Bounded rationality and learning in market competition

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Chapter 5

Endogenous Information Disclosure in Experimental Oligopolies

5.1 Introduction

Information sharing about prices or production levels can be efficiency enhancing. When firms can observe prices or production levels of their competitors, then they know all the relevant variables that affect their demand and therefore they may learn uncertain demand conditions better. In contrast, when not all the information that affects demand is available, firms can only work with a misspecified model and this can lead to a welfare loss.[1] However, information sharing may have anti-competitive effects as well. Competition authorities are concerned that information sharing can facilitate collusion: when firms observe past prices or quantities, then it is possible to identify the firm(s) that broke a cartel agreement, which makes cartels more sustainable.[2] Therefore competition authorities raise concerns about the dissemination of firm-

This chapter is based on a joint work with Anita Kopányi-Peuker.

[1] See Bischi et al. (2004) for example.

[2] See Stigler (1964) and Green and Porter (1984) for corresponding theoretical models. Kühn and Vives (1995) give a good overview of further theoretical results in Section 8.2.

specific data typically but not about aggregate values.[3]

The effect of the type of available information on the market outcome has been analyzed by means of laboratory experiments. Experimental results show that the view of competition authorities is not necessarily valid. Huck et al. (1999) and Huck et al. (2000) find that additional information about rivals' actions and profits leads to a more competitive outcome. On the other hand, Offerman et al. (2002) find more collusion when firms receive information about individual production levels but not about profits. When, however, profit information is available, the outcome is more competitive. Dufwenberg and Gneezy (2002) find that receiving information about all the bids leads to more collusive outcomes in a first-price sealed-bid auction.

This paper contributes to the debate on how the publication of aggregate or individual data affects competitiveness. We conduct a laboratory experiment in which we vary the information available to subjects about their competitors' past actions. Previous experiments on this question lack an important characteristic of markets, namely that sharing information is often a firm's own decision, therefore the information structure is *endogenous*. The choice of sharing information gives firms an important tool: the possibility for signaling. By voluntarily sharing information, firms can signal their willingness to collude with their competitors. When, however, the information structure is exogenously given, firms automatically receive information, removing important strategic considerations behind information sharing. This may lead to biased conclusions about the effect of information. Therefore we analyze in this paper how endogenous information sharing affects the market outcome. In particular, we address the following questions. Does the market outcome become more collusive as firms receive more detailed information about their competitors? Does it matter for the market outcome whether information sharing is compulsory or voluntary? Do firms use information sharing as a signaling device? Can it be desirable to make it compulsory for firms to share information (in order to remove signaling possibilities)?

We use the same market structure as Offerman et al. (2002). We consider the market of a

[3] For more details about regulation and examples for cases see Kühn and Vives (1995), Section 8.3 in Buccirossi (2008) and OECD (2010).

homogeneous good where firms compete in quantities. The demand function is nonlinear in the aggregate production and firms face increasing marginal costs. Subjects play the role of firms in the market and each market consists of three firms. There are four treatments in the experiment, each one consists of three parts. In each part, subjects act on the same market for 30 rounds, then a new market is formed. The market structure remains the same across parts, only the composition of groups and the available information changes. In the first two parts subjects either receive information about the other subjects' choices or not, while in part 3 information sharing is voluntary.[4] Treatments differ in the kind of information subjects receive (whenever they receive information). Subjects are informed either about aggregate production levels or about individual quantities, but not about profits.

The experimental results confirm that the voluntary nature of information sharing can have important consequences for the market outcome. The average individual production is significantly lower when subjects share information compared to when they decide not to share information. Furthermore, when subjects decide not to share information, production levels are significantly higher than when information is not available by default. Voluntary information sharing can enhance coordination as well. Individual production levels are closer to each other when information is shared voluntarily and subjects receive aggregate information. Concerning the type of information subjects receive, we find that the average total production is lower when firms receive individual information but this difference is not significant. We could observe more attempts for collusion under individual information though. This supports the view of competition authorities that firm-specific data has anti-competitive effects. This suggests that the concern about disseminating individual data is justified.

The effect of different information about competitors' actions has been analyzed in the experimental literature. Huck et al. (1999) conduct an experiment on a homogeneous Cournot market with four firms. One dimension of their experimental design is the amount of information subjects receive about their competitors: they either receive no information or they are

[4]We vary the order of the parts with and without information to control for the order effect. This ordering gives one of the treatment dimensions.

informed about the quantity choice of their competitors as well as the corresponding profits. The results show that more information about competitors leads to a more competitive market outcome.

Huck et al. (2000) analyze the effect of data aggregation on the market outcome. They consider the market of a differentiated good where firms compete either in prices or in quantities. Subjects are informed either about the aggregate action of other firms or they receive detailed information about firm-specific prices or quantities as well as about profits. The authors find that providing disaggregated information about actions and profits yield a more competitive outcome in case of quantity competition whereas there is no significant difference in competitiveness when firms compete in prices.

Offerman et al. (2002) consider a homogeneous Cournot oligopoly with three firms and they vary the available information about competitors. In treatment Q subjects receive information about aggregate production only, while they are informed about individual production levels as well in treatment Qq. Finally, individual profits are reported too in treatment $Qq\pi$. The results show that subjects produce less when they receive additional information about firm-specific production levels, moreover, there is evidence for collusion in some cases. On the other hand, the market tends to be more competitive when profit information becomes available but there is evidence for collusive behavior as well.

Our paper differs from the previous literature in important aspects. Most importantly, we impose an endogenous information structure in which subjects can decide whether they want to share information with others or not. This gives the possibility for subjects to signal their willingness to cooperate and this has important consequences for the market outcome. Second, we do not give information about profits. The reason for this is that in practice information sharing is implemented by trade associations and they collect information about prices or quantities but not about profits typically. From price or quantity information it is not necessarily possible to draw conclusion about profits since firms may not know the production technology of their competitors or the agreement they have with suppliers. Not providing profit information explains the difference between our conclusions and those of Huck et al. (1999) and Huck et al. (2000). They do not investigate the case when subjects receive information about quantities or prices only. Our results are in line with those of Offerman et al. (2002). We also do not observe a significant difference between total production under aggregate and individual information and we also find more attempts for collusion when subjects receive individual information.

The paper is organized as follows. The market structure and the benchmark outcomes are discussed in Section 5.2. Then we present the experimental design in Section 5.3. Section 5.4 summarizes our hypotheses, then we report the experimental results in Section 5.5. Section 5.6 concludes. Instructions of the experiment are presented in Appendix 5.A.

5.2 Market and information structures

We use the same market structure as Offerman et al. (2002). We consider the market for a homogeneous good that is produced by 3 firms. Firms compete in quantities and the inverse demand function is given by

$$P(Q) = 45 - \sqrt{3Q},$$

where $Q = \sum_{i=1}^{3} q_i$ is the total production of the three firms. Firms face the same cost function, the production costs of each firm i are given by

$$C_i(q_i) = q_i^{\frac{3}{2}},$$

where q_i is the production level of firm i. The number of firms, the inverse demand and the cost functions are common knowledge.

We consider this setup for the following reasons. Note that we need at least 3 firms in the market in order to have a difference between information about aggregate and individual production levels from the perspective of a given firm. However, Huck et al. (2004) do not observe any collusion when there are more than 3 firms on a Cournot market. Therefore we

	q_i	Q	π_i
N	81	243	729
C	56.25	168.75	843.75
W	100	300	500

Table 5.1: Quantities and profits in the benchmark outcomes. N: Nash equilibrium, C: collusion, W: Walrasian equilibrium.

choose to have 3 firms so that collusion would be feasible in the experiment. We use a nonlinear setup as the Cournot adjustment process (i.e. naive best-response dynamics) does not converge under linear demand and cost conditions for more than 2 firms (see Theocharis, 1960). Finally, the setup also facilitates comparisons with Offerman et al. (2002).

There are three benchmark outcomes for this market: the Nash equilibrium (N), collusion (C) and the Walrasian equilibrium (W). Table 5.1 summarizes the individual and total quantities and the individual profits in these outcomes.[5]

We consider a situation where firms compete on the market for a finite and known number of periods. When firms are perfectly rational, the Nash equilibrium of the stage game is the unique subgame-perfect equilibrium of the repeated game. Collusion cannot be sustained with rational players since the stage game is finitely repeated with a known end period. There is, however, ample empirical evidence that the assumption of perfect rationality and the standard equilibrium prediction does not necessarily describe actual behavior well.[6] Finding the Nash equilibrium and coordinating on it are complex tasks and subjects might not have sufficient cognitive and computational abilities to do so. In this situation, subjects may use different decision rules that have lower deliberation costs than calculating the Nash equilibrium. Examples for such rules are different versions of imitation. Vega-Redondo (1997) proposes a rule where firms imitate the action of the firm that made the highest profit in the previous round. Under this rule quantities converge to the Walrasian outcome. Offerman et al. (2002) propose an alternative rule where firms imitate the action of a so-called exemplary firm. This firm is the one whose action would have resulted in the highest total profit if each firm had chosen the same action. This imitation

[5]See Offerman et al. (2002) for the general formulas.
[6]See Conlisk (1996) for an overview of such results.

rule leads to the collusive outcome.[7]

In order to investigate how the market outcome depends on the type of available information and on firms' information sharing decisions, we conduct a laboratory experiment. In the next section we discuss the experimental design we use.

5.3 Experimental design and procedures

The experiment was conducted in the CREED laboratory of the University of Amsterdam in June 2014. In total, 180 subjects participated in 4 treatments in 14 sessions. None of the subjects participated more than once. Participants were mainly undergraduate students from different fields. Each session lasted about 2 hours, and participants earned on average 25.5 euros. Earnings were paid privately in cash at the end of the experiment. The experiment was computerized, and programmed in php. Participants read the instructions at their own pace from the computer screens, and questions were answered privately. After reading the instructions subjects had to answer control questions in order to ensure they understood the situation they faced in the experiment.

Each session consisted of 3 parts. In each part 3 participants formed a market. This market composition was fixed for the whole part but it changed between different parts: subjects were rematched in their matching group of 6. Subjects were informed that there are 3 parts and that they will not play in the exact same market again but we did not inform them about the size of the matching group. Each part consisted of 30 rounds. The number of rounds was known to the participants. During the experiment, subjects earned points in each part. At the beginning of each part they received a starting capital of 6000 points. At the end of the experiment one part was randomly chosen by rolling a die, and all participants' earnings from that part were converted to euros. Participants received 1 euro for each 1100 points they earned in the given

[7]These imitation rules lead to the Walrasian and collusive outcomes respectively, only when each firm uses the same rule. It is, however, unlikely that subjects use the same imitation rule in an experiment. In fact, subjects do not necessarily use imitation rules at all. Bosch-Domènech and Vriend (2003) investigate whether subjects use imitation more often as the environment is perceived to be more complicated. They find that the more complicated the market environment seems, the less frequently the subjects imitate each other.

part.

In every round subjects had to decide simultaneously how much to produce. They could choose integer production levels between 40 and 125. The parts differed only in the information participants received about other firms' production decisions. The demand and cost structure was the same through the whole experiment, as given in Section 5.2 and this was commonly known. In parts 1 and 2, either no information about others' production was provided, or aggregate / individual production details were provided. The order of these two parts differed across treatments to control for the possible order effects. In part 3 subjects decided not only about their production but they also decided at the same time whether to share information about their production with the other two subjects in their group. If they shared information, the other two firms in the market received information about this firm's production regardless of their own information sharing decision.[8] Subjects received feedback after each round. This feedback contained their own production, the market price, their own revenue, cost and profit. Additionally, they received information about other firms' production in the full information part, and in part 3 if applicable.

The second treatment dimension was the type of information subjects received about others' production. We had two treatments with aggregate information and two with individual information. In case of aggregate information subjects were informed about the *sum* of the others' production and they could not recover individual production levels from this information. In part 3, subjects could observe how many subjects shared information in their market and the aggregate output of the others who shared information. In case of individual information, individual production levels were shown and subjects could identify which firm produced a given amount.[9] In part 3, firms could see which firms shared information, and the exact production level of those firms who shared. This 2×2 design leads to 4 different treatments, which are

[8]That is, we applied a non-exclusionary disclosure rule. See Vives (1990) for a discussion about the effect of different disclosure rules on information sharing incentives.

[9]Subjects were distinguished as Firm A, Firm B and Firm C in the market. This firm ID was fixed in a given part.

Treatment	Type of info	Sequence of parts 1 and 2	# of matching groups
A-NF	aggregate	No info - Full info	8
A-FN	aggregate	Full info - No info	8
I-NF	individual	No info - Full info	8
I-FN	individual	Full info - No info	6

Table 5.2: Overview of the treatments

summarized in Table 5.2.[10] Subjects were informed about the kind of information they would receive and about the decision(s) they need to make in the different parts at the beginning of the experiment.

During the decision making, subjects could use a profit calculator which was built in the screen. Here subjects could enter a hypothetical own production and a hypothetical total production of others, and the calculator gave the corresponding price and profit. Participants could use the profit calculator as often as they wanted.

In each part, a history screen was always available for every subject. This screen contained information about past production in their own market. In the part with no information subjects could see their own production, price and profit for every round.[11] In the part with full information they additionally saw either the total output (in case of aggregate information) or the production levels of the other two subjects by firm ID (in case of individual information). In part 3, the additional information was their own information sharing decision and either the number of other firms who shared information and their total production (in case of aggregate information), or the individual production of the other firms by firm ID, showing "n.a." if a firm did not share information (in case of individual information). An example of the history screen for part 3 and instructions for treatment I-NF can be found in Appendix 5.A.

[10]We wanted to have 8 matching groups in treatment I-FN too but we had to cancel some sessions due to low show up.

[11]Even though subjects were not informed about total productions, they could infer this information using the inverse demand function or the profit calculator. Based on the usage of the profit calculator, subjects did not perform such calculations.

5.4 Hypotheses

Subjects receive different kinds of information about each other's choices across treatments and parts and this may affect their behavior. In this section we discuss how subjects may behave under the different information structures and we summarize our hypotheses.

When subjects do not receive any information about their competitors, we expect to observe substantial differences in individual production levels as subjects choose their quantities by trial and error. Even though the aggregate production can be calculated using the demand function and thus subjects could play the best response in principle, we do not expect them to perform such calculations.

When subjects receive aggregate information about their competitors, then we expect to observe smaller differences in individual production levels for two reasons. First, when aggregate production is directly observable, it becomes easier to find the best response, which drives the outcome towards the Nash equilibrium. Second, even if subjects do not calculate the best response, observing what the other subjects chose may drive individual quantities closer to each other through imitating the average, for example. Since playing the best response leads to the Nash equilibrium, we expect production levels to be distributed around the Nash equilibrium quantity. Subjects might also try to collude as they can monitor their competitors to some extent.

When individual information is available, we expect to observe more collusion. This is in line with the theoretical considerations that firms can monitor each other's behavior better. Moreover, as Offerman et al. (2002) show, the "imitate the exemplary firm[12]" rule leads to the collusive outcome and subjects have enough information to use this rule.

When the information structure becomes endogenous, subjects can signal their willingness to cooperate. This is due to the fact that sharing information unilaterally gives an informational advantage to the competitors but it is not directly beneficial for the firm that shares information. The rationale of sharing information is that subjects may induce their competitors to share

[12]The exemplary firm is the one whose action would have resulted in the highest total profit if each firm had chosen the same action.

their production level as well. Once cooperation is established in terms of information sharing, subjects might be able to collude in production levels easier. Similarly, when subjects *decide* not to share information with each other, this signals their willingness to compete and then it is hard to imagine that they will collude in their production choice. Thus, we expect a difference in the behavior of subjects that share information and those who do not share information.

Based on the above considerations, we formulate the following hypotheses about the results. The first set of hypotheses compares the *average total quantities under the aggregate and the individual information* treatments. When subjects receive no information about their competitors' production levels, it does not matter whether they are in the aggregate or in the individual information treatment, the average total quantities are the same:

Hypothesis 1.A. Average total production is the same under the individual and the aggregate information treatments when subjects receive no information about their competitors: $\bar{Q}_{I,NI} = \bar{Q}_{A,NI}$.

When, however, subjects do receive information about their competitors, the average total production is lower under individual information. Thus:

Hypothesis 1.B. Average total production is lower under the individual information treatment when subjects have full information about their competitors: $\bar{Q}_{I,FI} < \bar{Q}_{A,FI}$.

Under voluntary information sharing, we expect to observe some subjects that decide to share information with each other. Then, in line with Hypothesis 1.B, we expect to observe lower average total production under individual information.

Hypothesis 1.C. Average total production is lower under the individual information treatment when subjects voluntarily share information with each other: $\bar{Q}_{I,VS} < \bar{Q}_{A,VS}$.

The second set of hypotheses concerns the *effect of voluntary information sharing on total output*. As information sharing may work as a signaling device, we expect to observe more attempts for collusion, and consequently lower average production, under voluntary information sharing when subjects share information than under full information. The reason for this is that there might be subjects who would not collude by default but they cooperate with their competitors after receiving information from them.

Hypothesis 2.A. Average total production is lower under voluntary information sharing when subjects share information with each other than under full information: $\bar{Q}_{VS|share} < \bar{Q}_{FI}$.[13]

A similar reasoning holds when subjects decide not to share information with each other. If a subject would be willing to cooperate with his competitors but he is on a market where others decide not to share their production choice, then the subject in question may more easily give up attempts for cooperation compared to the case when information about production levels is not available by default. This leads to higher average total production under voluntary sharing when subjects do not share information with each other than under no information.

Hypothesis 2.B. Average total production is higher under voluntary information sharing when subjects do not share information with each other than under no information: $\bar{Q}_{VS|no\ share} > \bar{Q}_{NI}$.[14]

Finally, as subjects may show their willingness to cooperate by sharing information, we expect to observe lower average production level under voluntary sharing when subjects share information with each other compared to the case when they do not share information.

Hypothesis 2.C. Under voluntary information sharing, average total production is lower when subjects share information with each other than when they do not share information: $\bar{Q}_{VS|share} < \bar{Q}_{VS|no\ share}$.

In the last set of hypotheses we discuss the *effect of voluntary information sharing on coordination*. We call a group coordinating when individual productions in a given round on the

[13]For calculating $\bar{Q}_{VS|share}$, we consider the total production on markets where at least 2 subjects share information in a given round and we calculate the average of these total productions over markets and rounds.

[14]For calculating $\bar{Q}_{VS|no\ share}$, we consider the total production on markets where at most 1 subject shares information in a given round and we calculate the average of these total productions over markets and rounds.

same market are close to each other.[15] Then we measure the amount of coordination as the share of coordinating groups. Since voluntary information sharing may enhance collusion, we expect to observe a higher amount of coordination under voluntary information sharing when subjects share information than under full information:

Hypothesis 3.A. Coordination is higher under voluntary information sharing when subjects share information with each other than under full information: $C_{VS|share} > C_{FI}$.[16]

We do not expect to observe a difference in the amount of coordination when subjects decide not to share information with each other and when information is not available by default as subjects cannot observe each other's choice in either case.

Hypothesis 3.B. The amount of coordination is the same under voluntary information sharing when subjects do not share information with each other as under no information: $C_{VS|no\ share} = C_{NI}$.[17]

Finally, we expect to observe a higher amount of coordination when subjects choose to share information with each other than when they decide not to share information since observing what others choose helps coordination.

Hypothesis 3.C. Under voluntary information sharing, coordination is higher when subjects share information with each other than when they do not share information: $C_{VS|share} > C_{VS|no\ share}$.

In the next section we investigate whether the experimental results confirm our hypotheses.

[15] Thus, coordination means that subjects choose similar production levels, not that they are coordinating on one of the benchmark outcomes. We specify this definition in the next section.

[16] C denotes the measure of coordination. For calculating $C_{VS|share}$, we consider a one-round lag in information sharing: we consider the markets where at least 2 subjects share information in a given round and we examine whether individual production levels are close to each other in the following round.

[17] For calculating $C_{VS|no\ share}$, we consider again a one-round lag in information sharing: we consider the markets where at most 1 subject shares information in a given round and we examine whether individual production levels are close to each other in the following round.

5.5 Results

In this section we report the experimental findings. First we checked whether the different order of the parts with no information and full information had an effect on subjects' behavior. To do so, we tested with the Mann-Whitney ranksum test whether subjects behaved differently in part 3 if they faced No information or Full information first. We did not find significant differences in individual production, in total output and in the information sharing decision.[18] We also compared individual production levels and total output for parts No information and Full information for A-NF and A-FN, and for I-NF and I-FN. Here we did not find any significant difference either.[19] Because of these findings we conclude that there is no order effect in our experiment. Subjects behaved in the same way when they were facing the part with no information first as when they were facing the part with full information first. Thus we merge our data on one treatment dimension, and analyze them together. This means that we end up with two treatments: Aggregate (A) and Individual (I) with 16 and 14 matching groups, respectively.

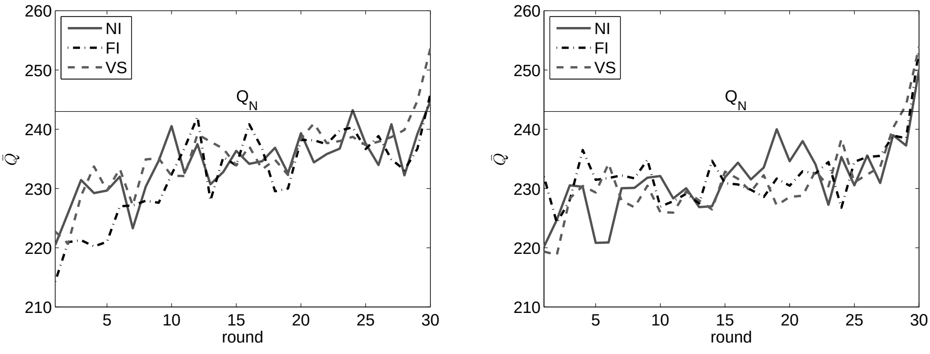
The remainder of this section is organized as follows. In Section 5.5.1 we compare the total outputs in the different parts of the two treatments. In Section 5.5.2 we focus on the effect of voluntary information sharing on the subjects' production choice and on total output. Then in Section 5.5.3 we investigate how groups coordinate under different information structures. Finally, in Section 5.5.4 we analyze the factors that influence the information sharing and production choice by means of panel regressions.

5.5.1 Output decisions

Figure 5.1 shows the average output over time for each treatment. We can see that there is no substantial difference in output across parts and across treatments. The average output seems to be lower under Individual information, however these differences are not significant. Further-

[18]The test was performed on matching group level. We compared part 3 behavior for A-NF and A-FN, and for I-NF and I-FN. For each test the p-value is at least 0.529.

[19]The tests were performed on matching group level again. The p-values are between 0.302 and 0.796. We also plotted the average production over time, and the plots are very similar to each other.



(a) Aggregate (b) Individual

Figure 5.1: Average total output over time in the Aggregate and in the Individual treatments

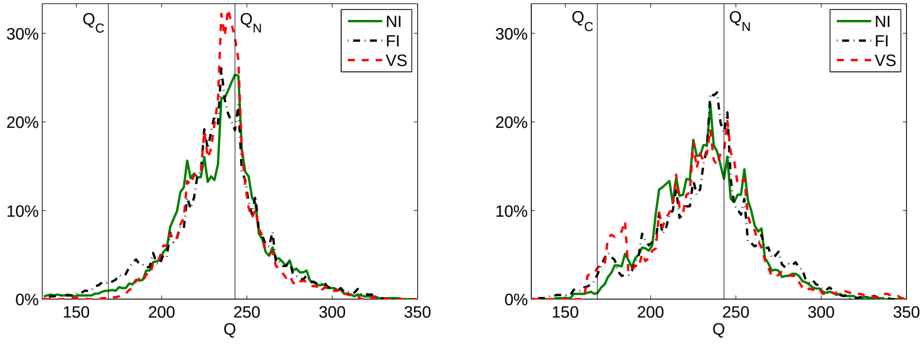
Treatment	NI	FI	VS	NI vs. FI	NI vs. VS	FI vs. VS
Aggregate	234.12 (27.28)	232.43 (29.35)	235.38 (21.91)	1.00	0.68	0.76
Individual	231.59 (27.67)	232.46 (31.31)	230.97 (31.25)	0.83	0.98	0.59
Agg. vs. Ind.	0.59	0.43	0.20			

Notes: The numbers in brackets are standard deviations of the output. p-values are according to two-sided ranksum test with $n_{\rm A} = 16$ and $n_{\rm I} = 14$ for the treatment differences, and Wilcoxon-test for the differences between parts.

Table 5.3: Average total output across treatments and parts, and the corresponding test results

more, we can observe an end-game effect after round 27. The output before that is quite stable, subjects quickly learn how the market works. Non-parametric tests (presented in Table 5.3) also confirm the similarities across treatments and parts; there is no significant difference between the output levels in different treatments or parts. Based on these tests we reject Hypotheses 1.B and 1.C, but we accept Hypothesis 1.A.

Although we cannot find any significant difference in *average* total productions across treatments, Figure 5.2 suggests that there might be differences across treatments and parts with respect to the *distribution* of total output. Interestingly there is a significant difference in distributions *between treatments* not only in the case of voluntary sharing but also in the case of No information (p=0.000 for both cases by the two-sample Kolmogorov-Smirnov test). In the case of No information total production is close to the Nash equilibrium value more often in the Aggregate treatment than in the Individual treatment. In the case of Full information there



(a) Aggregate (b) Individual

Figure 5.2: Frequencies of total output in the Aggregate and in the Individual treatments. For each Q, the plots show the percentage of outcomes that lie in the ± 5 neighborhood of a given Q.

is no difference between treatments (p=0.18). The parts with Full information can be compared to the *Q* and *Qq* treatments in Offerman et al. (2002). Their distribution in treatment *Q* is very similar to ours in A-FI. The shape of the distributions in their *Qq* and in our I-FI is also similar but we observe a smaller peak close to the collusive outcome. In our experiment, subjects try to collude more often in the case of Voluntary sharing.

The distributions are also significantly different within treatments *across parts*.[20] As we can see from the figures (and from the standard deviations in Table 5.3), the dispersion of the total output is not higher in NI than in other parts. This suggests that subjects could not coordinate better when they received information about each other's choices. The figure also shows that the total output was hardly ever around the Walrasian outcome of $Q_W = 300$. Attempts for collusion were observed a bit more often, especially in the case of VS in the Individual treatment.[21] We will return to this issue in Section 5.5.2. Our findings can be summarized as follows.

Result 1. *Production levels tend to be lower under individual information than under aggregate information but there are no significant differences in average total outputs across treatments and parts. When subjects receive individual information, we can observe collusive behavior*

[20] In case of the Aggregate (Individual) treatment, the difference between NI and FI is significant at 10% (5%) level, between NI and VS at 5% (5%) level, and between FI and VS at 1% (10%) level.

[21] However, the collusive outcome was hardly ever reached. The spike in case of I-VS is around 180.

Treatment	No info	Full info	VS
Aggregate	25.31% (40.74%)	19.06% (13.66%)	29.50% (35.34%)
Individual	13.57% (11.40%)	18.81% (66.46%)	16.67% (42.86%)

Notes: This table contains the frequency of total output in the ± 5 range of the Nash output (i.e. [238,248]). In brackets, we show the percentages of these cases in which all three individual productions are in the ± 5 range of the individual Nash quantity (i.e. [76,86])

Table 5.4: Percentage of outcomes in the ± 5 neighborhood of the Nash equilibrium quantity Q_N

under voluntary information sharing.

Table 5.4 summarizes how often the total output was in the neighborhood of the Nash outcome, and among these cases how often individual production levels were close to the individual Nash quantity.[22] The Nash outcome was always reached less often in the Individual treatment than in the Aggregate treatment. Furthermore, we can see that in the Individual treatment subjects are more often in the ± 5 range of the individual Nash quantity in case of Full information and VS. This suggests that subjects may coordinate better in that treatment when they receive information.

5.5.2 Consequences of information sharing on output decisions

Now we will focus on voluntary information sharing, and investigate how the endogeneity of the information structure affects production choice. Figure 5.3 presents the average frequency of information sharing in the Aggregate and in the Individual treatments. As we can see from the graph, subjects share information more often in the Individual treatment than in the Aggregate treatment, with an average information sharing of 60.2% in the Aggregate and 67.8% in the Individual case. These values are not significantly different from each other using the ranksum test on matching group levels (p=0.38).

Table 5.5 shows the average individual production levels in parts NI, FI, and VS. We separated the average production in VS by the observations in which subjects shared information,

[22]We also checked in how many cases chose all 3 firms close to the individual Nash quantity, but the results are not substantially different from the ones reported in the table. We have only 74 cases (about 16%) where all three individuals chose around the individual Nash quantity, but the total quantity is not in the ± 5 range of the Nash output.

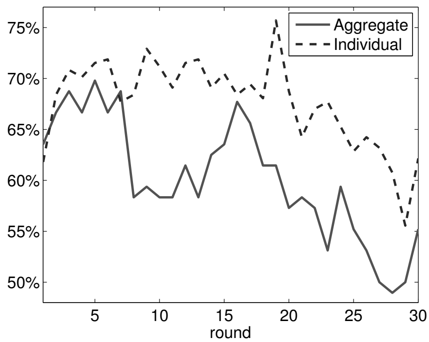


Figure 5.3: Average frequency of information sharing over time

Treatment		NI	FI	VS|n	VS|s	VS|s vs. VS|n	NI vs. VS|n	FI vs. VS|s
Aggregate	q	78.04	77.48	81.93	76.48	0.00***	0.01**	0.26
	Q	234.12	232.43	241.62	232.97	0.03**	0.04**	1.00
Individual	q	77.20	77.49	84.53	74.74	0.00***	0.02**	0.20
	Q	231.59	232.46	244.87	226.39	0.01**	0.06*	0.30
Agg. vs. Ind.	q	0.84	0.77	0.43	0.34			
	Q	0.59	0.43	0.60	0.34			

Notes: ***: significant at 1%-level, **: significant at 5% level, *: significant at 10% level according to two-sided ranksum test with $n_{\mathrm{A}} = 16$ and $n_{\mathrm{I}} = 14$ (and $n_{\text{I-VS|n-Q}} = 13$) for the treatment differences, and Wilcoxon-test for the differences between parts. The averages in the table are based on the matching group averages.

Table 5.5: Average individual and total production and their test results

and those in which they did not share. Although there are still no significant differences between treatments, now we can see a clear difference in behavior across different information structures. Subjects indeed choose different production levels in part VS when they voluntarily decide to share information than when they intentionally decide not to share it. Those who share information choose significantly lower production levels than those who do not share information. Furthermore, subjects who do not share information in part 3 choose significantly higher production level than the average production level in case of NI. If subjects share information in part 3, their average production is lower than the average production in FI (though this difference is not significant). These results are in line with our hypotheses about the effect of voluntary sharing on production choice. We can conclude that subjects self-select to sharing / not sharing information if they have an intention to collude / compete with the others. We also checked the relationship between the own production and the information sharing decision in part 3 with simple correlation: in both treatments this relationship is significantly negative.[23] Although these results are well in line with our hypotheses about the market outcome, we cannot accept or reject them yet since groups might be heterogeneous with respect to information sharing behavior, therefore we cannot draw conclusions about group behavior based on individual behavior only.

As a next step, we categorized groups as *sharing* group if there were 2 or 3 firms sharing information in a given round and *non-sharing* group otherwise. Note that with this definition a group might be a sharing group in some rounds while non-sharing in other rounds. Besides individual production, Table 5.5 also shows the average total output for the different information structure and the test results for differences across parts and treatments. We can see from the table that our results from the individual production still hold in this case (though the p-values are a bit higher for the sign-rank tests). So based on these test results, we reject Hypothesis 2.A but we accept Hypotheses 2.B and 2.C, which leads to our next result:

Result 2. *Information sharing works as a signaling device: subjects produce significantly less when they share information voluntarily compared to the case when they decide not to share information. Furthermore, if they decide not to share information, the market is significantly more competitive than if information is not available by default. However, there is no significant difference in the market outcome if firms receive information exogenously or they decide to share information voluntarily.*

Since we have seen that sharing groups choose significantly lower production than non-sharing groups in VS, we investigated whether sharing groups can explain the small peak close to the collusive outcome in the Individual treatment in Figure 5.2. The analysis shows that there were 4 sharing groups which shared information most of the times with each other (30, 29, 25 and 21 times out of 30), and chose low production levels (with an average total production below

[23] The correlation coefficient is -0.1855 for the Aggregate treatment and -0.2026 for the Individual treatment, with p=0.000 for both cases.

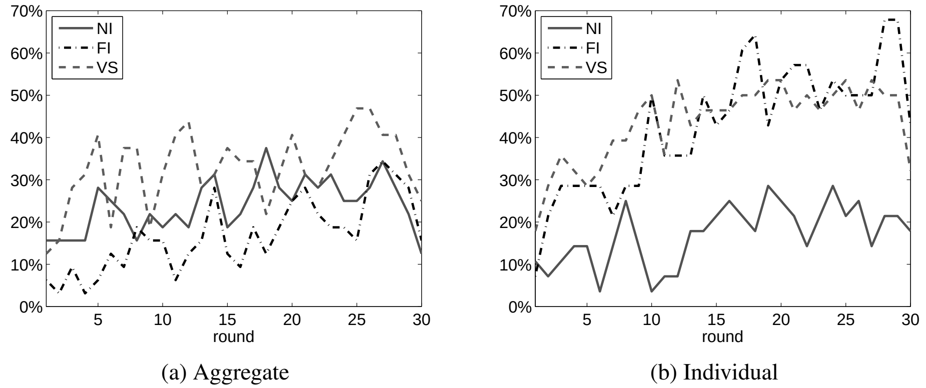


Figure 5.4: Average share of coordinating groups over time in the Aggregate and in the Individual treatments

200). Mainly the production of these four groups led to the smaller spike near the collusive outcome. Even though these groups were very successful in collusion, they only constitute less than one third of all the experimental markets. So letting firms decide about sharing firm-specific data can indeed result in collusion, but because firms are heterogeneous with respect to information sharing, this might not actually happen.

5.5.3 Coordination

To further analyze what causes the difference in the distributions of total output, we defined coordinating and non-coordinating groups by the following rule: a group is *coordinating* in a given round if the maximal absolute difference between the individual production levels and the average production level in the market is at most 5. Using this definition, Figure 5.4 shows the average share of coordinating groups over time in the different parts and treatments. Interestingly there is no substantial difference between parts in the Aggregate treatment, so more information does not seem to help coordination here. In contrast, more information clearly helps in the Individual treatment, irrespective of whether information is given exogenously or endogenously. Groups are able to coordinate more often under Full information and VS than under No information, and non-parametric tests, presented in Table 5.6 confirm that these dif-

Treatment	NI	FI	VS	VS|n	VS|s
Aggregate	23.96%	16.77%	32.71%	26.81%	32.92%
Individual	17.14%	42.74%	43.57%	14.46%	55.86%
Agg. vs. Ind.	0.47	0.00***	0.13	0.22	0.02**

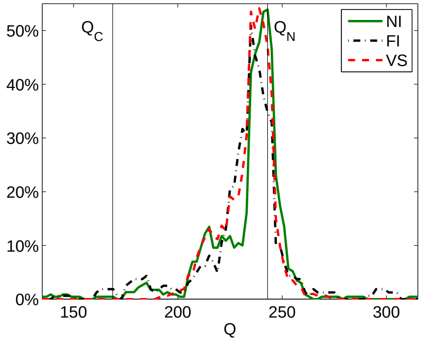
Treatment	NI vs. FI	NI vs. VS	FI vs. VS	VS|s vs. VS|n	VS|n vs. NI	VS|s vs. FI
Aggregate	0.37	0.19	0.00***	0.44	0.92	0.01***
Individual	0.00***	0.00***	0.95	0.00***	0.67	0.03**

Notes: ***: significant at 1%-level, **: significant at 5% level according to two-sided ranksum test with $n_{\mathrm{A}} = 16$ and $n_{\mathrm{I}} = 14$ (and $n_{\text{I-VS}|\text{n-Q}} = 12$) for the treatment differences, and Wilcoxon-test for the differences between parts. The averages in the table are based on the matching group averages.

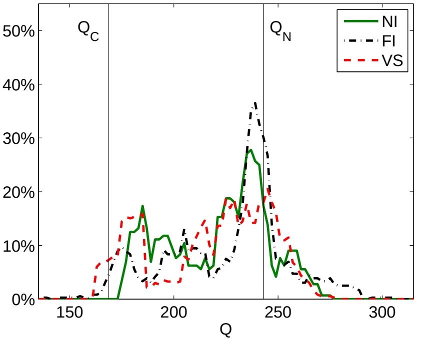
Table 5.6: Average share of coordinating groups across different treatments and different parts, and the corresponding test results

ferences are significant. Furthermore, in the Aggregate treatment there is significantly more coordination in VS compared to FI, but there are no other significant differences. As we move from NI to FI, we can see that coordination decreased in the Aggregate treatment but it increased in the Individual treatment, making the two treatments significantly different from each other in part FI. If subjects received disaggregated data, it indeed helped them to coordinate on specific output levels, whereas aggregate information does not have this effect. Table 5.6 presents the test results concerning Hypotheses 3.A-3.C as well. Based on these results, we accept all three hypotheses, although the difference in coordination between sharing and non-sharing groups is significant in case of individual information only.

So far we have focused on the *amount* of coordination. Next we analyze the *production levels* of groups that coordinated in a given round. Although in the Aggregate treatment coordination improved only between FI and VS, the distribution of the total output for the coordinating cases shows exactly the opposite result. Figure 5.5 presents these distributions. Even though the distributions look alike in the Aggregate treatment, that is, they all have a big spike close to the Nash outcome, the Kolmogorov-Smirnov test shows that NI and FI, and NI and VS are significantly different from each other (with p-values 0.002 and 0.056, respectively), but there is no difference between FI and VS (p=0.274). In the Individual treatment the difference between parts are more striking: the highest spike close to the Nash equilibrium production level is under FI, and the lowest is under VS. On the other hand, the highest spike near the collusive outcome



(a) Aggregate



(b) Individual

Figure 5.5: Frequencies of total output for the coordinating groups in the Aggregate and in the Individual treatments. For each Q the plots show the percentage of outcomes that lie in the ± 5 neighborhood of a given Q.

is in VS, and there is no spike here in NI at all. These differences are all highly significant with p-values between 0.000 and 0.007. The distributions are also different across treatments for given part (all p-values are 0.000 here).[24]

If we compare the distribution of coordinating groups to the total distributions in Figure 5.2, we can see that in the Aggregate treatment total output is less dispersed, coordinating groups more often reach an outcome around the Nash equilibrium than the whole population. On the other hand, distributions in the Individual treatment change differently across parts. It is common that all distributions for the coordinating groups have more spikes now (compared to the grand total where the most cases lie around the Nash equilibrium outcome), but the size of these peaks are different. If subjects get individual information about others' production, they tend to coordinate more often on a lower total output, they try to be more collusive. However, if information sharing is not voluntary, the mode is still around the Nash outcome. This analysis leads to the following result.

[24]We have also checked whether the average output for coordinators is different across treatments and parts, but we only found one weakly significant difference: in the Aggregate treatment the total output for coordinating groups was significantly higher than the total output in FI ($233.09 >^{*} 224.67$ with p=0.07). Note that much more groups managed to coordinate in VS than in FI, and it seems that they were indeed good at coordinating on the Nash outcome (see also Figure 5.5).

Result 3. *The voluntary nature of information sharing improves coordination in case of aggregate information but not with individual information. Coordinating markets still tend to reach the Nash outcome under aggregate information, whereas there are more observations for collusive behavior in the Individual treatment.*

We also investigate whether coordination and information sharing are side-by-side by checking the correlation between being a coordinating and being a sharing group. For both treatments the correlation is significantly positive, though for the Aggregate treatment it is weakly significant (correlation is 0.06 with p=0.072). For the Individual treatment the correlation coefficient is much higher, 0.39 with p=0.000.[25] Information sharing should help coordination. This is confirmed by the fact that coordinating groups share information more often in the preceding round than non-coordinating groups: in the Individual treatment in 90.86% of the cases the group was a sharing group in the preceding round if they were a coordinating group in a given round, whereas this percentage is only 55.21% for the non-coordinating groups. In the Aggregate treatment this difference is not that substantial: 65.48% vs. 58.39% for coordinating and non-coordinating groups. This is not surprising since sharing information in the Aggregate treatment does not reveal individual productions, thus it does not facilitate coordination to the same extent.

5.5.4 Factors influencing behavior

Finally we investigate what drives information sharing and production decisions. First we analyze how subjects decide whether to share information. As we have seen in the previous section, there is a significant and negative correlation between information sharing and production in a given round. Although correlation does not mean causation, we can say that production decisions have an effect on information sharing decisions, since firms make profit by choosing a production level, and if they want to collude to get higher profit, they can signal this by sharing

[25]The correlation was calculated based on coordination in the given round and information sharing type of the previous round. We decided to take the first lag of the information sharing type because the information firms receive about the others are more likely to have an effect on the decision in the next round.

Dependent variable: Information sharing	Model I	Model II
own production	-0.05 (0.01)***	-0.05 (0.01)***
1st lag of infosharing	1.23 (0.12)***	1.22 (0.12)***
2nd lag of infosharing	0.38 (0.13)***	0.34 (0.13)***
3rd lag of infosharing	0.42 (0.12)***	0.43 (0.12)***
1st lag of others sharing	0.62 (0.15)***	-
1st lag of 1 other firm sharing	-	0.55 (0.16)***
1st lag of 2 other firms sharing	-	1.52 (0.37)***
treatment $*$ 1st lag of 2 other firms sharing	-	-0.88 (0.37)**
Number of panels	116	116
Avg # of observations per panel	27	27
-Loglikelihood	976.92	967.82

Notes: ***: significant at the 1% level, **: significant at the 5% level. Std errors are in parentheses after the coefficients. Panels are the individuals. Infosharing is 1 if the subject shares information in the given round, 0 otherwise. Others sharing is 1 if there is at least one other firm sharing information in the given round. 1 (2) other firm(s) sharing is 1 if there is exactly 1 (2) other firm sharing information in the given round, 0 otherwise. Treatment*2 other firms sharing is an interaction between treatment dummy (0=Aggregate, 1=Individual) and the dummy for 2 firms sharing.

Table 5.7: Regression results for information sharing as dependent variable

information about their production level.

Table 5.7 shows the estimation outputs of the fixed effect panel logit regressions. The table shows that the own production has a significantly negative effect on the likelihood of sharing information. This is in line with the signaling feature of information sharing. Information sharing decisions in the previous 3 rounds have a significant and positive effect on present information sharing decisions. If subjects previously shared information, they are more likely to share information again. Additionally, if at least one firm shared information in the previous round, subjects are significantly more likely to share information (see Model I).[26] In Model II we can also see that subjects react differently on the number of firms that share information. If two firms share information, this has a larger effect on the information sharing likelihood than if only one firm shares information. However, in the Individual treatment the effect of two other firms sharing is smaller than in the Aggregate treatment. This might be due to the fact that sharing information is much more costly in the individual treatment in the sense that competitors receive more detailed information about the firm's behavior. Reciprocity plays a smaller role here, since it was already taken into account when one other firm shares information. There is no treatment-difference in either model in the effect of the other variables.

[26]Further lags of these dummies are not significant.

As Table 5.7 shows, the information sharing decision not only depends on others' information sharing decision, but the initial own decision also gives priming to the behavior. The intention for collusion is also present in the first round: the correlation between information sharing and own production is -0.33 which is significantly negative at 1% level (p=0.000). However, this is not necessarily the only source of the first round information sharing decision. Subjects have already gained experience with no information and with full information in parts 1 and 2, and they know their earnings in both parts. The difference in earnings under full information and under no information positively correlates with the information sharing decision in the first round: the higher this difference is (that is, the more they earned under FI compared to NI), the more likely the subject shares information. However, this relationship is only weakly significant (the correlation coefficient is 0.13 with p=0.09).

Finally, we investigate how subjects decide about their production in different parts. First of all, based on the usage of the profit calculator, subjects did not seem to calculate best responses. They used the profit calculator in total 6511 times during the $3 \cdot 30$ rounds (with 501 times in the very first round in part 1).[27] If information was available about others' decision, subjects used this information in only about 50% of the cases when the profit calculator was used. Subjects are considered to use the information about others' decision if they entered a number that was within the ± 5 range of the previously observed value.[28] These together suggest that subjects did not calculate best response against others' decision.

Table 5.8 shows which variables affect production choices in different parts. VS is divided into three parts according to the number of other firms sharing information. In all 5 cases we have, price has a significantly negative effect on production. This result is counter-intuitive at first sight because if the price is higher, production should be increased to make more revenue, and profit. However, subjects might expect a decrease in the price, which leads them to choose a lower production. Unfortunately we cannot test this hypothesis with our data. In VS, when

[27] Thus, a subject used the profit calculator approximately 2 times in every 5 rounds on average.

[28] We considered the ± 5 range as subjects may take into account that the others make a different choice in the current round. That is, subject may not focus on the *naive* best response.

at least one firm shares information, subjects also react on the price changes. After a price increase, production significantly increases which is in line with our expectations. In contrast to the price, the profit has a significantly positive effect on production (except for the case in VS where 2 others share information). Furthermore, if the profit and the quantity change in the same direction, then subjects significantly increase their production (except for the same VS case again with 2 others sharing).[29] This result is consistent with gradient learning where production is adjusted based on previous experience on profit and production changes (as we assumed in Chapter 2). If full information was available for the subjects, own production is (weakly) significantly decreasing in others' production choices. This result is also in line with theory since quantities are strategic substitutes in this market. However, if only one other subject shared information, this information does not significantly affect production choice.

We also investigate whether there is a difference in behavior between treatments by including interaction terms in the model. Table 5.8 shows only the final models, we do not include the insignificant interaction terms. As we can see from the table, in case of No information there is no difference in behavior across treatments which is what we expect, since there is no difference in the information subjects receive. This is also the same for VS without sharing subjects in the group. In these two cases subjects can base their decision on the same information from the previous round, and the corresponding parameter estimates are very similar to each other. Note however, that in case of VS, the constant term is much larger than in case of NI which suggests that subjects not only choose higher production if they intentionally do not share information compared to the case when they cannot share, but they also produce more if the others intentionally do not share information. On the other hand, in case of Full information and VS with 1 other sharing the direction of the profit and production change has a significantly lower effect in the Individual treatment. In fact, in VS this effect in the Individual treatment is not significant any more, and it is only weakly significant in the Full information case (as the effect of the others' quantity is also only weakly significant in the Individual treatment). Furthermore, the

[29]To illustrate this result: if a subject increased his quantity compared to the previous round and he earned a higher profit, then it makes sense to increase the production to increase the profit again.

Dependent variable:	No info	Full info	VS	VS	VS
Individual production			0 others share	1 other shares	2 others share
L. price	-5.01 (0.50)***	-6.36 (0.58)***	-5.56 (1.06)***	-4.81 (0.60)***	-6.20 (1.03)***
L. price change	0.43 (0.35)	0.37 (0.23)	0.14 (0.22)	0.72 (0.30)**	0.72 (0.34)**
L. profit	0.06 (0.01)***	0.04 (0.01)***	0.04 (0.02)*	0.05 (0.01)***	0.03 (0.02)
L. π / q change	1.68 (0.25)***	1.92 (0.48)***	1.51 (0.49)***	1.45 (0.65)**	0.49 (0.33)
L. others' (seen) quantity	-	-0.20 (0.05)***	-	0.04 (0.04)	-0.17 (0.10)*
tr * L. π / q	-	-1.15 (0.59)*	-	-1.70 (0.92)*	-
tr * L. others' q	-	0.12 (0.02)***	-	-	-
tr * L. price change	-	-	-	-	-1.15 (0.45)**
constant	124.93 (6.06)***	192.98 (19.08)***	150.14 (16.14)***	129.60 (11.14)***	199.70 (35.31)***
Number of panels	180	180	95	153	145
Avg # of obs. per panel	28	28	11.1	9.9	17

Notes: ***: significant at the 1% level, **: significant at the 5% level, *: significant at the 10% level. Std errors are in parentheses after the coefficients. Panels are the individuals. In VS the sample is unbalanced. The variables are lagged. Changes are calculated by taking the first difference of the variables. π / q change is -1 if profit and quantity changes in opposite direction, 1 if they change in the same direction, and 0 if one of them is unchanged. Others' (seen) quantity is the total quantity the subject can see about others' production. In VS it depends on the others' infosharing decision. Finally, the treatment effects (shown by tr) are calculated by the interaction between treatment dummy (0 for Aggregate, and 1 for Individual) and other variables. Insignificant treatment effects are not included in the final models, therefor they are also not reported here.

Table 5.8: Fixed effect linear panel regression results for individual production as dependent variable

price change in case of VS with 2 others sharing is also insignificant for the Individual treatment. Here subjects seem to care a bit more about others' quantity than about price change or profit change. Note that FI and VS with 2 sharing firms have the same available information from the previous round, but subjects react on these pieces of information differently. The variables are less significant in case of VS which might be due to the fact that here information provision is endogenous, which cannot be captured by this model. Previously we have already seen that others' information sharing decision affects subjects' information sharing decision which highly correlates with the own production decision.

As a final test, we also ran separate regressions in case of Full info and VS with 2 others sharing for the Individual treatment in which we included the absolute difference of the two other firms' production. By doing so, we can test whether getting disaggregated data has an effect on the production. In both cases the effect is insignificant, therefore we omit the regression outputs.

5.6 Conclusion

This chapter has stressed that the voluntary nature of sharing information with competitors has important consequences for market competitiveness. The reason for this is that information sharing works as a signaling device: firms can show their willingness to collude by sharing information unilaterally. On the other hand, not sharing information signals competitiveness.

We have conducted a laboratory experiment in which subjects act as firms in the market of a homogeneous good. Three subjects form a market, where they compete in quantities. When subjects receive feedback about their competitors' actions, we vary the type of information they receive. Subjects can observe either the total output of their competitors (aggregate information) or the production level of the firms separately (individual information). Moreover, in one part of the experiment subjects can choose whether they want to share information with others or not, making the information structure endogenous. This kind of endogeneity has not been taken into account in previous work analyzing the effect of aggregate and individual information on market competitiveness.

Our results show that both the voluntary nature of information sharing and the level of data aggregation can have important consequences for the market outcome. Subjects produce significantly less when they decide to share information with their competitors compared to the case when they intentionally withhold this information. This confirms that subjects use information sharing as a signaling device. When subjects decide not to share information, they produce significantly more compared to the situation when information sharing is not possible and subjects receive no information about competitors. On the other hand, there is no significant difference between average productions when subjects decide to share information and when information is available by default. Voluntary information sharing helps coordination as well compared to the case when subjects automatically get aggregate information about their competitors' action: individual production levels tend to be closer to each other. However, coordination does not improve between Full information and Voluntary information sharing in case of individual information. Concerning further effects of aggregate and individual information, our results show that the average total output is lower when subjects receive individual information. This difference is, however, not significant. Thus, the market outcome does not become significantly less competitive under individual information but we could observe more attempts for collusion in the individual treatment. This is in line with the view of competition authorities regarding the anti-competitive nature of individual information. So publication of aggregate data does not lead to a higher level of collusion though it does not increase competitiveness either. Publication of individual data is a bit more dangerous, especially if firms voluntarily decide whether to share the information. Of course this depends on the distribution of the different types of firms in the market: the more collusive types are in the market, the more likely collusion is if firms can decide to share information. Thus, allowing firms to decide about sharing individual data might not be desirable.

In the paper we have focused on information sharing about actions. However, there is another branch of the literature on information sharing in oligopolies. In this other branch firms face either demand or cost uncertainty, they receive an individual signal about some unknown parameter and they may share their signal with each other.[30] Note that information sharing concerns different types of uncertainty in the two branches of the literature. In the branch that this chapter belongs to, firms are assumed to know the market characteristics and they learn about the behavior of their competitors through information sharing. In contrast, the demand or cost structure is not fully known in the other branch and information sharing helps firms learning the true market characteristics.[31] It would be interesting to combine the two branches as both sources of uncertainty (market characteristics vs. competitors' behavior) can be relevant in real markets. One possibility is to assume that firms do not know the demand function, for example, and they learn both demand conditions and their competitors' behavior from market observations. When firms do not know the demand function and they cannot observe the actions of their competitors when learning about demand conditions, then they may reach a substantially different outcome than under known demand structure (see e.g. Brousseau and Kirman, 1992 and Chapters 2 and 3 of this thesis). This might result in welfare loss and this possible loss should be taken into account for analyzing the effects of information on the market outcome. Huck et al. (1999) investigate the effect of receiving additional information about market conditions and they find that more information about the market leads to less competitive outcomes. As we have seen, the voluntary nature of information sharing has important consequences for the market outcome, therefore it would be interesting to extend our current design with treatments where demand conditions are unknown.

[30] See Raith (1996) for a general model that incorporates different market structures and sources of uncertainty. Kühn and Vives (1995) give a good overview of the results in this literature.

[31] Moreover, Mailath (1989) and Jin (1994) point out another important difference between the two branches. While firms cannot affect their signal about the environment, they can strategically choose their price or production level to alter the beliefs of their competitors about market conditions.

Appendix 5.A Instructions for Treatment I-NF

This section contains the instructions for treatment I-NF. The other instructions are similar and are available upon request.

PAGE 1

Welcome to this experiment on decision making. Please read the following instructions carefully. If you have any questions, please raise your hand, and we will come to your table to answer your question in private. The experiment will consist of three parts. Each part consists of 30 rounds. Your overall earnings will be equal to your total earnings in one randomly chosen part. At the end of the experiment we will publicly roll a die to determine which part will be paid out. If the result of the roll is 1 or 2, then part 1 will be paid. If the result is 3 or 4, part 2 will be paid. If the result is 5 or 6, part 3 will be paid.

When everyone has finished reading the instructions and before the experiment starts, you will receive a handout with a summary of these instructions. At the start of each part, you will receive a starting capital of 6000 points. You will not have to pay back this starting capital. In addition, you will earn points in every round based on your decisions in combination with the decisions of other participants. At the end of the experiment, your earnings in points will be transferred into money. Each 100 points will be exchanged for 0.091 eurocent. This means that for each 1100 points you earn, you will receive 1 euro. Your earnings will be privately paid to you in cash.

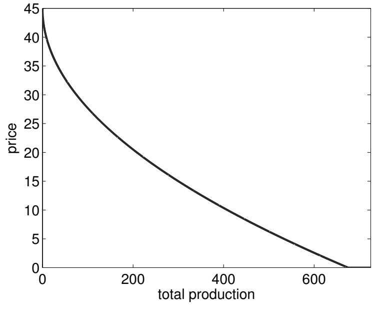
In this experiment, you will be randomly assigned to a "market" consisting of 3 firms denoted by firm A, firm B and firm C. During each part your market will not change, you will play with the same two other participants, and your role will be fixed to be one of the three above-mentioned firms. However, after each part of the experiment the composition of your market will change, and you will never be part of the exact same market again.

In the experiment you run one of the firms. You are interacting on the market with 2 other firms run by other participants. In every round you need to decide how much you want to produce. The price at which you sell the products depends on your production choice and on the production choice of the two other firms. Your earnings in each round will be equal to your profit from the production (which equals to your revenue minus your costs).

PAGE 2

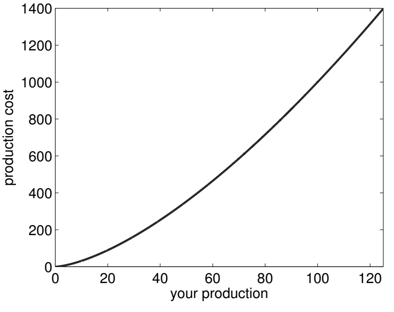
MARKET CHARACTERISTICS

In the experiment the market is characterized by the same structure in all three parts. In each part you need to decide how much you want to produce. You can choose any integer production level between (and including) 40 and 125 units. The price will depend on your production choice and on the production choice of the two other firms. The higher the total production (your production plus the production of the other firms) is, the lower the price is. The price is determined by the total production, according to the following formula: price = $45 - \sqrt{3} * \sqrt{(\text{total production})}$. The following graph illustrates how the price depends on the total production:



The price is the same for all firms in your market. Your total revenue is determined by the price and your own production in the following way: revenue = price * own production.

Production is costly. Your production cost depends on your own production choice only: cost = (own production)* $\sqrt{\text{(own production)}}$. The more you produce, the higher your production cost is. The production costs of the other firms depend on their own production level in the same way. The following graph illustrates how your total cost depends on your production:



Your profit in a given round is given by the revenue minus production cost:

$$\text{Profit} = (45-\sqrt{3}*\sqrt{\text{(total production)}})*\text{(own production)}-\text{(own production)}*\sqrt{\text{(own production)}}$$

DECISIONS IN EACH ROUND

PART 1

At the beginning of each round you choose your production, without knowing how much the other firms produce. After all three firms made their production choice, the price and the payoffs are determined. At the end of each round you are informed about your production choice, the price and your payoff (revenue, cost and profit) in the round.

PART 2

At the beginning of each round you choose your production, without knowing how much the other firms produce. After all three firms made their production choice, the price and the payoffs are determined. At the end of each round you are informed about your production choice, the price and your payoff (revenue, cost and profit) in the round. Additionally, all three firms are informed about the individual production levels of the other firms.

PART 3

At the beginning of each round you need to decide whether you want to inform the other firms about your production choice. They will receive this information only at the end of the round, after they made their own decision about informing others and production choice. Informing other firms is free, and both of your partners will receive the same information. Furthermore, you also choose your production, without knowing how much the other firms produce, and whether they decided to share information. After all three firms made their choices, the price and the payoffs are determined. At the end of each round you are informed about your production choice, the price and your payoff (revenue, cost and profit) in the round. Additionally, all three firms are also informed about the individual production levels of those firms that decided to inform others about their production choice.

PAGE 3

PROFIT CALCULATOR

When you are making your decision about production choice, you will see on the left-hand side of the screen a profit calculator. Here you can enter hypothetical production levels about your own production and the other two firms' total production, and you can calculate your profit with these production details. You can use the profit calculator as often as you want.

HISTORY OVERVIEW

On the lower part of the screen, a history screen will be provided. There, you can see the production details in your market for each round in the given part. One row contains information about one round. The history screen updates after every round. The observations are sorted descending by round, so you can find the most recent round always at the top. The history screen clears after every part.

The history screen is different in every part. In each part you will see your own production, the market price and your own profit. In addition, in part 2 you will see the individual production levels of the other firms by firm ID. In part 3, you will also see your information sharing decision, the individual production levels of those firms who shared. If a firm does not share information in certain rounds, you will see "n.a." for that firm in the table. Below you can find an example for the history screen in part 3.

Round	Information sharing	Own production	Production of firm B	Production of firm C	Price	Profit
3	yes	76	113	"n.a."	18	705.45
2	yes	95	"n.a."	76	19.72	947.45
1	no	84	70	101	17.34	686.69

On the next screens you will be requested to answer some control questions. Please answer these questions now.