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Endogenous information disclosure in experimental oligopolies*

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Abstract

With this research we examine whether observing firm-specific production levels leads to a less competitive market outcome. We consider an endogenous information setting where firms can freely decide whether they want to share information about their past production levels. By voluntarily sharing information, firms can show their willingness to cooperate. We conduct a laboratory experiment where firms decide only about their production levels first, and the information they receive is exogenous (either no information, or aggregate / disaggregated information about others' production, in varying order). Later, firms can also decide whether to share their past production levels with others. We vary the kind of information firms receive: they receive the shared information either in aggregate or in disaggregated form. Our results show no difference in average total outputs across data aggregation and information settings. However, we observe more collusion when individual information was shared voluntarily. Our results show that subjects use voluntary sharing to show their intentions to cooperate. If they share information, they produce significantly less than if they do not share information.

JEL classification: C72, C92, L13

Keywords: Cournot competition, information, collusion, experiment.

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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 (see Bischi et al. (2004) for example). 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.[1] Therefore competition authorities raise concerns about the dissemination of firm-specific data typically but not about aggregate values. For example in the Fatty Acids case the European Commission found the information exchange among the three largest firms in the market anti-competitive as it involved the exchange of individual information. In contrast, the exchange of aggregate information through the trade association of the industry was not objected.[2]

This research 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. We complement the existing experimental literature on this question by taking into account an important characteristic of markets, namely that sharing information is often a firm's own decision, therefore the information structure is *endogenous*. This endogeneity has two important features. First, the amount of information the firms may have about their competitors' choices lies between the two extreme cases of not having any information and having full information. This difference in the amount of information may influence the firms' choices.[3] Second, the choice of sharing information gives an important tool to firms: the possibility for showing their intentions. Sharing information gives a unilateral informational advantage to the competitors. Therefore, if a firm wants to collude and *voluntarily* shares its low production choice, then its competitors can interpret the information sharing decision as an additional sign for willingness to collude. When, however, the information structure

[1] 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.

[2] For more details about regulation and further examples see Kühn and Vives (1995), Section 8.3 in Buccirossi (2008) and OECD (2010). More information about the Fatty Acids case can be found in Kühn and Vives (1995).

[3] This is observed in Dufwenberg and Gneezy (2002), for example. The authors vary the amount of information subjects receive in a first-price sealed-bid auction and they find that the outcome is more collusive when subjects are informed about all the bids (compared to the cases when they do not get any information about others' bids or when only the winning bid is announced).

is exogenously given, firms automatically receive information, removing important strategic considerations behind information sharing. Thus, using exogenous information structures may lead to biased conclusions about the effect of information about competitors: The voluntary nature of information sharing may enhance the possibility of collusion between firms. Therefore in this paper we analyze 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 to show their intentions? Can it be desirable to make information sharing compulsory for firms (in order to reduce the possibility to show their intentions)?

In the experiment we use the same market structure as Offerman et al. (2002). We consider the market for a homogeneous good where three firms compete in quantities. We have a 2×3 design where we vary 1. the type of information subjects receive in one dimension (between subjects), and 2. the information structure in the other dimension (within subjects). Each session consists of three parts with different information structure. In the first two parts subjects either receive information about the other subjects' quantities or not, while in part 3 information sharing is voluntary, that is subjects not only decide about quantities but also about showing them to the others. In the other treatment-dimension we vary the kind of information subjects receive (whenever they receive information); they are either informed about *aggregate production levels* or about *individual quantities*, but never about profits.

The experimental results reveal no significant differences in the average total production across information type and structure. We observe more attempts for collusion under individual information though. This effect is even stronger under voluntary information sharing. This supports the view of competition authorities that firm-specific data has anti-competitive effects, justifying the concerns about disseminating individual data. Our results confirm that subjects use information sharing to show their intentions to collude. 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. The results show that the voluntary nature of information sharing can be important but it does not automatically lead to collusion on all markets.

The effect of different information about competitors' actions has already been analyzed in the experimental literature.[4] Experimental results show that the view of competition authorities is not necessarily valid. Huck et al. (1999) conduct an experiment on a homogeneous Cournot market with four firms. One di-

[4]Potters and Suetens (2013) give an overview about recent experimental oligopolies. In Section 3.3 they review studies about feedback, information and learning in oligopolies.

mension of their experimental design is the amount of information subjects receive about their competitors: They either receive no information or they are informed about the quantity choices 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 yields 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 productions 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.[5]

Our research differs from the previous studies 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 show their intentions to cooperate and this, as our results show, may have important consequences for the market outcome.[6] 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 typically collect information about prices or quantities but not about profits. 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, 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 do not observe a significant

[5]Gomez-Martinez et al. (2015) investigate the effect of data aggregation under direct communiation. They find the opposite effect than without communication: The market is more collusive when subjects receive firm-specific information about quantities and profits.

[6]Note that Bigoni (2010) also imposes endogenous information structure by letting subjects decide about what information to see from the past. She finds that subjects most often acquire firm-specific data. Their behavior is led by best-response dynamics and imitating the best firm.

difference between total production under aggregate and individual information either and we also find more attempts for collusion when subjects receive individual information.

There is another branch of the literature on information sharing in oligopolies, which is related to our research. 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. For theoretical studies see Novshek and Sonnenschein (1982), Vives (1984) and Gal-Or (1985) (and Kühn and Vives (1995) for an overview of the theoretical results). Raith (1996) develops a general model that incorporates different market structures and sources of uncertainty.[7] Note that information sharing concerns different types of uncertainty in the two branches of the literature. In the branch where our paper 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.[8] In Section 6 we discuss how the two branches of the literature can be connected.

Our research also contributes to oligopoly experiments with indirect communication. One type of indirect communication is to allow subjects to pre-announce intended prices at the communication stage. However, these prices are not binding. Even though this announcement is just cheap talk, it has a positive, but only temporary effect on collusion (see e.g. Cason, 1995 or Holt and Davis, 1990). This paper differs from this literature in the sense that our subjects are only allowed to truthfully communicate past actions with their competitors. They can only show their intentions by sharing their past behavior.

Finally, by letting subjects intentionally share or withhold information, we also contribute to another branch of the literature about how intentionality matters in different games. Previous results show that people perceive the same outcome differently based on the intentions behind the outcome (whether the decision maker is a human or a non-human, or whether the decision maker has interests in one outcome over the other). For experiments about the perception of different intentions, see Blount (1995), Offerman (2002) and Falk et al. (2008). These papers find that players punish others to a bigger extent if they were hurt by the partner intentionally compared to the case when the disadvantageous outcome is caused by nature, and the partner did not have a decision.[9]

[7] Experimental studies in this area include for example Cason (1994) and Ackert et al. (2000). Cason and Mason (1999) also compare exogenous and endogenous information structures, but they find little or no evidence that subjects use the available information differently based on the source of information (whether it was exogenously or endogenously shared).

[8] 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.

[9] Similarly, Charness (2004) and Falk and Kosfeld (2006) show that intentions also matter in labor market and principal-

The paper is organized as follows. The market game and the importance of endogenous information structure are discussed in Section 2. We present the experimental design in Section 3. Section 4 summarizes our hypotheses, then we report the experimental results in Section 5. Section 6 concludes.

2 The market environment

2.1 Market structure

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. First, we need at least 3 firms on 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 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 1 summarizes the individual and total quantities, the market price and the individual profits in these outcomes.[10] If we consider a situation where perfectly rational firms compete on the market for a finite and known number of periods (as in the experiment), then the repeated play of the Nash equilibrium of the stage game is the unique subgame-perfect equilibrium of the repeated

agent settings. Kopányi-Peuker et al. (2015) also provides experimental support for the importance of voluntary choice. They show that giving the possibility to the partner to punish induces cooperation in a prisoner's dilemma when punishment is offered voluntarily but not when it is exogenously available.

[10] See Offerman et al. (2002) for the general formulas.

	q_i	Q	P(Q)	π_i
N	81	243	18	729
C	56.25	168.75	22.5	843.75
W	100	300	15	500

Table 1: Quantities, market price and profits in the benchmark outcomes. N: Nash equilibrium, C: collusion, W: Walrasian equilibrium.

game no matter what information structure we impose (whether firms exogenously receive aggregate / individual data or they themselves can choose about sharing information). There is, however, ample empirical evidence that the assumption of perfect rationality and the standard equilibrium prediction does not necessarily describe actual behavior well.[11] Subjects can use different heuristics in their decision-making by e.g. imitating others' behavior. These decisions rules may require different types or pieces of information, and might lead to different outcomes.[12] Moreover, the market outcome may not only depend on the type of information but also on the way the information is made available. In the next section we elaborate on how the voluntary nature of information provision can affect the market outcome.

2.2 The importance of voluntary choice

In this section we discuss the consequences of having an endogenous information structure and we offer behavioral motivations behind information sharing decisions. The voluntary nature of information sharing can affect the market outcome for two reasons. First, endogenous choice can lead to a richer information structure. When firms can decide whether they want to share information with their competitors, then there are more possible information structures than having no information at all or having full information about competitors' choices. This difference in the amount of available information may influence the firms' choices, as observed by Dufwenberg and Gneezy (2002), for example.

Second, firms can show their intentions by their choice of sharing information. Sharing information gives a unilateral informational advantage to the competitors as they receive information even if they do not share their own actions with the firm. The rationale for sharing information is that firms may

[11] See Conlisk (1996) for an overview of such results. Furthermore, for example Andreoni and Miller (1993) discuss rational cooperation in prisoner's dilemma settings.

[12] Vega-Redondo (1997) proposes a rule where firms imitate the action of the firm that made the highest profit in the previous round. If all firms use 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 rule leads to the collusive outcome if everybody applies it.

expect to influence the behavior of their competitors in a favorable way. If a firm tries to collude with its competitors, then it chooses a low production level. It has an incentive to show this low production level to its competitors because otherwise the competitors would not know that the firm wants to collude. If a firm chooses a high production level, then it may take two approaches. It might want to show that it is tough and it will be tough in the future as well so that its competitors would adjust their choices to his by choosing a low output (i.e., the firm tries to act as a Stackelberg leader). Of course, the competitors could also respond by choosing a high production level in order to punish the firm. Thus, the firm may not want to reveal a high production level as it might take more time for its competitors to realize that the firm does not want to cooperate, therefore the firm may get a high profit in multiple periods. Which of the two approaches the firm takes depends on its *beliefs* about the competitors' reactions and on the competitors' actual reactions. It is not likely that the competitors would simply adjust to a high output so we expect that firms would rather hide a high output choice.

Showing intentions with information sharing choices can influence the market outcome in the following way. Firms might have different propensities towards collusion. On markets where many firms are willing to collude, these firms may show their intentions by choosing and revealing a low production level. This voluntary choice may induce other firms to join them as they can interpret the information sharing decision as an additional sign for willingness to collude. On the other hand, on markets where many firms are unwilling to collude, most firms will not share information with competitors. The competitors can conclude that many firms do not want to collude and therefore they would give up their attempts for establishing collusion. This shows that firms that are willing to collude may not be able to induce others to collude therefore voluntary information sharing does not enhance collusion in such markets.

To summarize, voluntary information sharing does not necessarily lead to collusion. It depends on the firms' intentions (or willingness to collude) whether collusion can be reached. If most of the firms are willing to collude, then information sharing may enhance collusion. But if firms are not willing to collude, then information sharing cannot establish collusion. Thus, voluntary information sharing may be important in some markets but not in others. In order to investigate how the market outcome depends on the type of available information and whether information sharing decisions indeed affect the market outcome, we conduct a laboratory experiment. In the next section we discuss the experimental design we use.

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 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 (with a maximum of 30 euros and a minimum of 21.3 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 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 2 and this was commonly known. In parts 1 and 2, either no information about others' production was provided (NI), or aggregate / individual production details were provided (that is, subjects received full information - FI). The order of these two parts varied across sessions to control for the possible order effects. In part 3 parallel to the production choice, subjects also decided whether to share information about their production with the other two subjects in their group (this part is the voluntary sharing part - VS). Sharing information was costless. If they shared information, the other two firms on the market received information about this firm's production regardless of their own information sharing decision.[13] Subjects received feedback after each round. This feedback contained their own production, the market price, their own revenue, cost and profit. Additionally, they received

[13] 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.

	No information (NI)	Full information (FI)	Voluntary sharing (VS)	# of matching groups
Aggregate	A-NI	A-FI	A-VS	16
Individual	I-NI	I-FI	I-VS	14

Table 2: Overview of the treatments with the number of matching groups

information about other firms' production in the full information part, and in VS if applicable.

Our within-subject treatment variation was the different information structure described previously: NI, FI and VS. The between-subject treatment variation concerned the type of information subjects received about others' production: Aggregate information (A) versus Individual information (I). 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 VS, subjects could observe how many other subjects shared information in their market and the aggregate output of the others who shared information.[14] In case of Individual information, individual production levels were shown by firm ID (which was fixed for a given part) and subjects could identify which firm produced a given amount. In VS, firms could see which firms shared information, and the exact production level of those firms who shared. The treatments are summarized in Table 2.[15] 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.[16]

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 own profit. Participants could use the profit calculator as often as they wanted to.

In each part, a history screen was always available for every subject. This screen contained information about past production in their own market. In case of NI subjects could see their own production, price and profit for every round. In case of FI 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

[14] Here we model how trade associations work who collect information and give them back in aggregated form to the firms.

[15] Due to low show up, we have fewer observations in the Individual treatments.

[16] We decided to use a within subjects design for the information structures because part 3 with voluntary information sharing is more complex than the parts with no information or full information. Therefore we wanted subjects to get experience about the market with as well as without receiving information about others' choices. That is also the reason why we give the instructions for all three parts at the beginning. We wanted subjects to know what they need to decide about in VS in order to facilitate making a sensible decision there. This also explains why we always have voluntary information sharing in part 3 and only vary the order of the other two parts.

	Observation		Inference	
	Aggregate	Individual	Aggregate	Individual
NI	q_i, p_i, π_i	q_i, p_i, π_i	Q	Q
FI	q_i, p_i, π_i, Q	$q_i, p_i, \pi_i, q_j, q_k$	$-$	Q, π_j, π_k
VS|0	q_i, p_i, π_i	q_i, p_i, π_i	Q	Q
VS|1	q_i, p_i, π_i, q_j	q_i, p_i, π_i, q_j	q_k, Q, π_j, π_k	q_k, Q, π_j, π_k
VS|2	$q_i, p_i, \pi_i, q_j + q_k$	$q_i, p_i, \pi_i, q_j, q_k$	$-$	Q, π_j, π_k

Notes: The observation column contains information subjects receive as feedback. The inference column contains what they can calculate. Here VS|x means that under VS x *other* firms share information.

Table 3: Overview of the information in different treatments

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 the Individual treatments (having NI as part 1) can be found in Appendix A.

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.

First of all note that even though subjects do not get full information in most of the treatments, they could infer some additional information. Table 3 gives an overview about the available information under different treatments, and different number of other firms sharing information in VS. Even though the aggregate production can always be calculated using the demand function (or at least inferred from the $P - Q$ plot in the instructions) and thus subjects could play the best response in principle, we do not expect them to perform such calculations.[17]

When aggregate production is directly observable, it becomes easier to find the best response, which drives the outcome towards the Nash equilibrium. Thus we expect production levels to be distributed around the Nash equilibrium quantity in A-FI. 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

[17] The use of the profit calculator suggests that they indeed did not calculate others' output and the best response to it. Subjects used the profit calculator approximately twice in every 5 rounds on average, and they took into account information about competitors only in 50% of the cases when it was available.

collusion (no matter whether the information is exogenously or endogenously given). This is in line with the competition authorities' argument that firms can monitor each other's behavior better. Moreover, as Offerman et al. (2002) show, the "imitate the exemplary firm"[18] rule leads to the collusive outcome and subjects have enough information to use this rule. This consideration is formulated in our first hypothesis.

Hypothesis 1 The effect of data aggregation
For a fixed information structure, average total production is not higher under individual information than under aggregate information: $\bar{Q}_{I,IS} \leq \bar{Q}_{A,IS}$ *(where* $IS \in \{NI, FI, VS\}$*), with strict inequality for* $IS = FI, VS$*.*

When the information structure becomes endogenous, subjects can show their willingness (or non-willingness) to collude. As we have argued in Section 2.2, 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 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 might suggest that they do not want to cooperate and then it is hard to imagine that they would collude in their production choices. Thus, we expect a difference in the behavior of subjects that share information and those who do not share information. This difference will also result in differences in the market outcome.

First of all, as information sharing decisions may convey information about subjects' intentions, we expect to observe more attempts for collusion, and consequently lower average production, under voluntary information sharing after 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. 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 after subjects do not share information with each other than under no information. Finally, as subjects may show their willingness to cooperate by sharing information, we expect to observe lower average production level under voluntary sharing after subjects share information with each other compared to the case when they do

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

not share information. We formulate these conjectures in our second hypothesis.

Hypothesis 2 The effect of voluntary sharing

For given data type, subjects can show their intentions by sharing / not sharing information resulting in a more collusive / more competitive market outcome:

- $\bar{Q}_{D,VS|share} < \bar{Q}_{D,FI}$
- $\bar{Q}_{D,VS|no\ share} > \bar{Q}_{D,NI}$
- $\bar{Q}_{D,VS|share} < \bar{Q}_{D,VS|no\ share}$ *(where* $D \in \{A, I\}$*)*[19]

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

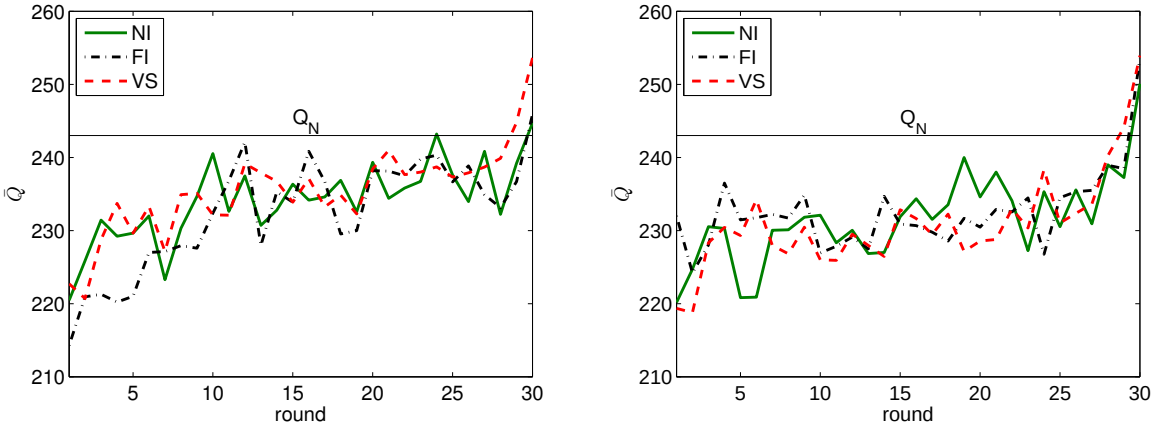
5 Results

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.[20] Our findings show that there is no order effect in the data. 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 can merge our data for given information type and information setting, and analyze them together.

The remainder of this section is organized as follows. In Section 5.1 we analyze the effect of data aggregation on total output. In Section 5.2 we focus on the effect of voluntary information sharing on the subjects' production choice and on total output. Finally, in Section 5.3 we investigate how groups coordinate under different information structures.

[19] For calculating $\bar{Q}_{VS|no\ share}$, we consider the total production on markets where at most 1 subject shares information in the given round and we calculate the average of these total productions over markets and rounds. Similarly, for calculating $\bar{Q}_{VS|share}$, we consider the total production on markets where at least 2 subjects share information in the given round and we calculate the average of these total productions over markets and rounds.

[20] To do so, we tested with the Mann-Whitney ranksum test whether subjects behaved differently in VS if they faced No information or Full information first. We did not find significant differences in individual productions, in total outputs and in the information sharing decisions. The test was performed on matching group level, and all p-values are at least 0.529. We also compared individual production levels and total outputs for parts No information and Full information in case they were played first vs. second. Here we did not find any significant difference either. These tests were also performed on matching group level, and 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 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			

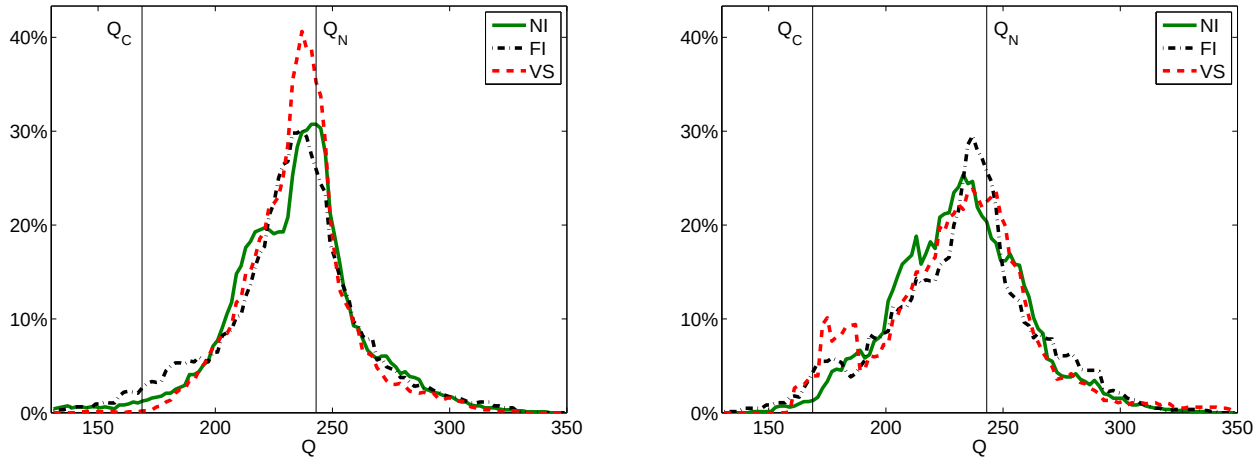
Notes: The numbers in brackets are standard deviations of the output. p-values are according to two-sided ranksum test with $n_A = 16$ and $n_I = 14$ for the between-subject differences, and Wilcoxon-test for the within-subject differences.

Table 4: Average total output, and corresponding test results

5.1 Effect of data aggregation

Figure 1 shows the average output over time for each treatment. We can see that production levels do not converge to the Nash equilibrium output, therefore the equilibrium prediction of the model with fully rational agents does not describe subjects' behavior well. There are no substantial differences in total outputs across treatments. The average output seems to be slightly lower under Individual information, however these differences are not significant. Furthermore, we can observe an end-game effect after round 27. The output before that is quite stable, markets quickly settle down around a certain output level. Non-parametric tests (presented in Table 4) also confirm the similarities; there are no significant differences in output levels across treatments. Our results do not support Hypothesis 1 that Individual information results in lower output than Aggregate information.

Although we cannot find any significant difference in *average* total productions between treatments, Figure 2 suggests that there might be differences across treatments with respect to the *distribution* of



(a) Aggregate

(b) Individual

Figure 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 ± 7 neighborhood of a given Q.

total output. Under both Individual treatments where information is available for the subjects, collusion is observed a bit more often, and the output is more dispersed compared to the corresponding Aggregate treatments. Furthermore, under A-VS aggregate production is close to the Nash-output in the vast majority of the cases. 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 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 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. However, the collusive outcome was hardly ever reached. The peak in case of I-VS is around 180. We will return to this issue in Section 5.2.

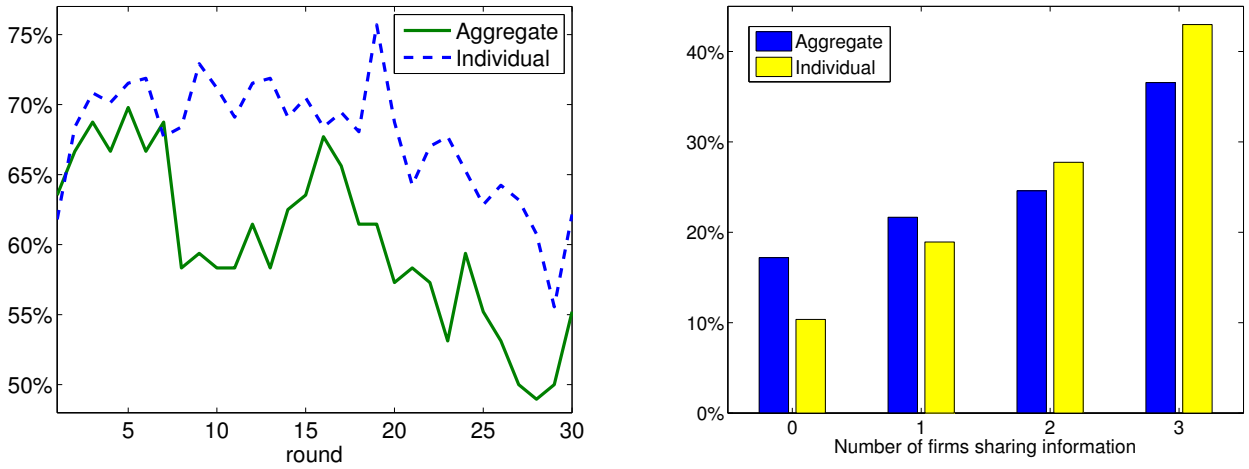
Table 5 summarizes how often the total output was in the neighborhood of the Nash outcome. As expected, the Nash outcome was always reached less often in the Individual treatments than in the Aggregate treatments, however the differences are only (weakly) significant in VS.[21] Finally, the neighborhood of the collusive outcome (i.e. $Q \in [160, 176]$) is reached more often in the Individual treatments than in the Aggregate treatments, though these differences are not significant either in any of the information structures.[22] These results are well in line with those of Offerman et al. (2002), except that we observe a

[21] Using the ranksum test with $n_A = 16$, $n_I = 14$, we obtain the following p-values: $p_{NI} = 0.32$, $p_{FI} = 0.72$, and $p_{VS} = 0.05^*$.

[22] It can also be seen from Figure 2 that the fraction of collusive outcome is not substantial. They vary from about 0.2%

Treatment	No info	Full info	VS
Aggregate	30.73%	25.94%	35.21%
Individual	20.36%	25.71%	22.50%

Table 5: Percentage of outcomes in the ±7 neighborhood of the Nash equilibrium quantity Q_N (i.e. [236,250])



(a) Frequency of information sharing over time

(b) Occurance of different information structures

Figure 3: Average frequency of information sharing over time and the frequency of markets with different information structure

significant difference between A-VS and I-VS compared to A-FI vs. I-FI considering the Nash outcome. Our findings can be summarized as follows.

Result 1 *Average production levels are not significantly different across treatments. However, significantly fewer observations are around the Nash outcome in I-VS than in A-VS.*

5.2 Consequences of information sharing on output decisions

Now we focus on voluntary information sharing, and investigate how the endogeneity of the information structure affects production choice. First we only focus on VS, and then we compare the production choices across all information structures.

Figure 3a 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

(in A-VS) to 3.9% (in I-FI).

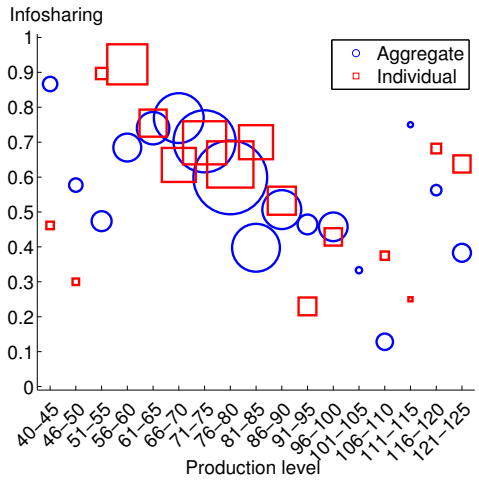


Figure 4: Information sharing as the function of the production level

Notes: We define 17 categories for the different production levels. Each category covers a range of 5 units of production (except the first one). The size of the markers is proportional to the frequency of production in that particular range.

67.8% in the Individual case. However, these values are not significantly different from each other using the ranksum test on matching group levels ($p = 0.38$). As we can see, a substantial fraction of subjects share information during the experiment resulting in a richer information structure in the markets (see Figure 3b): about half of the observations differ from the cases no information (i.e. 0 firms sharing information) and full information (i.e. all 3 firms sharing information). The figure shows that full information occurs the most often, and no information the least often for both Aggregate and Individual information.[23]

The different information structures correspond to different productions as well. Ex ante we expected that those who want to collude choose a low production level and they share it while those who would not collude choose a high production level and they do not share it. Figure 4 shows the fraction of sharing decisions as a function of the chosen production levels (the size of the markers indicates the frequency of that given observation). The figure shows that there is a clear negative correlation between the information sharing decision and the production level, supporting our conjectures. Although correlation does not mean causation, it is reasonable to assume that production decisions have an effect on information sharing decisions since profits depend on production levels but not on information sharing decisions. Fixed effect panel logit regressions with information sharing as dependent variable confirm this negative correlation. The result, presented in the first column of Table 6, shows that the own production has a significantly

[23]The pattern is the same when we display only the second half of the data which suggests that markets do not converge to any of the extreme cases with no or full information. In fact, some markets converge to one of the extreme information structures over time, but firms on most markets keep changing their information sharing decisions.

Dependent variable:	Information sharing	Individual production
own production	-0.06 (0.00)***	-
1st lag of infosharing	1.45 (0.10)***	-3.10 (0.48)***
1st lag of 1 other firm sharing	0.69 (0.15)***	-2.54 (0.53)***
1st lag of 2 other firms sharing	1.52 (0.20)***	-2.86 (0.66)***
constant	-	82.07 (0.54)***
Number of panels	122	180
Number of observations per panel	29	29
-Loglikelihood	1097.80	-
F-statistics	-	24.10***

Notes: ***: significant at the 1% level, **: significant at the 5% level. Std errors are in parentheses after the coefficients. The first column corresponds to a fixed effect logit model, the second column to a fixed effect regression. Panels are the individuals. Infosharing is 1 if the subject shares information in the given round, 0 otherwise. 1 (2) other firm(s) sharing is 1 if there is exactly 1 (2) other firm sharing information in the given round, 0 otherwise.

Table 6: Regression results for information sharing decisions and production choices in VS

negative effect on the likelihood of sharing information. Information sharing decision in the previous round has a significant and positive effect on present information sharing decision. 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.

If we decompose the production decisions in VS based on the information sharing decisions, we find that subjects indeed choose different production levels 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.[24] This result confirms our expectation, that subjects self-select to sharing / not sharing information if they have an intention to collude / not to collude (compete) with the others.[25] Furthermore, others' information sharing decision also has a significantly negative effect on the production in VS which shows that subjects interpret others' information sharing

[24]In the Aggregate treatment the average production based on matching group averages are 76.48 in case of sharing, and 81.93 in case of non-sharing, whereas in the Individual treatment these numbers are 74.74 vs. 84.53. The differences are significant at 1% level (both p-values are 0.00).

[25]The intention for collusion is also present in the first round. If we decompose individual production in the exogenous parts based on the first round information sharing decision, we also find a negative relationship between production levels and the first information sharing decision under Individual information. We can see that those subjects who shared information in the first round of VS produced significantly less on average in the 30 rounds of both exogenous parts ($p = 0.02$ for I-NI, and $p = 0.10^*$ in I-FI). This also supports that subjects intend to show their willingness for collusion by sharing information.

Treatment	NI	FI	VS|n	VS|s	VS|s vs. VS|n	NI vs. VS|n	FI vs. VS|s
Aggregate	234.12	232.43	241.62	232.97	0.03**	0.04**	1.00
Individual	231.59	232.46	244.87	226.39	0.01**	0.06*	0.30
Agg. vs. Ind.	0.59	0.43	0.60	0.34			

Notes: **: 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 $n_{\mathrm{I\text{-}VS|n}} = 13$) for the between-subject differences, and Wilcoxon-test for the within-subject differences. The averages in the table are based on the matching group averages. For ease of exposition we repeat averages from Table 4.

Table 7: Average total productions

decision as a signal for collusion as well. To control for the correlation between the own information sharing decision and production choice, we run a fixed effect panel regression with individuals as panels on the production choice as dependent variable and (own and others') information sharing decisions in the previous round as independent variables. The results, presented in the second column of Table 6, show that after others share information subjects significantly reduce their production. Although these results are well in line with Hypothesis 2 about the market outcome, we cannot accept or reject them yet since groups are heterogeneous with respect to information sharing behavior (as we can see from Figure 3b), therefore we cannot draw conclusions about group behavior based on individual behavior only.

To analyze the market outcome, we categorized groups as *sharing* group if there were 2 or 3 firms sharing information in a given round and as *non-sharing* group otherwise.[26] Table 7 shows the average total output for the treatments, and the corresponding test results. We decomposed the production in VS for sharing and non-sharing groups based on the previously mentioned definition of groups.[27] 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). Interestingly, there is no significant difference between markets with exogenously and endogenously provided information (FI vs. VS|s), but the market is significantly more competitive when subjects intentionally decide to withhold their information compared to the case when no information is supplied by default (NI vs. VS|n).[28] This suggests that subjects intentionally hide

[26]Note that with this definition a group might be a sharing group in some rounds while non-sharing in other rounds.

[27]The trend is similar if we not only define sharing and non-sharing groups, but decompose the output into four different groups based on the number of firms sharing information. Under both Aggregate and Individual data the output decreases as the number of sharing firms increases (except for the Aggregate case where the output increases between 0 and 1 sharing firm). However, the differences between output levels with n and $n+1$ sharing firms is only (weakly) significant under Aggregate treatment between 1 and 2 sharing firms, and under Individual treatment with 0 and 1 sharing firm.

[28]We not only find that voluntary information sharing makes markets more collusive if information is shared, but we also find that sharing groups make significantly higher total profit than non-sharing groups under both information types

their intention to compete when they are able to do so.[29]

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 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 200). Mainly the production of these four groups led to the smaller peak 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. Thus, allowing firms to decide about sharing firm-specific data can indeed result in collusion, but because firms are heterogeneous with respect to information sharing, collusion may not always be observed. Based on our findings, we can partly accept Hypothesis 2, and the effect of voluntary information sharing can be summarized as follows:

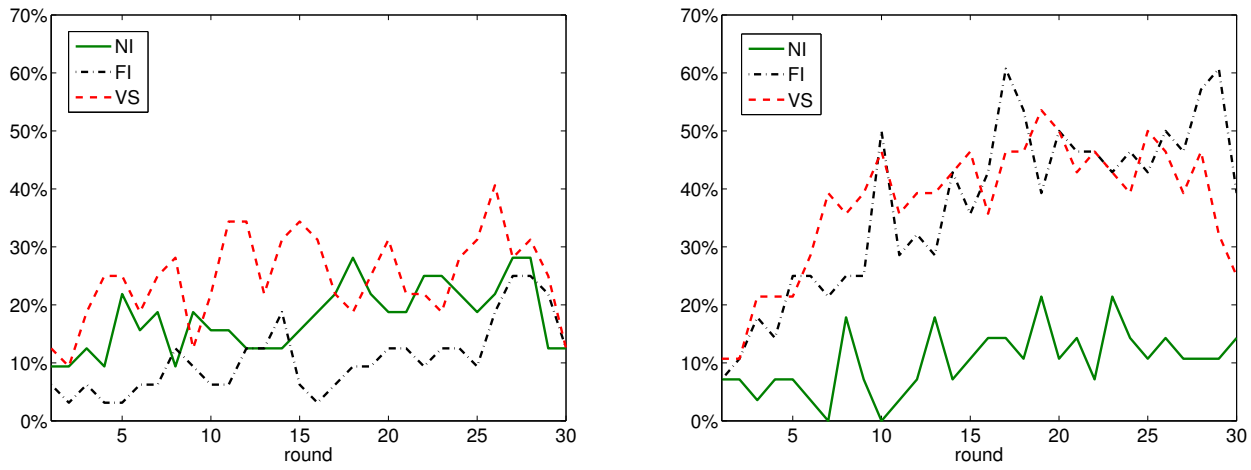
Result 2 *Subjects show their intentions with information sharing: They produce significantly less when they share information voluntarily compared to the case when they decide not to share information. Furthermore, if they decide not to share information, the market is significantly more competitive than if information is not available by default. However, when firms have information, the way information is received (exogenously vs. voluntarily shared) does not significantly influence the market outcome.*

5.3 Coordination

Although in terms of the market outcome it does not matter how the total production is distributed among the three firms, we further analyze what causes the difference in the distributions of total output by investigating whether firm-specific information or endogenous information structure helps firms coordinate on a given outcome. To do so, we define 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 is at most 7. Using this definition, Figure 5 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

($p < 0.04$). However, this result does not hold for individuals, we do not find significant differences in individual profits for sharing and non-sharing individuals. This shows that sharing information can be harmful if others do not follow.

[29] An alternative approach would be to decompose the production in VS by being a sharing or a non-sharing group in the *preceding* round. By doing so, we can measure the effect of information sharing on future production. In this case the qualitative results are the same, but we do not have significant differences any more between sharing and non-sharing groups, and between NI and VS|n. This suggests that it is not enough that subjects share information once, but they need to maintain the information flow in order to maintain lower production.



(a) Aggregate

(b) Individual

Figure 5: Average share of coordinating groups over time in the Aggregate and in the Individual treatments

Aggregate treatment, so more information does not seem to help coordination to a great extent there.[30] In contrast, more information clearly helps in the Individual treatment, irrespective of whether information is given exogenously or endogenously. Groups manage to coordinate more often under I-FI and I-VS than under I-NI, and non-parametric tests (presented in Table 8) confirm that these differences are significant. Furthermore, under Aggregate information Voluntary sharing (weakly) significantly helps coordination compared to both NI and FI case. Comparing the different information types, we can see that as we move from NI to FI, coordination decreased under Aggregate info but it increased under Individual info, making the two treatments (A-FI and I-FI) significantly different from each other. Also under VS groups coordinate significantly more often under Individual information than under Aggregate information. Thus Individual information helps coordination more than Aggregate information.

Considering the effect of endogenous information structure, we can observe a positive correlation between being a coordinating group in a given round and being a sharing group in the preceding round (the correlation coefficient is 0.12 in A-VS, and 0.36 in I-VS). 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 I-VS in 91.64% 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 58.28% for the non-coordinating groups. In A-VS this difference is not that substantial: 65.67% vs. 60.00% for coordinating and non-coordinating groups. This is not surprising since sharing information in

[30] Note however, that more information provided in the Aggregate treatments does not necessarily leads to more effective information since total output can always be inferred based on the demand function and price.

Treatment	NI	FI	VS	VS|n	VS|s
Aggregate	17.71%	10.62%	24.69%	18.58%	25.91%
Individual	10.24%	37.14%	37.38%	9.87%	48.49%
Agg. vs. Ind.	0.37	0.00***	0.03**	0.38	0.00***

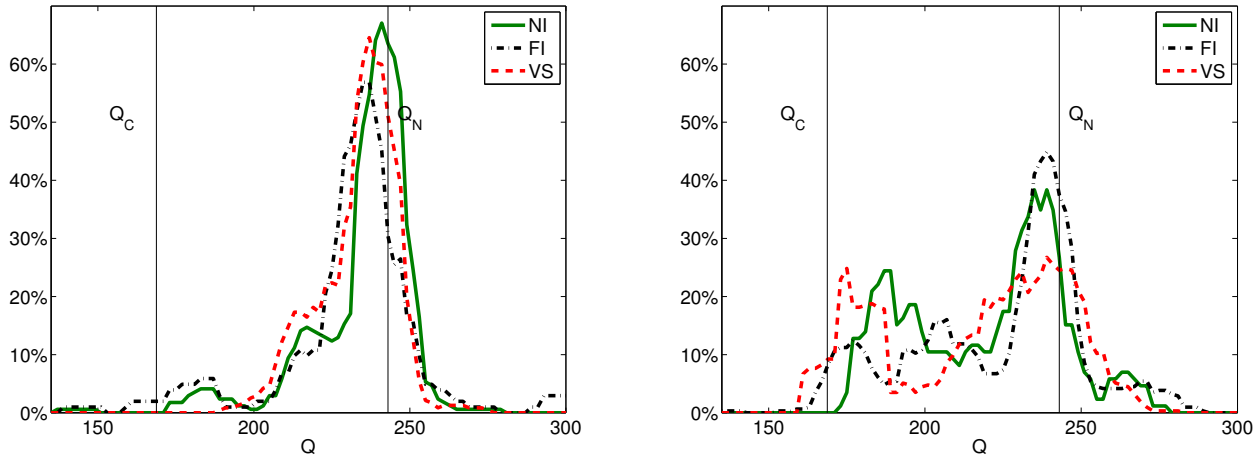
Treatment	NI vs. FI	NI vs. VS	FI vs. VS	VS|s vs. VS|n	VS|n vs. NI	VS|s vs. FI
Aggregate	0.35	0.08*	0.00***	0.21	0.59	0.01***
Individual	0.00***	0.00***	0.57	0.00***	0.97	0.06*

Notes: ***: significant at 1%-level, **: significant at 5%-level, *: significant at 10%-level according to two-sided ranksum test with $n_{\text{A}} = 16$ and $n_{\text{I}} = 14$ (and $n_{\text{I-VS|n}} = 12$) for the between-subject differences, and Wilcoxon-test for the within-subject differences. The averages in the table are based on the matching group averages. To calculate coordination for sharing and non-sharing groups in a given round, we assign (non-)sharing types based on the previous round's information sharing decision.

Table 8: Average share of coordinating groups across treatments, and corresponding test results

the Aggregate treatment does not reveal individual productions, thus it does not facilitate coordination to the same extent. These results are also presented in Table 8 in a somewhat different format (by giving the amount of coordination for sharing and non-sharing groups). The test-results also confirm that in I-VS sharing groups coordinate significantly more often, whereas in A-VS we cannot establish such result. Furthermore, we find that coordination is higher if subjects voluntarily share information compared to FI, and coordination is the same when they do not share or they cannot share information with each other.

So far we have focused on the *amount* of coordination. Next we analyze the *production levels* of groups that coordinated in a given round. Figure 6 presents the distributions of total production for the coordinating groups. These distributions look very different across information type. In the Aggregate treatments, all three distributions are similar, they are all centered around the Nash outcome. If we compare them to the total distributions in Figure 2, we can see that the total output is less dispersed here, coordinating groups reach an outcome around the Nash equilibrium even more often than the whole population. Moving to the Individual treatments, we can see that the total output is much more dispersed, and they look different across information structure (both compared to the Aggregate treatments and compared to the total distribution in Figure 2). Whereas there is a relatively high peak around the Nash outcome under I-FI, there are two equally high peaks under I-VS, one near the Nash outcome and another one close to the collusive outcome (around $Q = 180$). If information sharing is not voluntary, the mode is still around the Nash outcome, as we had it with the whole population. Comparing the frequencies



(a) Aggregate

(b) Individual

Figure 6: 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 ± 7 neighborhood of a given Q.

of Nash and collusive outcome between treatments we find significantly more observations around the collusive outcome in I-VS than in A-VS ($p = 0.06$), other comparisons are not significant.[31] Our analysis leads to the following result.

Result 3 *The voluntary nature of information sharing improves coordination in case of Aggregate information but not with Individual information where the presence of information is already enough to foster coordination. Furthermore, sharing groups in VS coordinate significantly better than groups under FI. Finally, coordinating markets still tend to reach the Nash outcome under Aggregate information, whereas there are more observations for collusive behavior under Individual information.*

To summarize our results, we have found that in average terms there are no significant differences in total outputs across information structure and the type of information. However, if we decompose VS decisions, we can see that subjects indeed show their intentions with information sharing. Those who share information choose significantly lower production levels than those who do not share information. Additionally, those who do not share information choose even higher production levels than in the No information case when information sharing was prohibited. So in average terms markets are neither more collusive nor more competitive if more information is available irrespective of the type of information, but there are more attempts for collusion when individual information is shared voluntarily.

[31] The procedure here is the same as before. We took the percentage of outcomes in the ± 7 neighborhood of the Nash and the collusive quantity, and compared those. We have also checked whether the average output for coordinators is different across treatments, but we did not find any significant differences across treatments.

6 Conclusion

This paper stresses that the voluntary nature of sharing information with competitors might have important consequences for the market outcome. The reason for this is that firms can show their willingness to collude by sharing information unilaterally, thus voluntary information sharing might serve as a device to enhance collusion.

We conducted a laboratory experiment in which subjects acted as firms in the market of a homogeneous good. Three subjects formed a market, where they were competing in quantities. When subjects received feedback about their competitors' actions, we varied the type of information they received. Subjects could 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 could 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 works analyzing the effect of data aggregation 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 device to show their intentions. 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 market outcome does not become significantly less competitive under Individual information but we could observe more attempts for collusion in the Individual treatments. 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 higher level of collusion though it does not increase competitiveness either. Publication of individual data is a bit less innocuous, especially if firms voluntarily decide whether to share the information. Of course this depends on the composition of 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 focused on information sharing about actions with known demand. However, it would be interesting to combine this branch of the literature with the other branch where information sharing concerns sharing signals about unknown demand or cost conditions. This is of particular interest as both sources of uncertainty (market characteristics vs. strategic uncertainty) can be relevant on 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 Anufriev et al., 2013). This might result in a 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 unknown demand conditions.

Appendix A Instructions

This section contains the instructions for the Individual treatment with No information first. The other instructions are similar and available upon request from the authors.

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.

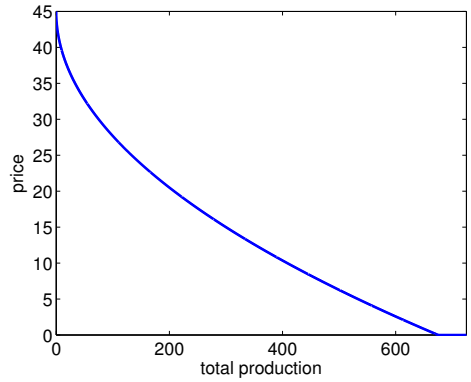
In this experiment, you will be randomly assigned to a "market" consisting of 3 firms denoted by firm A, firm B and firm C. During each part your market will not change, you will play with the same two other participants, and your role will be fixed to be one of the three above-mentioned firms. However, 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

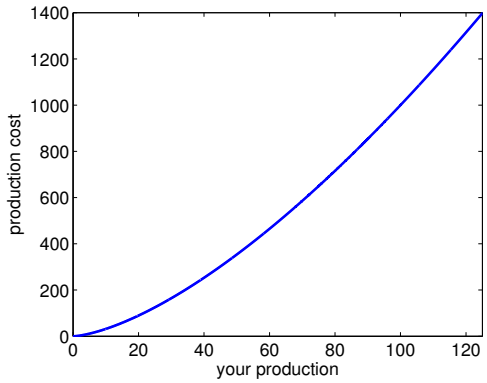
MARKET CHARACTERISTICS

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.

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