6. Experimental Evaluation of different Market Mechanisms for Knowledge Trading

To evaluate the appropriateness of knowledge markets, we experimentally test the hypothesis that a knowledge market leads to an increased contribution of knowledge as opposed to an open knowledge repository. For this purpose, we have designed and used the *Data Trader Game* [138, 137, 85, 81]. This is a computer-assisted game for testing different market mechanisms and their effects on knowledge transfer. The data-trader game consists of two elements: a business game and a knowledge contribution mechanism. In the business game, the players must solve a decision problem with uncertain information, as efficiently as possible. They may improve their decision by acquiring knowledge assets from others. For the contribution of knowledge, we have modelled six types of knowledge-transfer mechanisms. These are a public-good situation, a posted-price auction, a sale at fixed prices, Vickrey and English auction as well as a call market. Hereby, we measure success with respect to the degree of knowledge transfer achieved by a knowledge transfer mechanism.

6.1. Experimental Environment

We developed the Data Trader Game to experimentally test the different propositions of Section 5.7.4, and analyzed which auction types might be an appropriate medium for knowledge transfer. We established an experimental game environment in which different types of auctions can be tested on different groups of participants.

6.1.1. Overview

The Data Trader Game is a non-cooperative game—i.e. communication among the participants of the game is strictly prohibited, and the creation of obligatory agreements outside the market is not allowed either. The game consists of two parts: a business game and a knowledge transfer mechanism. The business game gives the player the motive for knowledge sharing because the more knowledge assets the player has the better he can solve the decisions in the business game. The knowledge transfer mechanism allows the player to transfer knowledge assets to other players and to receive monetary compensation, if applicable.

The aim of the game—from the view of the market designer—is to maximize the benefit of all players while optimizing the allocation of knowledge and other goods. The tradable knowledge assets consist of information packages. Within the Data Trader Game, the knowledge market serves as a tool to optimize the knowledge transfer. In each round, a player owns only one knowledge asset. However, it is possible to purchase usage rights for further knowledge assets during the game. After each round the profit of each player is calculated.

6.1.2. Description of the Game Environment

The players act as managers from different countries. They all produce a different kind of product, which they want to sell to the other players' countries. For this reason they need to know the demand for their product in each foreign country. The other players own this information. However, each player knows the demand of all products including his own product in his own country. There is no competition between the players because the products from the different countries' markets do not compete with each other.

There are n=8 players. Each player i ($1 \leq i \leq n$) is the only producer of the product i. The player i resides in country i. As the origin for each player i is in the country i, the player has better market knowledge about his country than the rest of the players. He knows the demand d_{ij} in his country i of all products j, $1 \leq j \leq n$, including the demand for his own product i in country i. Therefore, the tradable knowledge assets ka_i consist of all demand information in the country i, i.e. $ka_i = (d_{i1}, \ldots, d_{in})$. This knowledge is owned by the player of the respective country, (see Figure 6.1). An exception is the call market: to also model supply competition, each knowledge asset of a player additionally contains the demand information of their two neighboring countries.

6.1.3. Game Process

The game is sketched in Figure 6.2 as a UML activity diagram.

Registration. Each player has to register before the game period can start. Each player receives a start capital of 800 tokens for period 1. Tokens are used as the currency of the game.

After the registration all players pass through the following steps, in each period:

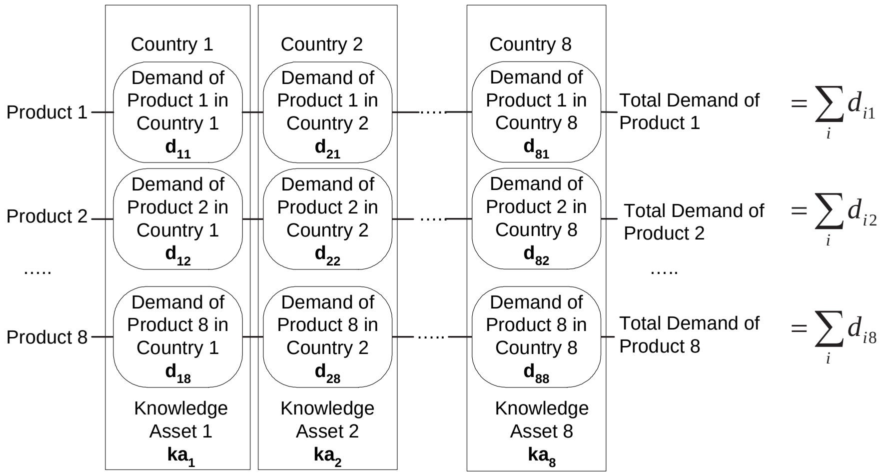

Figure 6.1.: Knowledge Assets and Demand by country and product

Knowledge Trading. At the beginning of each round each knowledge account contains exactly one knowledge asset with information about the demand for the different products (including one's own product) in the player's country. The demand is generated by the system and is randomly chosen with equal probability from the interval (1, 99). At the beginning of each of the following periods each player will receive additional 80 tokens. Firstly, each player receives an overview of the demands of the products in his own country.

In the next step, the players can decide whether or not they want to offer their knowledge in a knowledge market. A player can simultaneously act as a seller and as a purchaser. If a player wants to purchase or sell knowledge assets, he has to make a bid. If a player submits one of the winning bids in one of the knowledge markets, he receives the usage rights for this asset. The sharing of knowledge is time consuming, and therefore costly to the contributor. Also, he loses the (possible) advantage that he is the only one with that knowledge asset. Therefore, explication costs of eight tokens (10% of the periodical pay-out of each player) will be charged as a transaction fee. This fee has to be paid by the seller. Depending on the knowledge-transfer mechanism the player can now choose to sell and/or purchase the knowledge assets or bid for them.

We analyze the following six knowledge-transfer mechanisms: public-good situation, fixed price, English auction, posted price, Vickrey auction and call market. The function of the different knowledge-transfer mechanisms is ex-

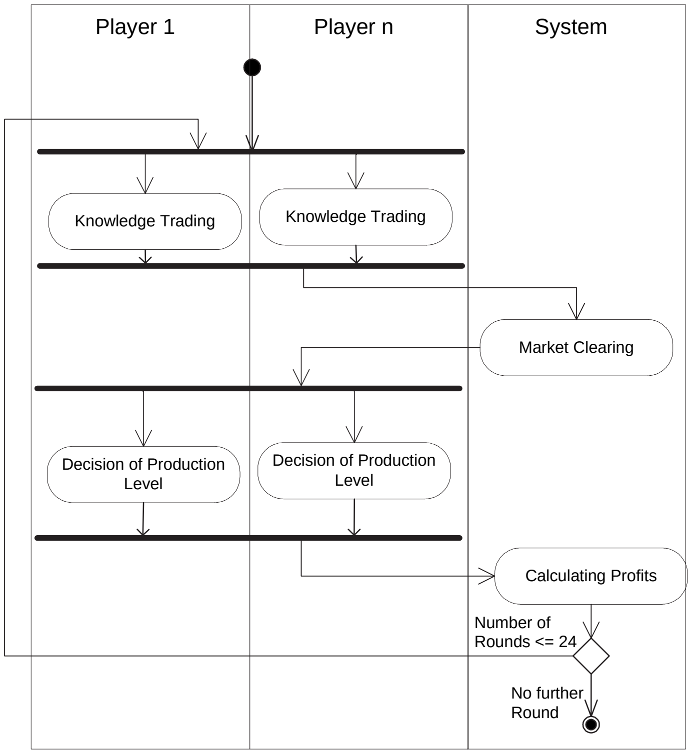

Figure 6.2.: Activity Diagram of the Game

plained in Section 5.7.2 on page 131.

Market Clearing. After all bids are collected from the players, the experimental system decides (1) who gets access to which knowledge assets and (2) how much each player must pay, depending on the knowledge transfer mechanism. The players can then study the knowledge assets they have access to. When all players have finished their transactions, they can proceed to the next step.

Decision of Production Level. The player has to determine the supply of his product for each country. The goal is to try to be as close to the actual demand as possible.

Calculating Earnings. Subsequently the production levels are evaluated in the form of a status report. The status report shows the success of the business decisions. The player will receive a surcharge if his estimated demand differs from the actual demand. In this case the difference will be subtracted from his deposit.

New Round. After the round is finished, the system updates the payoff account of each player and launches a new round, provided that the previous round was not the last one.

6.1.4. Experimental Realization

The motivation of test persons is a critical aspect in experimental economic research. The main problem is to apply the incentive system of the model perfectly to the test person, in order to provide for high identification and to ensure adequate relevance in the decision-making behavior of the test person. For this purpose the participants usually receive a financial reimbursement, to eliminate the risk of bias caused by individual preferences in non-monetary reward systems [200, p. 44]. The announced prize for the winner of the game was 40 Euros. Given a duration of the game of approximately 45 minutes with 8 players this means that the expected reward per hour was approximately 6.66 Euro. This is about the wage level of a student job. Therefore, the incentives are relevant for the players.

The software of this computer supported experiment is web-based. However, all experiments were conducted under laboratory conditions. The players were divided randomly into groups of eight people. Within each experiment there were 24 rounds to play (exception: English auction with 12 rounds). Six different playing variants representing the different market mechanisms (see Section 5.7.2) were implemented.

It was possible to recruit 80 students as test persons for the experiment. 56 participants were students from the Freie Universität Berlin, and 24 were students from the Otto-von-Guericke Universität, Magdeburg. Although the participants were students, the transferability of our reasoning is warranted according to Davis and Holt [52, p. 17].

The local conditions and the number of experiments were designed as follows: 7 experiments were carried out in the computer labs of the Department of Economics at the Freie Universität Berlin, and 3 experiments were held at the Department of Information Systems of the Otto-von-Guericke Universität, Magdeburg. 4 of the 6 mechanisms were conducted twice; the remaining 2 mechanisms were executed only once (fixed price and English auction). Table 6.1 shows in which locations the experiments were conducted.

The computer labs were each equipped with 9 computers, where 8 were intended for the test persons, and one for the supervisor. Partition walls separated the different workplaces. Therefore, the information displayed on the screens or entered via the

Knowledge Transfer Mechanism	Experiments in Berlin	Magdeburg	$\sum$
Public-Good Situation	1	1	2
Fixed Price	1		1
English Auction	1		1
Posted Price	2		2
Vickrey Auction	1	1	2
Call Market	1	1	2
$\sum$	7	3	10

Table 6.1.: Overview of Game Types in Each Location

keyboard were not visible to the other participants. Moreover any discussion among the test persons was not allowed. To ensure the necessary anonymity and impartiality of the decisions, the participants were personally supervised.

The participants of the experiment were free to choose one of the available workplaces in the computer lab. Before the execution of the experiment starts, the instructions and rules were read to the test persons. Afterwards they were given to everybody in printed form, along with a detailed description of the respective experiment. Each player was assigned a random number. Any further questions were answered separately by one of the supervisors. Direct communication among the participants was prohibited—interaction was only possible through the software user interface.

The Data Trader Game provided all required information for the game. The test persons entered their decision values by mouse and keyboard. The entered data was simultaneously processed by the system, which stored it in a database for further statistic analysis. After all the game activities were finished, the winner was determined and received the announced amount of money in cash. All the participants of a game were advised not to talk about their results to other students in order to avoid any interferences with further experiments.

6.2. Experimental Results

6.2.1. Cut-offs

The first two rounds of the game were not taken into account for analysis due to inertia effects, but were considered as test rounds (according to [178]). However, the test persons were not aware of this situation (cf. [178, p. 13]).

6.2.2. Measures

The first variable is the *transaction ratio*. This is the ratio between the actually executed transactions and the amount of possible transactions. This measure is used to make the different knowledge-transfer mechanisms comparable, which is difficult because these different mechanisms allow varying numbers of transactions. We define the transaction ratio *TR* in round k as

$$TR_k = \frac{\sum_j T_j^k}{TP} \tag{6.1}$$

where *TP* is the maximal number of possible transactions, and $\sum_j T_j^k$ is the sum of all actual transactions of all players ($1 \leq j \leq n$) in round k.

The maximum number of transactions (*TP*) for public good, posted price, fixed price and English auction is 56 (8 players each can sell their knowledge assets to the other 7 players). For the Vickrey auction *TP* is 32 (8 players can sell knowledge assets to the highest 4 bids), and for the call market *TP* is 24 (8 players can buy 3 knowledge assets).

The second measure is the decision error (*DE*), which is the difference between the estimated and actual demand. It measures the success of the decision-making in the business game. Let d_{ij}^k be the demand of product j in country i in round k. For the player j the decision error DE_j^k in round k is the sum of all the absolute differences of his supply decisions s_{ij}^k with the respective demand:

$$DE_j^k = \sum_i |d_{ij}^k - s_{ij}^k| \quad . \tag{6.2}$$

The total decision error in round k is consequently $DE_k = \sum_j DE_j^k$.

Four knowledge-transfer mechanisms have been executed twice, and two mechanisms have been conducted once under experimental conditions. To ensure comparability of the different mechanisms, we try to further aggregate the data from the knowledge-transfer mechanisms repeated twice. In the following, we analyze if an aggregation is appropriate.

6.2.3. Group Effect

The question has to be answered whether the data from both available random samples may be aggregated or not. For this purpose, the U-Test was used to test for significant differences between the groups. The U-Test or Mann and Whitney Test [26, p. 135] can be used to compare two independent random samples according to their level or mean. The U-Test is a two-sided non-parametric test, which can be used even if the data is not normally distributed. The results of the U-Test (see Table 6.2) with a significance level of $p = 0.05$ shows that the two samples from the posted-price auction as well as from the Vickrey auction can be viewed as one sample from a uniform population. Therefore, it is possible to aggregate the two experiments of each auction. The two samples for the public-good situation and for the call market were significantly different. Therefore, we analyze these samples separately.

Table 6.2.: Result of the U-Test for the different Experiments

Knowledge-Transfer Mechanism	Hypothesis	p-Value	Aggregation
Public-Good Situation	$\mu_B = \mu_M$	0.036	No
Posted-Price Auction	$\mu_{B1} = \mu_{B2}$	0.234	Yes
Vickrey Auction	$\mu_B = \mu_M$	0.300	Yes
Call Market	$\mu_B = \mu_M$	0.000	No

Decision rule: $p > 0.05$. Location of the experiment: B = Berlin, M = Magdeburg

6.2.4. Round Aggregation

Samples which can be merged are aggregated as follows: The average is computed for the transaction ratio (TR_k), for each round k, for the posted-price auction and the Vickrey auction, respectively. Therefore, the transaction ratio of round k is

$$TR_k = \frac{1}{2}(TR_k^B + TR_k^M) \tag{6.3}$$

where B refers to an experiment in Berlin and M to Magdeburg.

To check the efficiency of a knowledge-transfer mechanism, the different market mechanisms were compared with each other. A market mechanism is appropriate for knowledge sharing, when the average of the transaction ratio is high. In the following test procedures the dependent variable is the transaction ratio.

6.3. Effects of different Market Mechanisms for Electronic Knowledge Markets

A comparison of the different knowledge-transfer mechanisms shall help to detect the most efficient type for an electronic knowledge market.

Table 6.3.: Analysis of Variance.

	SS	df	MS	F	p
Between groups	10.31	7	1.473	87.87	0.000
Within groups	2.61	156	0.0166		
Overall	12.92	163			

Independent variable: Knowledge-Transfer Mechanism,
Dependent Variable: Transaction Ratio,
SS: Sum of Squares, MS: Mean of Squares

6.3.1. Hypotheses

We have developed three propositions according to the effectiveness of different market mechanisms in Section 5.7.4. Out of these we shall now develop testable hypotheses.

From Proposition 20 on page 137 we infer Hypothesis 5.

Hypothesis 5. *Knowledge-transfer mechanisms with compensation outperform mechanisms without compensation with respect to the knowledge transfer, measured with the transfer ratio. That means that the posted-price auction as well as static and dynamic pricing outperform the public-good situation according to the transfer ratio.*

From Proposition 21 on page 137 we deduce Hypothesis 6.

Hypothesis 6. *Knowledge-transfer mechanisms with exclusion outperform mechanisms without exclusion with respect to the knowledge transfer, measured with the transfer ratio. That means that static and dynamic pricing outperform the posted-price auction and the public-good situation according to the transfer ratio.*

And from Proposition 22 on page 138 we infer Hypothesis 7.

Hypothesis 7. *Knowledge-transfer mechanisms with dynamic pricing outperform mechanisms with static pricing with respect to the knowledge transfer, measured with the transfer ratio. That means that the call market, as well as the Vickrey and the English auction outperform the fixed-price situation according to the transfer ratio.*

6.3.2. Analysis of Variance (ANOVA)

The single-factorial Analysis of Variance (ANOVA) is used to compare average transaction ratios of the different market mechanisms. Normal distributed test statistics

Table 6.4.: Descriptive Statistics of Knowledge-Transfer Mechanisms

Mechanism	Location	N	Transfer Ratio		
			Mean	SD	Rank
Vickrey Auction	B,M	22	0.898	0.141	1
English Auction	B	10	0.823	0.075	2
Call Market	B	22	0.795	0.116	3
Fixed Price	B	22	0.567	0.109	4
Posted Price	B,B	22	0.518	0.177	5
Call Market	M	22	0.383	0.156	6
Public Good	M	22	0.248	0.093	7
Public Good	B	22	0.183	0.112	8

Location of the experiment: B = Berlin, M = Magdeburg

corresponding to the random samples, as well as the homogeneity of the variances have to be assumed. First of all, the Kolmogorov-Smirnov-Test is applied to find out whether the transaction ratios are normally distributed. However, this test as well as a graphical analysis of the histograms showed that not all mechanisms were normally distributed.

Secondly, the Levene-Test is used to find out whether the variances of the dependent variables differ significantly. The homogeneity of variance is rejected if the p-value is lower than the level of significance, which was fixed to $\alpha = 0.05$. The Levene Test results in a p-value of 0.005. Consequently, there is a heterogeneity of variance. However, due to the low power of non-parametric test methods, we conducted ANOVA as a kind of pilot test, and backed-up the results by Boxplots, see later.

The ANOVA shows (see Table 6.3) that the knowledge-transfer mechanism has a significant effect on the transaction ratio (df = 7, F = 87.87, p = 0.000). The aggregated subgroups show significant differences, whereas there is no evidence of any significant within-group effects.

6.3.3. Comparison of the Market Mechanisms

The previously described test methods can be used to derive a ranking of the market mechanisms. The analysis of the overall average of transaction ratios shows that the

Table 6.5.: Ranking according to the Duncan Test

Knowledge-Transfer Mechanism	N	1	2	3	4
Vickrey Auction	22	0.898			
English Auction	10	0.823			
Call Market (Berlin)	22	0.795			
Fixed Price	22		0.567		
Posted Price	22		0.518		
Call Market (Magdeburg)	22			0.383	
Public-Good Situation (Magdeburg)	22				0.248
Public-Good Situation (Berlin)	22				0.183
Significance		0.021	0.240	1.000	0.123

p = 0.01

Vickrey auction ranks highest, whereas the English auction had the second highest and the call market in Berlin had the third highest rank. The lowest transaction ratio occurred in both public-good experiments (see Table 6.4).

The multiple ranking test of Duncan shows, which market mechanisms differ significantly from each other. For the Duncan Test we use a significance level of $\alpha = 0.01$. As a result of the Duncan Test there are four homogeneous subgroups (see Table 6.5). The group with the highest transaction ratio includes the Vickrey auction, the English auction, and the call market (Berlin). In the middle there is the group of the fixed-price situation and the posted-price auctions. The call market (Magdeburg) is a separate group according to the Duncan Test. The public-good situations showed the lowest transaction ratio and were therefore gathered in the last group. The results of the analysis are displayed in a Boxplot (see Figure 6.3).

High knowledge transfers lead to low decision errors. Consequently, there is a negative correlation between transaction ratio and decision error in all market mechanisms ($p = 0.006$). Regression models for each market mechanism explain the variance between 80% and 50%. The ranking of the decision error is nearly identical to the ranking of the transaction ratio, except for one market mechanism. Therefore, the results of the analysis of the transaction ratio measure are consistent with the decision error measure.

6.3.4. Test of the Hypotheses

According to ANOVA, the public-good situations were located at the end of the ranking. This was also confirmed by an additional Analysis of Variance with $n = 10$ rounds. Therefore, knowledge-sharing mechanisms with compensation outperform

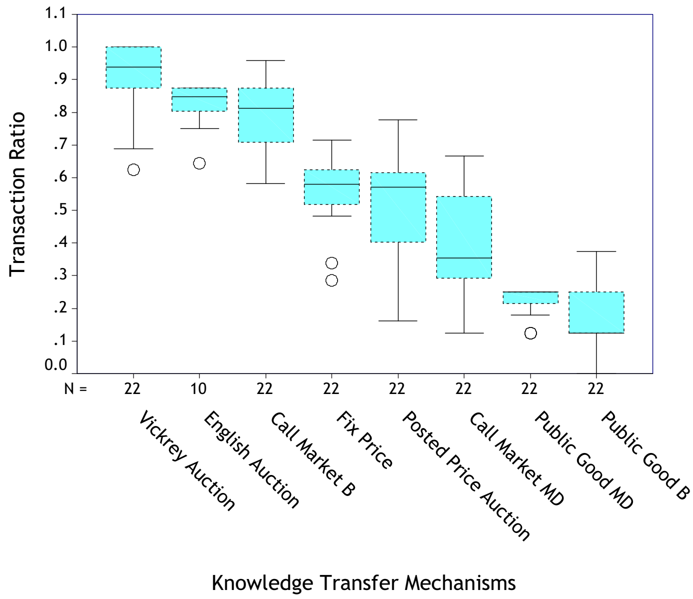

Figure 6.3.: Boxplot of the Ranking of the Knowledge-Transfer Mechanisms

mechanisms without compensation and Hypothesis 5 is supported.

The call-market experiment in Magdeburg was not consistent with our Hypothesis 6. Except for this outlying experiment, all mechanisms with exclusion outperform the posted-price auction. The fixed-price situation ranked better than the posted-price auction but the ranking was not significant at the level $p = 0.01$. Therefore, we can conclude that knowledge-sharing mechanisms with exclusion mostly outperform mechanisms without exclusion, and Hypothesis 6 is also mostly supported.

Evidently, the different dynamic pricing mechanisms generally showed a better result than the fixed-price and the public-good situations. If the outlier (call market in Magdeburg) is again omitted, it becomes evident that the Vickrey auction, the English auction, and the call market provided the best results with regard to the highest transaction ratio. Therefore, knowledge-sharing mechanisms with dynamic pricing outperform mechanisms with static pricing and Hypothesis 7 is supported.

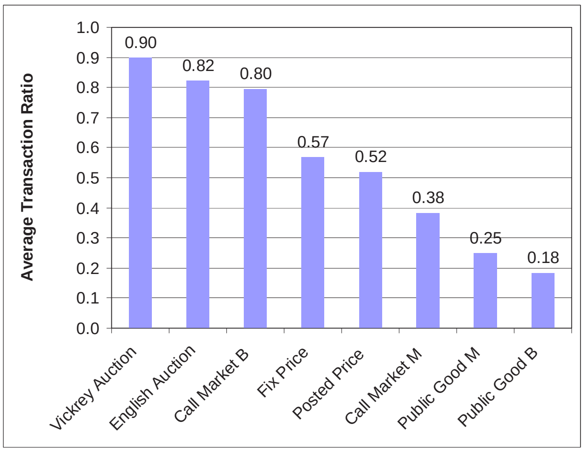

Figure 6.4.: Ranking of the Knowledge-Transfer Mechanisms

6.4. Free Riding and the Free-Riding Trend in the Public-Good Situation

Two of the experiments have used the public-good situation. Therefore, we can use the results of these experiments to also test some propositions from the knowledge sharing part (see Chapter 3).

6.4.1. Hypotheses

In Proposition 1 (p. 61) we predicted a high free riding proportion among the users. In Proposition 2 (p. 64) we predicted a knowledge sharing ratio less than the companies optimum. This leads to Hypotheses 8 and 9.

Hypothesis 8. *In the public-good situation the majority of the participants is free riding with respect to knowledge sharing (transaction ratio < 0.5).*

Hypothesis 9. *In the public-good situation the transaction ratio is much less than the Pareto Optimum, which would be that everybody is sharing all his knowledge assets (transaction ratio = 1).*

Hypothesis 8 is more restrictive than Hypothesis 9. If Hypothesis 8 is supported, Hypothesis 9 also is supported.

Propositions 5 (p. 76) and 6 (p. 78) state that the conditional cooperation motive and the strategic reciprocity motive have a positive influence on knowledge sharing if

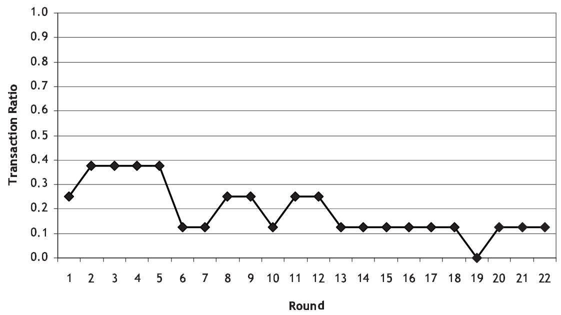

Figure 6.5.: Trend of Knowledge Sharing in the Public-Good Experiment Berlin

there is a relatively high knowledge sharing level. If there are only a few participants who share their knowledge, they have a negative influence on knowledge sharing. In this case, this would result in a downward spiral in knowledge sharing.

Hypothesis 10. *If the majority will free ride in the public-good situation there is a negative downward trend for knowledge sharing.*

6.4.2. Results

We can see from the descriptive statistics in Table 6.4 that in both experiments the average knowledge sharing level is much less than the collective optima, which would be complete sharing. On average 75.2% of the participants in Magdeburg and 81.7% of the participants in Berlin are free riding. In the last round of both experiments (see Figures 6.5 and 6.6) only one participant (12.5%) shares his knowledge.

We use the t-test to examine whether the difference between the average knowledge sharing in an experiment and the threshold 0.5 is significant or not. For this test, we have to assume the normal distribution of the transactions.

We test the hypothesis of normal distribution of the transaction ratio of the two knowledge-transfer mechanisms with the Kolmogorov-Smirnov Test (KS Test). At a significance level of $\alpha = 0.05$, the hypothesis of normal distribution cannot be rejected. However, both public-good samples are not very well described by the normal distribution (Magdeburg: KS Statistics = 1.23, p = 0.097; Berlin: KS Statistics = 1.35, p = 0.053).

The one-sided t-test shows that in both experiments the transaction ratio is significantly lower than 0.5 (Berlin: t = -13.30, df = 21, p = 0.000; Magdeburg: t = -12.77,

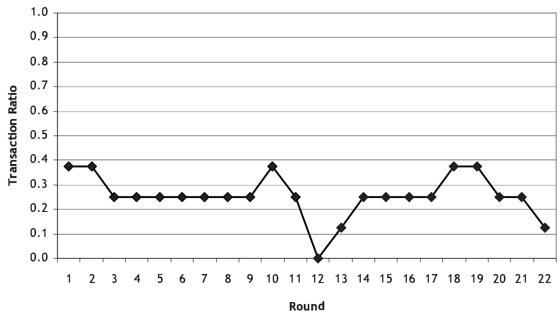

Figure 6.6.: Trend of Knowledge Sharing in the Public-Good Experiment Magdeburg

df = 21, p = 0.000). Therefore, we conclude that our Hypothesis 8—that more than half of the participants are free riding—is well supported. Consequently knowledge sharing is also not collectively optimal and therefore Hypothesis 9 is also supported. The public-good situation does not reach the Pareto Optimum, which would be mutual knowledge sharing, but triggers a high proportion of free riding.

The Figures 6.5 and 6.6 show the trends of knowledge sharing in both experiments. From Hypothesis 8 we already know that the majority is free riding. Therefore, the question is whether there is a downward trend of knowledge sharing.

We use a paired t-test to check if there is a significant difference between the first half of the rounds (rounds 1 to 11) and the second half (rounds 12 to 22). For this purpose, we have to assume the normal distribution of the transactions. We have already checked both samples for normal distribution with the Kolmogorov-Smirnov Test. The results of the paired t-test are shown in Table 6.6. The paired t-test shows a significant difference between the first and the second half of the rounds for the public-good experiment in Berlin ($p = 0.003$). In the public-good experiment in Magdeburg there is also a decrease in the average transfer ratio; however, the difference is not significant ($p = 0.242$).

Because both samples are not very well described by a normal distribution, we additionally use the non-parametric Wilcoxon Test for checking Hypothesis 10. The Wilcoxon Test compares two dependent random samples according to their level and is even applicable if the data is not normally distributed [26, p. 131]. It shall be tested if there is a significant difference between the first half of the rounds (Rounds 1 to 11) and the second half (Rounds 12 to 22). The results of the Wilcoxon Test

Table 6.6.: Paired-Samples t-Test Statistics

Mechanism	Rounds	N	Mean	SD	Paired Differences Mean	Paired Differences SD	t	df	p
Public Good B	1-11	11	0.261	0.104	0.136	0.118	3.83	10	0.003
	12 - 22	11	0.125	0.056					
Public Good M	1 - 11	11	0.284	0.058	0.0568	0.155	1.24	10	0.242
	12 - 22	11	0.227	0.109					

Location of the experiment: B = Berlin, M = Magdeburg

with a significance level of $\alpha = 0.05$ show that only the samples from Berlin have a significant downward trend ($p = 0.014$). The sample in Magdeburg shows no significant difference between the first and the second half of the rounds ($p = 0.236$). Therefore, the Wilcoxon Test gives the same result as the paired sample t-test.

However, the Cox and Stuart trend test (cf. [49] and [184, p. 91]) shows a negative trend for both experiments at a significance level of $\alpha = 0.05$ (Berlin: $T = 0, l-r^* = 6.23$; Magdeburg: $T = 2, l - r^* = 5.73$).

Therefore, we find only partially supporting evidence for Hypothesis 10.

6.5. Related Work

There is only little comparable related work for this chapter. Connolly et al. [46] experimentally analyze the behavior dynamics in a discretionary database. Rafaeli and Raban [157] analyze how the subjective value of information is influenced by the ownership. However, both have not checked different market mechanisms in detail.

6.6. Conclusion

Overall for most of our hypotheses we found supporting evidence. Market mechanisms are more efficient with respect to the sharing of knowledge than public-good situations, which result in suboptimal private knowledge sharing, as is the case in open knowledge repositories. We are aware that there are some aspects that are relevant in knowledge asset trading which we omitted. For example, in the described game we have not analyzed the problem of how to overcome the asymmetric information about the quality of the knowledge assets and the related question of trust. For this purpose different quality management procedures have been suggested in Section 5.10. Regarding a classification of dynamic auction mechanisms it is not yet possible to give a conclusion with high likelihood. Further empirical investigations and advanced experiments are mandatory.