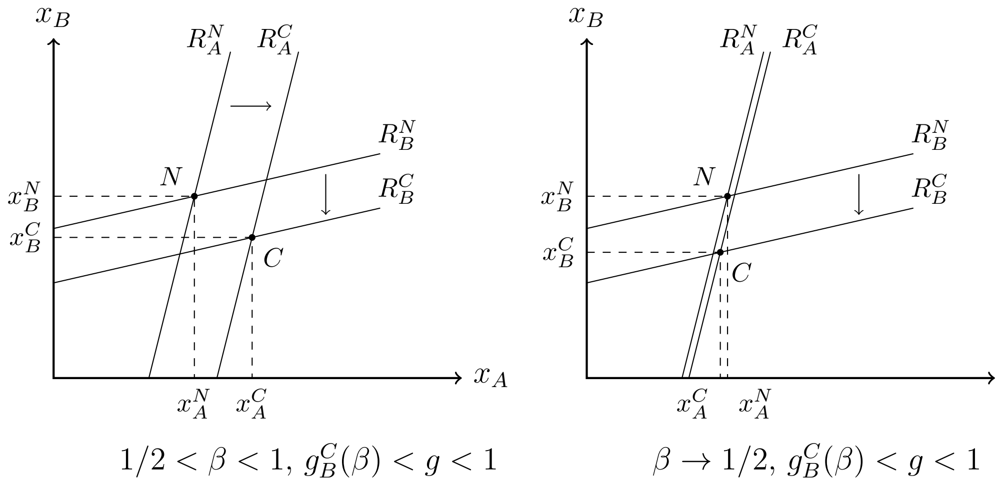



Figure 3.4: Optimal R&D investment levels under competition and cooperation

From the two diagrams in Figure 3.4 we can see that, in the observed interval, the R&D investment level of firm B is lower under cooperation than under competition. Additionally, the R&D investment level of firm A could also be lower under cooperation than under competition when $\beta \to 1/2$ and $g \neq 0$.

In the following Proposition, we summarize the effects of R&D cooperation on the investment levels of both firms when all parameter constellations are taken into account. Figure 3.5 illustrates these results graphically.

**Proposition 3.3** *There is an upward sloping function $g_A^C(\beta) : [0,1] \to (0,1)$ such that:*

*(i) $x_A^C < x_A^N$ if $0 < \beta \leq 1/2$ for $0 < g \leq 1$ and if $1/2 < \beta < 1$ for $g_A^C(\beta) < g < 1$; otherwise $x_A^C > x_A^N$.*

*(ii) $x_B^C < x_B^N$ if $0 < \beta \leq 1/2$ for $0 < g \leq 1$ and if $1/2 < \beta < 1$ for $g_B^C(\beta) < g < 1$; otherwise $x_B^C > x_B^N$.*

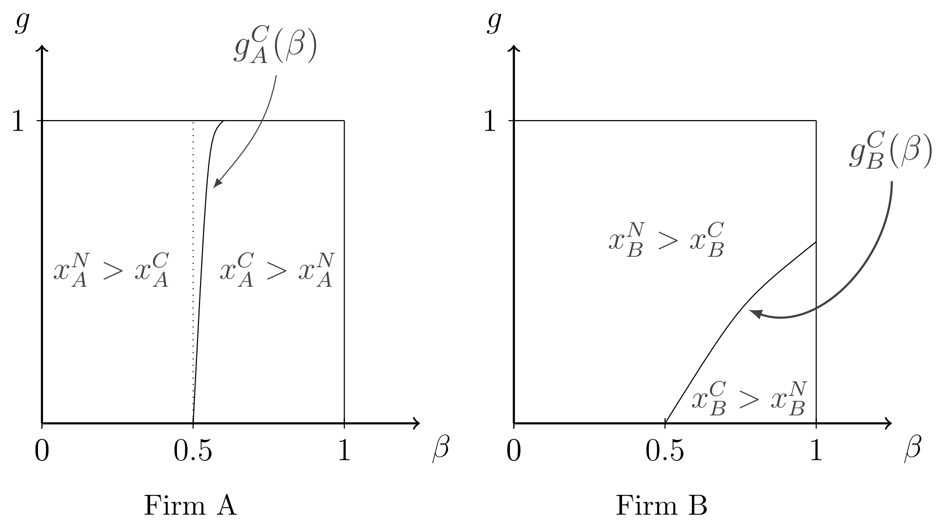



Figure 3.5: Comparison of R&D investments under competition and cooperation

We find that whether the level of R&D investment, $x_i$, increases or decreases following cooperation depends not only on the technological spillover but also on the degree of substitution between the two products. If spillovers are sufficiently high and the degree of substitution is relatively low, R&D investment levels under cooperation exceed those of competition. The internalization leads to an increase in R&D because the positive effect of the spillover on firm $j's$ profit is higher than the adverse effect of the reduction in the marginal cost on firm $j's$ profit.

If the products are independent ($g = 0$), our result replicates the standard result by D'Aspremont and Jacquemin (1988), as seen in Figure 3.5. Due to the positive product differentiation in our analysis, we find that the R&D investment of firm B is higher under competition than under cooperation even when the spillover is high.

From a policy perspective, it is important to determine the overall effect of cooperation on total R&D due to the marginal cost reduction. Total R&D depends on the sum of the changes in $x_A$ and $x_B$. Let total competitive R&D investment be $x^N \equiv x_A^N + x_B^N$ and total cooperative R&D investment be $x^C \equiv x_A^C + x_B^C$. The next proposition directly follows from Proposition 3.3. Figure 3.6 illustrates the result.

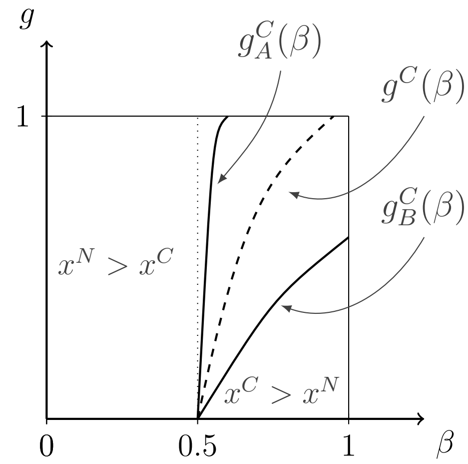



Figure 3.6: Comparison of total R&D investment

**Proposition 3.4** *Total investment under cooperation is lower than under competition if* $0 < \beta \leq 1/2$ *and* $g > 0$ *and if* $1/2 < \beta < 1$ *and* $g$ *high enough.*

When $\beta > 1/2$ and $g_B^C(\beta) < g < g_A^C(\beta)$, cooperation will reduce $x_B$ but increase $x_A$. It is, therefore, unclear whether R&D competition or R&D cooperation lead to a higher overall investment level. The net effect on total R&D will depend on the magnitudes of these changes.

We simulate the overall effect of cooperation on total R&D. We use the following specification: $a = 1000$, $c = 50$ and $\gamma = 60$. The resulting Figure 3.6 shows that, indeed, there exists a function $g^C(\beta)$, such that for for every $g > g^C(\beta)$ and $\beta > 1/2$ the overall investment in R&D under competition is greater than under R&D cooperation.

## 3.8 Conclusion

In this chapter, we study strategic R&D investment between a multi-product firm and a single-product firm. Investigating whether such asymmetric firms should be allowed to coordinate their decisions at the R&D stage, as in D'Aspremont and Jacquemin (1988), we find that R&D investment levels under cooperation are lower when the established and the innovative product are close substitutes even if the spillover is substantial. Hence, the asymmetry between the firms leads to higher R&D investment levels under competition than under cooperation for many values of the technology spillovers and degrees of product substitution. Our results, therefore, indicate that regulators need to be more cautious about allowing R&D joint ventures in an asymmetric context.

Besides, we also identify several strategic effects that are incorporated under R&D cooperation. For the multi-product firm, investment incentives are lower under cooperation when spillovers are low because the negative *within-product coordination effect* then dominates the positive spillover and *cross-product coordination* effects. For the single-product firm, if product substitutability is high, investment incentives are also lower under cooperation even when spillovers are significant. Following R&D investment by the single-product firm, the multi-product firm would lose significant market share in the established good if the products are close substitutes. Then this loss cannot be offset by the spillover effect.

It would seem natural to assume that the spillovers of the two firms are not identical, given that large multi-product firms can protect their patents better than smaller firms. Hence, we can extend our analysis for asymmetric spillovers, namely $\beta_A < \beta_B$. However, our main result (Proposition 3.4) still holds.

## 3.9 Appendix

**Proof of Lemma 3.1:**

From the optimal quantities (3.6)-(3.8) in the second stage and profit maximization of (3.13) with respect to $x_i$ the relevant first-order conditions lead to the following R&D best-response functions

$$\begin{aligned} R_A^N(x_B) =& \frac{1}{K_1}(a(g-1)(g-8+4\beta(1+g)) - c(8+g^2+4\beta(g^2-1)) \\ &+ (4(2-\beta)(2\beta-1) + (8+\beta(8\beta-11))g^2)x_B) \end{aligned} \tag{3.26}$$

$$R_B^N(x_A) = \frac{(2-\beta)(a-c-(1-2\beta)x_A)}{9\gamma-(2-\beta)^2} \tag{3.27}$$

where $K_1 = 36\gamma(1-g^2) - 16 + 7g^2 + 4\beta(\beta-4)(g^2-1)$. The derivative with respect to the strategic variable of the competitor, $x_j$, yields the slope of the reaction function. For firm A, we obtain from (3.26)

$$\frac{dR_A^N(x_B)}{dx_B} = \frac{(8+\beta(8\beta-11))g^2 - 4(\beta-2)(2\beta-1)}{36\gamma(1-g^2) - 16 + 7g^2 + 4\beta(\beta-4)(g^2-1)} \tag{3.28}$$

To determine the slope of $R_A^N(x_B)$ we need the sign of (3.28). By assumption 1 the denominator is always positive. Hence, it remains to show the sign of the numerator of (3.28), which has two components. The first component, $(8+\beta(8\beta-11))g^2$ is positive for all $0 < \beta < 1$ and $0 < g < 1$. The second component, $-4(\beta-2)(2\beta-1)$, is, for all $g \geq 0$, positive if $1/2 < \beta < 1$ and negative if $0 < \beta < 1/2$.

Therefore, the derivative in expression (3.28) is always positive if $1/2 \leq \beta < 1$. Moreover, if $0 < \beta < 1/2$, it is also positive if substitutability is high:

$$g > \bar{g}_N(\beta) \equiv \sqrt{\frac{4(\beta-2)(2\beta-1)}{8+\beta(8\beta-11)}} \tag{3.29}$$

For $0 < \beta < 1/2$ and $0 < g < \bar{g}_N(\beta)$, the derivative is negative.

For firm B, we obtain from (3.27)

$$\frac{dR_B^N(x_A)}{dx_A} = \frac{(2-\beta)(2\beta-1)}{9\gamma - (2-\beta)^2} \tag{3.30}$$

The sign of sign of (3.30) determines the slope of $R_B^N(x_A)$. Substituting $\gamma > \gamma_{min}$ (assumption 1) into the denominator we find that the denominator is always positive. Then it is easy to see that for all $g > 0$ the derivative in (3.30) is positive if $1/2 < \beta < 1$ and negative if $0 < \beta < 1/2$.

Hence, this concludes the proof of Lemma 3.1. ■

**Proof of Proposition 3.1:**

First, we derive each effect in (3.15) for firm A separately:

(i) From (3.1), (3.2) and (3.4), the direct effect

$$\frac{\partial \pi_A}{\partial x_A} = q_{A2} > 0 \tag{3.31}$$

is always positive.

(ii) The within-product competition effect consists of two components. From

(3.1), (3.2) and (3.4), the first component

$$\frac{\partial \pi_A}{\partial q_{B2}} = -(gq_{A1} + q_{A2}) < 0 \tag{3.32}$$

is always negative. The second component derived from (3.8)

$$\frac{\partial q^*_{B2}}{\partial x_A} = \frac{2\beta - 1}{3} \tag{3.33}$$

is positive if $1/2 < \beta \leq 1$, zero if $\beta = 1/2$ and negative otherwise. Hence, the within-product competition effect

$$\frac{\partial \pi_A}{\partial q_{B2}} \frac{\partial q^*_{B2}}{\partial x_A} = -\frac{2\beta - 1}{3}(gq_{A1} + q_{A2}) \tag{3.34}$$

is negative if $1/2 < \beta \leq 1$, zero if $\beta = 1/2$ and positive otherwise.

Second, we derive each effect in (3.16) for firm B:

(i) From (3.1), (3.2) and (3.5), the direct effect

$$\frac{\partial \pi_B}{\partial x_B} = q_{B2} > 0 \tag{3.35}$$

is always positive.

(ii) The within-product competition effect consists of two components. Also from (3.1), (3.2) and (3.5), the first component

$$\frac{\partial \pi_B}{\partial q_{A2}} = -q_{B2} < 0 \tag{3.36}$$

is always negative. The second component derived from (3.7) is given by

$$\frac{\partial q^*_{A2}}{\partial x_B} = \frac{4\beta + (2 - \beta)g^2 - 2}{6(1 - g^2)} \tag{3.37}$$

The denominator is always positive for $0 < g < 1$. Hence, the whole term is positive if

$$\beta > \frac{2g^2 - 2}{g^2 - 4} \equiv \bar{\beta} \tag{3.38}$$

Hence, the within-product competition effect

$$\frac{\partial \pi_B}{\partial q_{A2}} \frac{\partial q^*_{A2}}{\partial x_B} = -\frac{4\beta + (2-\beta)g^2 - 2}{6(1-g^2)} q_{B2} \tag{3.39}$$

is negative if $\bar{\beta} < \beta < 1$ and $0 \leq g < 1$ and positive otherwise.

(iii) The cross-product competition effect consists of two components. Also derived from (3.1), (3.2) and (3.5),the first component

$$\frac{\partial \pi_B}{\partial q_{A1}} = -g q_{B2} < 0 \tag{3.40}$$

is negative. The second component derived from (3.6)

$$\frac{\partial q^*_{A1}}{\partial x_B} = -\frac{\beta g}{2(1-g^2)} < 0 \tag{3.41}$$

is also negative. Hence, the cross-product competition effect

$$\frac{\partial \pi_B}{\partial q_{A1}} \frac{\partial q^*_{A1}}{\partial x_B} = \frac{\beta g^2}{2(1-g^2)} q_{B2} > 0 \tag{3.42}$$

is positive $\forall \beta, g$. ■

**Proof of Lemma 3.2:**

From optimal second stage quantities (3.6)-(3.8) and joint profit maximization of (3.19) with respect to $x_i$ the relevant first-order conditions yield $x_i$ as a function of $x_j$:

$$\begin{aligned} R^C_A(x_B) =& \frac{1}{K_2}(-4(1+\beta)c + (4\beta-5)cg^2 - a(g-1)(4-5g+4\beta(1+g)) \\ &+ (-8(\beta-2)(2\beta-1) + (16+\beta(16\beta-31))g^2)x_B) \end{aligned} \tag{3.43}$$

$$\begin{aligned} R^C_B(x_A) =& \frac{1}{K_3}(-c(4(1+\beta) + (5\beta-4)g^2) + a(g-1)(-4(1+g) + \beta(5g-4)) \\ &+ (-8(\beta-2)(2\beta-1) + (16+\beta(16\beta-31))g^2)x_A) \end{aligned} \tag{3.44}$$

where $K_2 = 36\gamma(1-g^2) - 20 + 11g^2 + 4\beta(5\beta-8)(g^2-1)$ and $K_3 = -32\beta(g^2-1) + \beta^2(11g^2-20) - 4(g^2-1)(9\gamma-5)$. The derivative of $R^C_i(x_j)$ with respect to the strategic variable of the competitor, $x_j$, yields the slope of $R^C_i(x_j)$. For firm

A, we obtain from (3.43)

$$\frac{dR_A^C(x_B)}{dx_B} = \frac{(16+\beta(16\beta-31))g^2 - 8(\beta-2)(2\beta-1)}{36\gamma(1-g^2) - 20 + 11g^2 + 4\beta(5\beta-8)(g^2-1)} \tag{3.45}$$

In order to determine the slope, we need the sign of (3.45). By assumption 1 the denominator is always positive. It remains to show the sign of the numerator of (3.45), which has two components. The first component, $(16+\beta(16\beta-31)g^2)$ is positive for all $0 \leq \beta \leq 1$ and $0 \leq g < 1$. The second component, $-8(\beta-2)(2\beta-1)$, is positive if $1/2 < \beta \leq 1$ and negative if $0 \leq \beta < 1/2$. Therefore, the derivative in expression (3.45) is always positive if $1/2 \leq \beta \leq 1$. Moreover, if $0 \leq \beta < 1/2$, it is also positive if substitutability is high:

$$g > \bar{g}_C(\beta) \equiv \sqrt{\frac{8(\beta-2)(2\beta-1)}{16+\beta(16\beta-31)}} \tag{3.46}$$

For $0 \leq \beta \leq 1/2$ and $0 \leq g \leq \bar{g}_C(\beta)$, the derivative is negative.

For firm B, we obtain from (3.44)

$$\frac{dR_B(x_A)}{dx_A} = \frac{(16+\beta(16\beta-31))g^2 - 8(\beta-2)(2\beta-1)}{-32\beta(g^2-1) + \beta^2(11g^2-20) - 4(g^2-1)(9\gamma-5)} \tag{3.47}$$

In order to determine the slope of $R_B^C(x_A)$, we need to determine the sign of (3.47). By assumption 1 we find that the denominator is always positive. It remains to show the sign of the numerator of (3.47), which is equivalent to the numerator of (3.45). Hence, for $0 \leq \beta < 1/2$ and $0 \leq g \leq \bar{g}_C(\beta)$, the derivative is negative. This concludes the proof of Lemma 3.2. ■

**Proof of Proposition 3.2:**

First, we derive each part in (3.22) for firm A. The first term, $d\pi_A/dx_A$ is derived in proposition 3.1. We use (3.1), (3.2) and (3.5) to determine some of the following components.

(i) The spillover effect given by

$$\frac{\partial \pi_B}{\partial x_A} = \beta q_{B2} > 0 \tag{3.48}$$

is positive.

(ii) The within-product coordination effect consists of two components. The first component

$$\frac{\partial \pi_B}{\partial q_{A2}} = -q_{B2} < 0 \tag{3.49}$$

is always negative. The second component derived from (3.7) is given by

$$\frac{\partial q^*_{A2}}{\partial x_A} = \frac{4 + (2\beta - 1)g^2 - 2\beta}{6(1 - g^2)} \tag{3.50}$$

The term is always positive for all $\beta, g \in [0, 1]$. Hence, the within-product coordination effect

$$\frac{\partial \pi_B}{\partial q_{A2}} \frac{\partial q^*_{A2}}{\partial x_A} = -\frac{4 + (2\beta - 1)g^2 - 2\beta}{6(1 - g^2)} q_{B2} \tag{3.51}$$

is always negative.

(iii) The cross-product coordination effect consists of two components. The first component

$$\frac{\partial \pi_B}{\partial q_{A1}} = -g q_{B2} < 0 \tag{3.52}$$

is negative. The second component derived from (3.6)

$$\frac{\partial q^*_{A1}}{\partial x_A} = -\frac{g}{2(1 - g^2)} < 0 \tag{3.53}$$

is also negative. Hence, the cross-product coordination effect

$$\frac{\partial \pi_B}{\partial q_{A1}} \frac{\partial q^*_{A1}}{\partial x_A} = \frac{g^2}{2(1 - g^2)} q_{B2} > 0 \tag{3.54}$$

is positive $\forall \beta, g$.

Second, we derive each effect of firm B in (3.23). The first term, $d\pi_B/dx_B$ is derived in proposition 3.1. For the following components, we use (3.1), (3.2) and (3.4).

(i) The spillover effect given by

$$\frac{\partial \pi_A}{\partial x_B} = \beta q_{A2} > 0 \tag{3.55}$$

is positive.

(ii) The within-product coordination effect consists of two components. The first component

$$\frac{\partial \pi_A}{\partial q_{B2}} = -(gq_{A1} + q_{A2}) < 0 \tag{3.56}$$

is always negative. The second component derived from (3.8) is given by

$$\frac{\partial q^*_{B2}}{\partial x_B} = \frac{2-\beta}{3} > 0 \tag{3.57}$$

is always positive. Hence, the within-product coordination effect

$$\frac{\partial \pi_A}{\partial q_{B2}} \frac{\partial q^*_{B2}}{\partial x_B} = -\frac{2-\beta}{3}(gq_{A1} + q_{A2}) \tag{3.58}$$

is always negative. ■

**Proof of Lemma 3.3:**

As seen in (3.22), the marginal benefit for firm A under cooperation can be decomposed into two components, where $d\pi_B/dx_A$ is the additional component under cooperation. Whether $R^C_A(x_B)$ lies above or below $R^N_A(x_B)$ under competition depends only on the sign of this additional component. If the additional component is positive, then $R^C_A(x_B) > R^N_A(x_B)$. When substituting (3.48), (3.51) and (3.54) into the additional component of (3.22) we obtain (3.24).

It is easy to see that whenever $\beta > 1/2$, then $d\pi_B/dx_A > 0$. Moreover, if $\beta < 1/2$, then $d\pi_B/dx_A < 0$ and if $\beta = 1/2$, then $d\pi_B/dx_A = 0$. This concludes the proof. ■

**Proof of Lemma 3.4:** In (3.23) the marginal benefit under cooperation for firm B can be decomposed into two components, where $d\pi_A/dx_B$ is an additional component under cooperation. Whether $R^C_B(x_A)$ lies above or below $R^N_B(x_A)$ under competition depends only on the sign of the additional component. If the additional component is positive, then $R^C_B(x_A) > R^N_B(x_A)$. When substituting (3.55) and (3.58) into the additional component of (3.23) we obtain (3.25). It is easy to show that if $0 \leq \beta < 1/2$ and any $g \geq 0$, then equation (3.25) will be negative.

Next, if $g = 0$ (as in D'Aspremont and Jacquemin (1988)) and $\beta = 1/2$, we have

$$\frac{d\pi_A}{dx_B} = 0. \tag{3.59}$$

This implies that then $R^C_A(x_B) = R^N_A(x_B)$.

If we now keep $\beta = 1/2$ and increase $g$, we have

$$\frac{d\pi_A}{dx_B} = -\frac{gq_{A1}}{2} < 0. \tag{3.60}$$

This means that for $\beta = 1/2$ and every $g > 0$ the reaction function under coordination is below the one under competition.

It remains to show what happens if $\beta > 1/2$ and $g > 0$. Expression (3.25) is positive if

$$g < g_B^C(\beta) \equiv \frac{2(2\beta - 1)q_{A2}}{(2-\beta)q_{A1}} \tag{3.61}$$

and negative otherwise.

Given that the quantities $q_{A1}$ and $q_{A2}$ depend on the parameter $g$ themselves, we cannot obtain the closed form for $g_B^C(\beta)$. However, when $1/2 < \beta \leq 1$, it is $2\beta - 1 > 0$ and also $q_{A1} > 0$ and $q_{A2} > 0$, $g_B^C(\beta) \in (0, 1)$. ■

**Proof of Proposition 3.3:** To compare R&D investment levels under competition and cooperation, we need to analyze the positions of $R_A^C(x_B)$ and $R_B^C(x_A)$ under R&D cooperation compared to $R_A^N(x_B)$ and $R_B^N(x_A)$ under R&D competition.

We observe that all relevant reaction functions, (3.26), (3.27), (3.43) and (3.44), are linear. Hence, it is convenient to compare R&D investment levels under cooperation and cooperation graphically in a $x_A - x_B$-diagram.

**Case 1: $0 \leq \beta < 1/2$.** According to Lemmas 3.3 and 3.4, both $R_i^C(x_j)$ under R&D cooperation lie below $R_i^N(x_j)$ , hence R&D investment levels under cooperation are lower than under competition. Figure 3.3 illustrates the case when $0 < g < \bar{g}_N(\beta)$. For this parameter range, from Lemmas 3.1 and 3.2, we know that the slopes of $R_i^k(x_j)$ for $k \in C, N$ are negative. The cases $\bar{g}_N(\beta) < g < \bar{g}_C(\beta)$ and $\bar{g}_C(\beta) < g < 1$ are depicted in Figure 3.7.

We conclude that when $0 \leq \beta < 1/2$ and $0 \leq g < 1$, both firms invest more under R&D competition than under R&D cooperation, hence $x_A^N > x_A^C$ and $x_B^N > x_B^C$.

**Case 2: $1/2 \leq \beta < 1$.** When $g_B^C(\beta) < g < 1$, by Lemma 3.3, $R_A^C(x_B) > R_A^N(x_B)$, while by Lemma 3.4, $R_B^C(x_A) < R_B^N(x_A)$. According to Lemmas 3.1 and 3.2 the slopes of the reaction functions under both regimes are positive. This

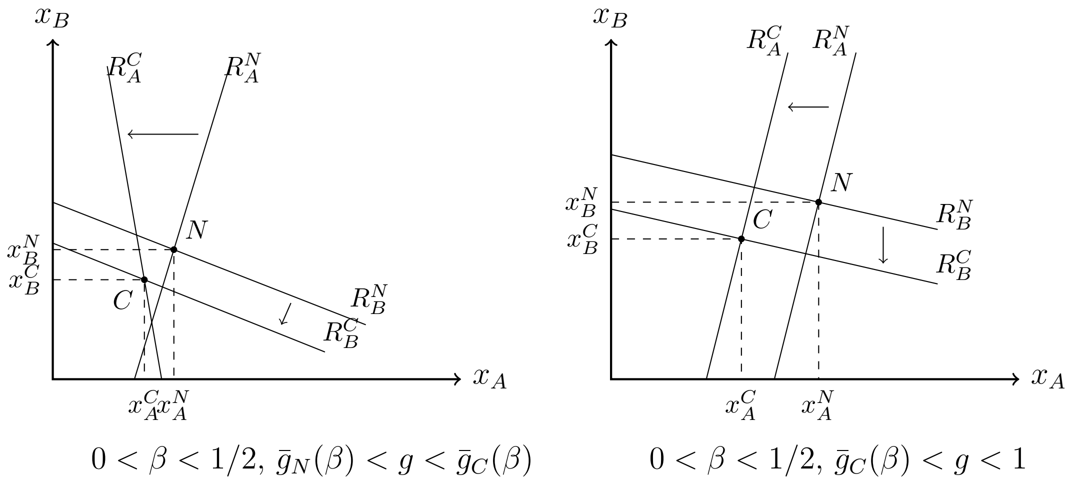



Figure 3.7: Optimal R&D investment levels under competition and cooperation

is illustrated in Figure 3.4. The R&D investment level of firm B is lower under cooperation than under competition and the R&D investment level of firm A could also be lower under cooperation than under competition when the difference $|R_B^C(x_A) - R_B^N(x_A)|$ is significantly greater than the difference $|R_A^C(x_B) - R_A^N(x_B)|$. This scenario happens when $\beta \to 1/2$ and $g \neq 0$. There exists a function $g^A(\beta) : [1/2, 1] \to (0,1)$ with $g_B^C(\beta) \leq g_A^C(\beta) \leq 1$ such that $x_A^N > x_A^C$, when $g > g_A^C(\beta)$ and $x_A^N < x_A^C$, when $g < g_A^C(\beta)$.

Moreover, when $\beta = 1/2$ and $g \in (0,1)$ by Lemma 3.3, $R_A^C(x_B) = R_A^N(x_B)$, while, by Lemma 3.4, $R_B^C(x_A) < R_B^N(x_A)$. This case is depicted in the left diagram of Figure 3.8. It is easy to see that $x_A^N > x_A^C$ and $x_B^N > x_B^C$. Only if $g = 0$, both (3.24) and (3.25) are the same as under competition such that $x_A^N = x_A^C$ and $x_B^N = x_B^C$.

It remains to analyze the case when $0 < g < g_B^C(\beta)$. According to Lemmas 3.3 and 3.4, $R_i^C(x_j)$ of both firms under cooperation lie above those under competition. According to Lemmas 3.1 and 3.2, the slopes are all positive. This is illustrated in the right diagram of Figure 3.8. It is easy to see that $x_A^N < x_A^C$ and $x_B^N < x_B^C$. ■

**Proof of Proposition 3.4:** From proposition 3.3, it follows directly that when

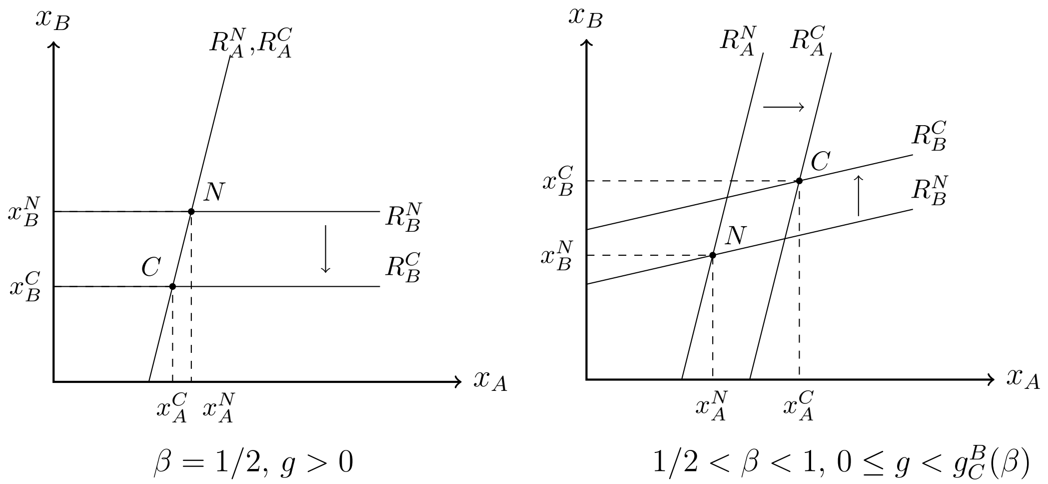



Figure 3.8: Optimal R&D investment levels under competition and cooperation

$0 < \beta \le 1/2$ and $0 < g < 1$ and when $\beta > 1/2$ and $g_C^A(\beta) < g < 1$:

$$x_A^C < x_A^N \tag{3.62}$$

$$x_B^C < x_B^N \tag{3.63}$$

Hence, for these parameter values, $x^C = x_A^C + x_B^C < x_A^N + x_B^N = x^N$.

Further on, in the area $1/2 < \beta < 1$ and $0 < g < g_B^C(\beta)$ the following holds:

$$x_A^C > x_A^N \tag{3.64}$$

$$x_B^C > x_B^N \tag{3.65}$$

Thus, for these parameter values, $x^C = x_A^C + x_B^C > x_A^N + x_B^N = x^N$.

In the remaining area, i.e. $1/2 < \beta < 1$ and $g_B^C(\beta) < g < g_A^C(\beta)$, we have

$$x_A^C > x_A^N \tag{3.66}$$

$$x_B^C < x_B^N \tag{3.67}$$

hence, there exists a function $g^C(\beta) : [0, 1] \to (0, 1)$ with $g_B^C(\beta) \le g^C(\beta) \le g_A^C(\beta)$, such that $x^C > x^N$, when $g > g^C(\beta)$ and $x^C < x^N$, when $g < g^C(\beta)$. We, however, do a numerical analysis for this special case. See Figure 3.6 for clarification. ■

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# Summary

This thesis addresses the interplay between regulation and investments in various contexts. The regulatory framework has a significant influence on the innovation activities of companies, industries, and whole economies. The first chapter investigates the effects of a net neutrality regulation on the competition between content providers and the investment incentives of the internet service provider. It considers a situation, in which a monopoly internet service provider is vertically integrated with one of the content providers, and content providers compete in prices. The results indicate that the integrated internet service provider and consumers as a whole are better off without net neutrality. From a social welfare perspective, no regulation is also desirable unless product differentiation and congestion intensity are low. Moreover, when the degree of product differentiation is low, investment incentives are lower without net neutrality. The second chapter explores investment incentives of competing network providers under different alternatives to access regulation. The network providers are an incumbent telecom operator and a cable operator and it is assumed that only the incumbent can grant access to its network. The results show that the cable operator invests more than the incumbent with access regulation while the incumbent invests more than the cable operator without access regulation. The results also indicate that without regulation the incumbent never forecloses the retail entrant from the market as this generates access revenues. Moreover, with investment sharing the incumbent and the entrant invest more than the cable operator. The analysis shows that co-investment leads to the highest social welfare as it provides strong investment incentives and intense retail market competition. The third chapter, joint work with Ružica Rakić, provides an analysis of the impact of cooperation on R&D investment incentives in a market where a multi-product firm competes with a single-product firm. Specifically, it considers the multi-product firm to produce an established good and an innovative good whereas the single-product firm only produces the innovative good. The results indicate that investment incentives with R&D cooperation are lower than with R&D competition when the established good and the innovative good are close substitutes even if the spillover is substantial.

# Zusammenfassung

Die vorliegende Dissertation beleuchtet das Zusammenspiel von Regulierung und Investitionen. Die regulatorischen Rahmenbedingungen haben einen großen Einfluss auf die Innovationsaktivitäten von Unternehmen. Im ersten Kapitel werden die Auswirkungen einer Netzneutralitätsregulierung auf den Wettbewerb zwischen Inhalte-Anbietern sowie die Investitionsanreize eines Internet-Anbieters untersucht. Dabei geht es darum, dass ein monopolistischer Internet-Anbieter mit einem der Inhalte-Anbieter vertikal integriert ist, und mit einem anderen Inhalte-Anbieter im Preiswettbewerb steht. Die Ergebnisse zeigen, dass sowohl der Internet-Anbieter als auch die Verbraucher ohne Netzneutralität besser gestellt sind. Auch aus sozialer Sicht ist Netzneutralität nicht wünschenswert, solange Produktdifferenzierung und Netzüberlastung gering sind. Allerdings sind die Investitionsanreize nicht immer höher ohne Regulierung. Das zweite Kapitel untersucht die Investitionsanreize konkurrierender Netzbetreiber unter verschiedenen Alternativen zur Netzzugangsregulierung. Die Netzbetreiber sind ein etablierter Telekommunikationsnetzbetreiber und ein Kabelnetzbetreiber. Unter der Annahme, dass nur der Telekommunikationsbetreiber Zugang zu seinem Netz gewähren kann, wird gezeigt, dass der Kabelnetzbetreiber mehr investiert als der Telekomanbieter mit Zugangsregelung, wohingegen der Telekomanbieter mehr als der Kabelnetzbetreiber ohne Zugangsregelung investiert. Ohne Zugangsregulierung gewährt der Telekommunikationsnetzbetreiber einem Dritten immer Zugang zu seinem Netz, da er dadurch zusätzliche Einnahmen generieren kann. Die Analyse zeigt auch, dass Co-Investment zu dem höchstem Wohlfahrtsniveau führt, da dies zu starken Investitionsanreizen im Netzausbau und intensiven Wettbewerb fhrt. Das dritte Kapitel, eine gemeinsame Arbeit mit Ružica Rakić, analysiert die Auswirkungen einer Forschungs-und Entwicklungs (FuE)- Kooperation auf die Investitionsanreize in einem Markt, in dem eine Mehrproduktfirma mit einem Einzelproduktunternehmen konkurriert. Die Multiproduktfirma produziert sowohl ein etabliertes Produkt als auch ein innovatives Produkt, wobei die andere Firma nur das innovative Gut produziert. Die Ergebnisse zeigen, dass die Investitionsanreize mit einer FuE-Kooperation meist geringer sind als bei Wettbewerb, so auch wenn die Produkte enge Substitute sind und die Wissensübertragung erheblich ist.