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Chapter 1
Introduction

Allocation rules, information sharing requirements or precommitments of firms to specific actions can strongly influence the outcome of a market. The understanding of how these features affect incentives of players in a given context is hence essential for market designers, antitrust authorities and legislators. In the following three chapters of this dissertation these effects are analyzed. Methodologically, all chapters have in common that they first develop and discuss a game theoretic model, which is then used for the derivation of hypotheses that are tested in a laboratory experiment. Each chapter thereby connects to and extends previous findings in industrial organization, experimental economics or mechanism design.

A key difference between the chapters lies in the level of abstraction. Chapter 2 analyzes specific price commitments of firms in a well-defined market environment. Chapter 3 looks more generally at the incentives of firms for sharing information in environments which differ in the degree of information asymmetry and the type of competition. Finally, the last chapter examines how institutions in general can be designed to lead to a desired outcome, even if players have social preferences which are unknown to the market designer.

Chapter 2 is motivated by a new low-price guarantee which was recently introduced in the German gasoline market by Shell.[1] The guarantee promises to registered customers of Shell that its effective gasoline price never exceeds the current price of any regional competitor by more than 2 Cents. In addition, this guarantee does not need to be explicitly claimed by participating customers, but is implemented automatically since Shell checks every purchase with a complete and real-time dataset from the German antitrust authority on whether the conditions of its guarantee are met. This chapter investigates, how this new type of price guarantee in general influences competition and, in particular, whether it can induce collusive high prices.

To this end, we analyze the guarantee in a sequential Hotelling duopoly model with two symmetric competitors which are located at the opposite ends of a road and compete in prices for a homogeneous good. We find that whenever at least the price-leader, i.e. the first moving firm, provides a guarantee with a sufficiently low markup, the equilibrium price level in the market is on average at the monopoly price

[1] Chapter 2 is written without coauthors. Despite this, the terms *we* or *us* instead of I are used throughout the chapter for consistency with the following chapters.

level. The data from a laboratory experiment supports this theoretical prediction. Here, we find that in the treatment where the first moving firm has a guarantee with a low markup, prices of both firms are significantly higher in comparison with the treatments where the markup is high, or no price guarantee is in place.

The findings contribute to the previous theoretical and experimental literature on perfect price-matching guarantees and emphasize that this new type of price guarantee should be carefully reviewed by regulators and antitrust authorities.

Chapter 3 is joint work with Jos Jansen. It is motivated by a conflict between accounting rules and antitrust policies.[2] In particular, antitrust authorities are typically skeptic about information sharing among competitors because this might lead to price coordination, while accounting rules often force firms to publicly disclose information in order to protect investors. This chapter studies strategic incentives for the disclosure of private information by firms about common market characteristics, like input costs or the demand level, and the corresponding consequences for the market outcome.

For the analysis, we use a duopoly model with incomplete information on a common demand intercept. This intercept can be either high or low and is drawn according to some distribution. Each duopolist can learn the intercept with a predefined probability. If they are successful in learning, they can voluntarily share this information with their competitor before competing with each other in a product market. Within this framework, we vary the demand distribution, the chances of learning the intercept and whether the competition is in prices or quantities.

We find that, independently on the variation of the model, firms selectively disclose information in order to gain a strategic advantage. By doing this, they manage their competitor's belief about the demand intercept as well as about their own conduct. Hereby, they manipulate their competitor's conduct in the product market in a way favorable for them. However, what kind of information they disclose and how strong the disclosure affects the market outcome depends on the information asymmetries among firms and the type of competition. With Cournot competition, firms typically disclose low demand and conceal high demand. However, we also identify conditions under which one Cournot competitor follows this strategy and

[2]Both authors were equally involved in generating the general research ideas, the experimental design as well as the hypotheses and in writing the draft. The theoretical model was developed by Jos Jansen. Mathematical proofs were done by Jos Jansen. The experiment was programmed, planned and conducted by Andreas Pollak. Statistical analyses were carried out by Andreas Pollak. — The chapter is a modified version of Jansen and Pollak (2015). The data collection for the homogenous goods Cournot treatments and parts of the empirical analysis regarding the first hypothesis was done in Pollak (2012). The current version of the chapter was submitted to the "International Journal of Industrial Organization" where it received a Revise & Resubmit.

the other chooses the reverse strategy. Moreover, the reverse disclosure strategy is always chosen in Bertrand competition, irrespective of the demand distribution and the degree of information asymmetry.

The chapter connects to previous theoretical and experimental studies on information disclosure. In particular, it is related to a paper by Ackert et al. (2000) who find evidence for selective disclosure in a model where only one firm has the ability to obtain and share information. We replicate and extend their findings by considering bilateral disclosure decisions, Bertrand competition, and information asymmetries between firms. We show that the previous finding of selective disclosure is robust to various kinds of market environments. In addition, we provide a tool to examine the resulting effect of disclosure on the market outcome.

In summary, our results help to evaluate the effects of economic policies regulating information disclosure by firms, such as competition policies or accounting rules.

Chapter 4 is joint work with Felix Bierbrauer, Axel Ockenfels and Désirée Rückert.[3] Standard mechanism design literature takes selfish preferences of players for granted. Consequently, the mechanisms proposed by this literature might systemically fail when players are motivated by social preferences. In this chapter, we compare standard mechanisms with social-preference-robust mechanisms by studying two classical challenges of mechanism design, the bilateral trade problem and the problem of optimal income taxation.

For the bilateral trade problem, we first characterize a standard optimal and seller surplus maximizing mechanism, where the "buyer" and the "seller" are expected to truthfully report their type. We test this mechanism in a laboratory experiment and find that a non-negligible fraction of high valuation buyers understate their valuation. This finding contradicts to the underlying assumption of selfish preferences in classical mechanism design but is consistent with models of social preferences such as Fehr and Schmidt (1999) and Falk and Fischbacher (2006). We then characterize a mechanism which is externality-free, i.e. where each player's equilibrium payoff does not depend on the other player's type, and is thus social-preference-robust. Testing this mechanism in the laboratory, we find that there are no longer deviations from truth-telling. Hence, the social-preference-robust mechanism is able to

[3]The research question and the experimental design were developed by Felix Bierbrauer and Axel Ockenfels, with comments from Andreas Pollak and Desiree Rückert. The theoretical analysis was done by Felix Bierbrauer and Desiree Rückert. The experiment was planned, programmed and conducted by Andreas Pollak. The statistical analyses were carried out by Andreas Pollak. All authors contributed equally to writing the paper. The current version of the paper is forthcoming in the "Journal of Public Economics".

induce the desired outcome. However, in theory under the standard assumption of selfish preferences, this social-preference-robust mechanism is inferior in terms of performance relative to the standard mechanism, because the implementation of externality-freeness comes with a cost. Due to this cost, the standard mechanism outperformed the social-preference-robust mechanism in the experiment as the number of deviations in the former was too small to compensate for that cost. Based on this observation, we engineered a hybrid mechanism by implementing externality-freeness only for the cases where a deviation from truthful behavior was observed, and tested it in the laboratory. In this experiment, the hybrid mechanism outperformed the standard mechanism in terms of both truth-telling and performance.

For the problem of optimal income taxation, we compare a mechanism proposed by Piketty (1993), which is optimal in the classical sense, with a mechanism of Mirrlees (1971) which is externality-free. In an additional experiment, we find that the (globally) externality-free Mirrleesian mechanism outperforms the standard optimal (but not social-preference-robust) mechanism by Piketty in terms of both truthful reporting and welfare.

Thus, Chapter 4 shows theoretically and experimentally that classic mechanisms can fail in generating a desired outcome, whereas externality-free mechanisms can preclude players from untruthful reporting. Whether a classic or a social-preference-robust mechanism is superior in terms of performance depends on the extent of deviations of players from truth-telling in the former. If the market designer knows where deviations can be expected, externality-freeness can be implemented locally and at a lower cost.

Chapter 2

Do Price-Matching Guarantees with Markups Facilitate Tacit Collusion? Theory and Experiment*

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Abstract

This paper studies how competitive prices are affected by price-matching guarantees allowing for markups on the lowest competing price. This new type of low-price guarantee was recently introduced in the German retail gasoline market. Using a sequential Hotelling model, we show that such guarantees, similar to perfect price-matching guarantees, can induce collusive prices. In particular, this occurs if the first mover provides a price guarantee with a markup which is below a threshold value. In these cases, prices are on average set at the monopoly level. A laboratory experiment supports the theoretical predictions.

Keywords: price-matching guarantee, tacit collusion, Hotelling, spatial competition, sequential pricing, laboratory experiment
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2.1 Introduction

Since summer 2015, Shell promotes a new kind of low-price guarantee for standard gasoline: a price-matching guarantee with a markup on the lowest competing price within the regional market. In order to benefit from this guarantee, Shell's customers have to register once, which is free of charge. Hereafter, Shell automatically checks for any purchase whether the posted gasoline price exceeds the lowest competing price by more than 2 Cents per liter, and, if this is the case, reduces its selling price to the lowest price plus the markup of 2 Cents.[1]

The introduction of the guarantee followed a change in the design of the gasoline retail market, implemented by the German antitrust authority in 2013. More precisely, the *Bundeskartellamt* established a real-time database for standard gasoline and diesel, called the *Markttransparenzstelle für Kraftstoffe* or market transparency unit, and forced almost all gasoline retailers to keep their prices in the database up to date.[2] The market transparency unit is accessible for anyone free of charge via various websites or smart-phone apps. The purpose of its introduction was to increase competition in the German gasoline retail market, as this market was found to be prone to (tacit) price coordination.[3] However, it also enabled Shell to introduce this kind of guarantee, by providing the data for its automatic price comparisons. This made the guarantee especially attractive to customers, because they do not incur any costs of invoking the guarantee.

The question arising from this motivating example is whether this new kind of low-price guarantee might have an anti-competitive effect. Previous theoretical, empirical and experimental literature suggests that perfect price-matching guarantees are anti-competitive if the costs of invoking the guarantee are low. In contrary, other forms of low-price guarantees, especially price-beating guarantees, can even be pro-competitive. In a nutshell, the anti-competitive effect of the perfect price-matching guarantees results from making it virtually impossible to effectively undercut a rival's price. However, this argument does not apply if the guarantee comes with a markup, since effective undercutting within the markup is possible. To the authors best knowledge, no previous theoretical or experimental paper studied the effect of a price guarantee with a maximal markup on competing prices, except for a recent empirical study by Dewenter and Schwalbe (2015), who find evidence for an anti-competitive effect of Shell's guarantee.

[1] For exact condition terms of the guarantee see Shell Deutschland Oil GmbH (2016).
[2] See Bundeskartellamt (2014, 2015) for details.
[3] See Bundeskartellamt (2011).

This paper intends to close this gap. First, it analyzes the effects of price-matching guarantees with non-negative markups on competition in a theoretical framework inspired by the motivating example. Second, the obtained theoretical predictions are tested in a laboratory experiment. Both, theoretical and experimental results show that the guarantee with a non-negative markup can indeed induce price coordination and leads to (on average) monopoly prices in these cases.

The remainder of the paper is structured as follows. The second section provides a brief overview of previous theoretical, experimental and empirical literature on low-price guarantees. The third section theoretically analyzes the price guarantee with a markup in a sequential Hotelling framework with two symmetric firms competing in prices and producing homogeneous goods. The fourth section presents an experimental design which is used to test the main theoretical predictions. Finally, the last section summarizes and discusses the results.

2.2 Previous literature

The effects of low-price guarantees have been discussed extensively in the economics and law literature since the early 1980s.[4]

Salop (1986) was the first to intuitively point out that perfect price-matching guarantees potentially lead to inefficient and anti-competitive market outcomes. The basic idea is that, when a firm faces a competitor with a perfect price-matching guarantee, its incentive to undercut the competitor's price is dampened since his *rebate mechanism effectively creates a penalty* (Salop, 1986, p.16), as individual price cuts become mutual. Accordingly, whenever all firms offer price-matching in markets with simultaneous price competition, new equilibria arise with prices above the competitive level. This was later formalized by Doyle (1988). A further study by Logan and Lutter (1989) shows that under certain conditions, it is sufficient for a collusive market outcome if at least one firm offers a perfect price-matching guarantee. The authors endogenize the adoption of perfect price-matching guarantees in a model with asymmetric costs, differentiated goods and simultaneous price competition. They find that only the high-cost firm offering a guarantee can induce an anti-competitive market outcome. In particular, if cost asymmetries are small, it adopts the guarantee and hereby creates incentives for supra-competitive pricing, whereas under large asymmetries it does not offer price-matching.

Additional literature focuses on further potentially negative effects of price matching guarantees. Edlin and Emch (1999) study the role of market entry and find

[4] Hviid (2010) provides a detailed survey.

that in markets with perfect price-matching, new entrants are attracted by collusive profits and also adopt the given pricing strategy. Hence, these entries only create inefficiencies, due to their entry and fixed costs, without making prices more competitive. Furthermore, Corts (1996) and Chen et al. (2001) suggest that low-price guarantees can be a tool to facilitate price discrimination between informed and uninformed customers, as only the former can invoke the guarantee. Consequently, in most cases uninformed customers loose whereas informed customers gain.[5]

In line with the previous argumentations Hay (1982), Sargent (1993) and Edlin (1997) advocate in favor of legislative prohibition of low-price guarantees and advise anti-trust authorities to at least carefully monitor markets in which they are used.

Further theoretical literature points out restrictions of the previous arguments against low-price guarantees. Hviid and Schaffer (1999) introduce the term *hassle costs*, which subsumes all non-pecuniary costs of invoking the guarantee. They show that whenever hassle costs exist, a perfect price-matching guarantee does not prevent a competitor from undercutting within the hassle costs, since customers would not enforce the guarantee in these cases. This reasoning implies that in the presence of hassle costs, price-matching guarantees do not give rise to collusive equilibria in symmetric markets, while in asymmetric markets the potential for collusive outcomes is limited.[6] Moorthy and Winter (2006) show that in highly asymmetric markets with costly information, low-costs firms adopt price guarantees not to foster collusion, but rather as a signaling device. In these cases, under certain conditions low-price guarantees can increase welfare.

A different strand of literature studies price-beating guarantees, i.e. promises to strictly underbid the lowest competing price to a certain percentage or amount. Hviid and Schaffer (1994) as well as Corts (1995) find that these guarantees do not lead to collusive market outcomes and in turn can be used to offset perfect price-matching guarantees. The reason is that price-beating guarantees reestablish the firms' ability to unilaterally undercut prices, even if the competitors offer price-matching or beating. Intuitively, by posting a higher price, a firm offering a price-beating guarantee forces itself to effectively undercut the competitors' prices, while at the same time the guarantees of the competitors are not activated. Kaplan (2000) criticizes these findings by pointing out that these results are restricted to price guarantees which pertain to posted prices, although admitting that these form of guarantees are empirically more relevant.

[5]Corts (1996) finds, for a special case where informed customers have the less elastic demand and firms can offer price-beating guarantees, that prices fall for both groups.

[6]Mao (2005) comes to a similar conclusion when focusing on the costs of returning of ex ante uninformed customers to stores that provide price-matching.

Empirical studies qualitatively confirm most of the theoretical results. For example, Hess and Gerstner (1991) study the price development of five supermarket chains in North Carolina in the mid 1980s. They find that after the first chain adopted a perfect price-matching guarantee for specific goods, the others followed suit by adopting similar guarantees. Consequently, prices of the goods included in the guarantees rose significantly in comparison to those excluded, while the differences in the former prices almost vanished completely. Arbatskaya et al. (2004) study over 500 price guarantees by using data from newspaper advertisements. They find that 56 percent of the perfect price-matching guarantees and only about 10 percent of the price-beating guarantees led to pricing above the competitive level. In addition, they find that most of the latter referred to posted instead of effective prices. A further study by Arbatskaya et al. (2006) comes to a similar conclusion when reviewing low-price guarantees in the retail tire market. Moorthy and Winter (2006) as well as Moorthy and Zhang (2006) find support for the usage of price-matching guarantees as signaling device by low-cost firms. A recent paper by Dewenter and Schwalbe (2015) studies the effect of low-price guarantees in the German gasoline market. With a difference-in-difference panel regression, controlling for exogenous effects and using data from the market transparency unit, they examine changes in pricing of two chains which recently started offering low-price guarantees. For the chain HEM, which are offering a non-automatic prefect price-matching guarantee, they do not find any significant price effect. The authors speculate, that this is a result of the relative high hassle costs customer faces for invoking the guarantee. For Shell's hassle cost free price-matching guarantee with a markup, the authors find a significant price increase by Shell of 2.4–2.8 Cent per liter standard gasoline after the introduction of the guarantee.

Furthermore, experimental literature also supports most of the theoretical implications. Dugar (2007) and Mago and Pate (2009) consider perfect price-matching guarantees and focus on the resulting equilibrium selection in symmetric and asymmetric markets with homogeneous goods and simultaneous pricing. They find evidence for the selection of the most collusive equilibrium, as long as the asymmetries in costs are sufficiently small. In addition, Fatas and Manez (2007) and Fatas et al. (2013) results support the prediction that perfect price-matching guarantees lead to a collusive outcome when symmetric firms compete simultaneously in a market with differentiated goods. Finally, Fatas et al. (2005) find no evidence that price-beating guarantees cause an anti-competitive market outcome.

2.3 Theory

2.3.1 Framework

The model is based on the Hotelling duopoly framework with linear transportation costs. There are two firms producing a homogeneous good, which are located at the opposite ends of a road and compete in prices (Hotelling, 1929).

Customers are uniformly distributed along the road, normalized to a mass of 1, and have a valuation of $v > 0$ for a unit of the good. They behave as price takers, since they are infinitely many. Customers have full transparency about prices and incur linear transportation costs of $t > 0$ times the distance to their dealer. The transportation costs are assumed to be moderate, i.e. $t < \frac{v}{3}$, which keeps the analysis simple and assures that the firms serve the entire road in equilibrium. All customers behave rationally and have a single unit demand. Thus, they buy at the best deal they can get whenever their net benefit is positive, otherwise they do not buy at all.

Firms do not face capacity constraints and incur neither fixed nor variable costs. They are allowed to set any non-negative price, i.e. dumping is prohibited. Firm A is located at the left end of the road, at position $x_A = 0$. The main new element of the model is that it provides a price-matching guarantee with an (exogenous) markup $m \geq 0$.[7] That is, it guarantees to customers that it never exceeds the competitor's price by more than m.[8] Firm B is located at the right end of the road, i.e. at $x_B = 1$, and offers no price guarantee. Restricting to only Firm A offering a price guarantee is sufficient to show the collusive effect of the price guarantee. In Appendix 2.B we prove that any version of the model where Firm B additionally has an arbitrary price guarantee with a non-negative markup leads to identical prices in equilibrium, compared to the game with only Firm A offering such a guarantee.

The timing of the game is as follows. In the first stage, Firm A chooses its posted price p_A^p (i.e. its initially announced price). After observing p_A^p, Firm B chooses its price p_B in the second stage. Based on these posted prices the effective price of Firm A, denoted as p_A, results by applying the guarantee, i.e.

$$p_A := \min\{p_A^p,\ p_B + m\} \quad \text{with} \quad m \in [0, t[. \tag{2.1}$$

[7] A markup smaller than zero would be an exotic form of a price-beating guarantee, which is activated if the competitors price is not sufficiently higher than the price of the guarantee issuing firm. For a discussion of price-beating guarantees see the previous literature section and the references therein.

[8] For simplification, the analysis is restricted to cases where $m < t$, since otherwise the market share would be zero for Firm A whenever the price guarantee is active.

The effective price of Firm B always equals its posted price. Once the effective prices are determined, customers make their purchasing decisions, and the game ends.

The game is solved by backward induction, i.e. the solution concept is a sub-game perfect Nash equilibrium.

2.3.2 Market demand in equilibrium

Now, we derive the market demand function of Firm i. The location of the customer who is indifferent between purchasing at Firm A or Firm B is denoted by $\tilde{x}^{AB}$ (i.e. $\tilde{x}^{AB} \in [0,1]$ is the share of customers located to the left of this customer on the road). If this customer has a non-negative net benefit from consumption, his position determines market shares, since all customers to the left of him will buy at Firm A whereas all customers to the right of him will find it more profitable to buy at Firm B.

In general, a customer located at position x gets a net benefit of u_x^A from buying at Firm A, which equals his valuation minus the price and the incurred transportation costs:

$$u_x^A = v - p_A - x \cdot t. \tag{2.2}$$

The same customer receives a net benefit of u_x^B if he instead buys at Firm B:

$$u_x^B = v - p_B - (1-x) \cdot t. \tag{2.3}$$

Consequently, the location of the customer who is indifferent between Firm A and Firm B is

$$\tilde{x}^{AB} = \frac{1}{2} + \frac{p_B - p_A}{2t}.$$

This position is interior (i.e., between 0 and 1) if and only if

$$p_A - t < p_B < p_A + t. \tag{2.4}$$

Naturally, being indifferent between buying at Firm A and Firm B does not necessarily assure that the customer is willing to buy at all. This is only the case if his net benefit of purchasing is non-negative, i.e. $u_{\tilde{x}^{AB}}^A = u_{\tilde{x}^{AB}}^B \geq 0$. This is equivalent to:

$$p_B \leq 2v - t - p_A. \tag{2.5}$$

Next, we consider four possible cases depending on the location and preferences of the indifferent customer.

Case 1: Condition (2.5) is not satisfied, while the indifferent customer does not exist along the road. The non-existence of the indifferent customer implies that condition (2.4) does not hold, i.e. the price difference between the firms exceeds the highest possible transportation cost. Then, all customers on the road prefer the firm with the lower price over the other firm (whose demand is then 0 anyway). The former firm hence faces a monopolistic demand function:

$$D_M(p_i) = \begin{cases} 1 & \text{if} \quad p_i \leq v - t, \\ \dfrac{v - p_i}{t} & \text{if} \quad v - t < p_i < v, \\ 0 & \text{else.} \end{cases} \tag{2.6}$$

Case 2: Condition (2.5) is not satisfied, while the indifferent customer exists along the road. In this case, there exists a range of customers along the road who do not buy from any of the firms. Then, firms do not effectively compete with each other, since the price of one firm does not affect the demand of the other, and hence again face a monopolistic demand function given by (2.6), except that the first segment with $D_M(p_i) = 1$ does not exist in this case.

Case 3: Condition (2.5) is satisfied, while the indifferent customer does not exist along the road. Then, as in Case 1, the firm with a higher price has a demand of zero, while the firm with a lower price faces monopolistic demand. However, one can show that under considered conditions it always holds for the latter firm that $p_i \leq v - t$, which by (2.6) implies that it demand is 1.

Case 4: Condition (2.5) is satisfied, while the indifferent customer exists along the road. In this case, the indifferent customer prefers to buy the good over not buying. Hence, Firm A (B) faces competitive demand given by the fraction of customers positioned to the left (right) from the indifferent customer. That is, the market demand for Firm $i \in \{A, B\}$, denoted as D_i, is a function of the effective prices p_i and p_{-i}:

$$D_i(p_i, p_{-i}) = \frac{1}{2} + \frac{p_{-i} - p_i}{2t}. \tag{2.7}$$

Finally, note that a firm gets a demand of 1 if and only if the following condition is satisfied:

Lemma 1. *Firm i receives the whole demand if and only if* $p_i \leq v - t$ *and* $p_i < p_{-i} - t$.

Proof. A given firm receives the whole demand if and only if the following two incentive constraints for the customers are satisfied: 1) all customers prefer buying from this firm over not buying; 2) all customers prefer buying from this firm over buying from the other firm. Given (2.2) and (2.3), these conditions are equivalent to the conditions stated in the lemma. ■

Thus, summing up all four cases and taking Lemma 1 into account, the market demand for Firm $i \in \{A, B\}$ is:

$$D_i(p_i, p_{-i}) = \begin{cases} 1 & \text{if } p_i \leq v - t \ \wedge \ p_i < p_{-i} - t \ , \\ \dfrac{1}{2} + \dfrac{p_{-i} - p_i}{2t} & \text{if } p_i \leq 2v - t - p_{-i} \ \wedge \ p_i \in [p_{-i} - t, p_{-i} + t] \, , \\ \dfrac{v - p_i}{t} & \text{if } p_i > 2v - t - p_{-i} \ \wedge \ p_i \in]v - t, v[\, , \\ 0 & \text{else.} \end{cases} \tag{2.8}$$

2.3.3 Equilibrium pricing without guarantees - The competitive benchmark case

To begin, we relax the assumption that Firm A offers a price guarantee and look what happens in the competitive benchmark case, i.e. $p_A^p = p_A$.[9] In the next section, we will then consider the model with Firm A having a price-matching guarantee with a non-negative markup, as described above.

In stage 2, Firm B knows p_A^p and maximizes π_B by choosing the optimal p_B. Since Firm A's posted price is also its effective price and given (2.8), we get the following piecewise defined profit function:

$$\pi_B^{No\,PG}(p_B, p_A^p) = \begin{cases} p_B & \text{if } p_B \leq v - t \ \wedge \ p_B < p_A^p - t \ , \\ p_B \cdot \left[\dfrac{1}{2} + \dfrac{p_A^p - p_B}{2t} \right] & \text{if } p_B < 2v - t - p_A^p \ \wedge \ p_B \in [p_A^p - t, p_A^p + t] \, , \\ p_B \cdot \left[\dfrac{v - p_B}{t} \right] & \text{if } p_B \geq 2v - t - p_A^p \ \wedge \ p_B \in]v - t, v[\, , \\ 0 & \text{else.} \end{cases} \tag{2.9}$$

[9]This is technically equivalent to offering a guarantee with an infinitely high markup on the competitor's price, which therefore cannot be activated.

This implies the following result:

Proposition 1. *Firm B's reaction function, when Firm A does not provide a price guarantee, is given by:*

$$R_B^{No\,PG}(p_A^p) = \begin{cases} v - t & \textit{if} \quad p_A^p > v, \\ p_A^p - t & \textit{if} \quad 3t \leq p_A^p \leq v, \\ \frac{p_A^p + t}{2} & \textit{if} \quad p_A^p < 3t. \end{cases}$$

Proof. See Appendix 2.B.

Thus, Firm B's best response depends on p_A^p being in one of three different cases. Now, we discuss the intuition for B's best response in each of these cases.

Case 1 – Firm A posts a prohibitively high price, i.e. $p_A^p > v$. In this case, Firm B is de facto a monopolist. Since the transportation costs are moderate, a monopolist wants to serve the entire road and sets a price of $v - t$.

Case 2 – Firm A posts a price between $3t$ *and* v. In this interval, p_A^p is not prohibitive, but high enough to make it profitable for Firm B to serve the full market on its own. Thus, Firm B undercuts Firm A's price just to the extent of the transportation costs.

Case 3 – Firm A posts a price between 0 *and* $3t$. For this interval of p_A^p, it is not optimal, even in some cases not possible, for Firm B to serve the entire road. Hence, Firm B shares the market with Firm A. The price $p_B = \frac{1}{2}(p_A^p + t)$ solves Firm B's trade-off between gaining a higher market share and charging a higher price.

In the first stage, Firm A anticipates Firm B's reaction function given by Proposition 1 and hence faces the following maximization problem:

$$\underset{p_A^p}{\operatorname{argmax}} \ \pi_A^{No\,PG}(p_A^p) | R_B^{No\,PG} = \begin{cases} 0 & \text{if} \quad p_A^p \geq 3t, \\ p_A^p \cdot \left[\frac{1}{2} + \frac{t - p_A^p}{4t} \right] & \text{if} \quad p_A^p < 3t \end{cases} \tag{2.10}$$

If p_A^p is at least $3t$, Firm B, according to Proposition 1, undercuts Firm A's price at least by t. In these cases, the demand of Firm A will be zero, as even the closest customer at $x = 0$ would prefer to buy from Firm B.

If p_A^p is smaller than $3t$, Firm B undercuts, if at all, to a lesser extent than t by setting $p_B = \frac{p_A^p+t}{2}$. In these cases, all conditions of the second case of the demand function in (2.8) are fulfilled: First,

$$\begin{aligned} p_A^p - p_B &= \frac{p_A^p - t}{2} < t, \\ p_B - p_A^p &= \frac{t - p_A^p}{2} > -t, \end{aligned}$$

where the inequalities follow from $p_A^p < 3t$. Second,

$$\begin{aligned} p_B = \frac{p_A^p + t}{2} &\leq 2v - t - p_A^p \\ \Leftrightarrow \qquad p_A^p &\leq \frac{4}{3}v - t, \end{aligned}$$

which holds for $p_A^p < 3t$ because $t \leq \frac{v}{3}$. Thus, by (2.8), whenever p_A^p is smaller than $3t$ the demand for Firm A is

$$\frac{1}{2} + \frac{p_B - p_A^p}{2t} = \frac{1}{2} + \frac{\frac{1}{2}p_A^p + \frac{1}{2}t - p_A^p}{2t} = \frac{1}{2} + \frac{t - p_A^p}{4t},$$

which implies the above profit maximization problem of Firm A. That is, if Firm A posts a price higher than $3t$, Firm B will serve the market on its own and consequently A's profits are zero, whereas for lower prices Firm A has to share the market with Firm B and the profits are equal to its market share multiplied by its charged price.

Solving the maximization problem of Firm A gives the optimal price of $p_A^p = \frac{3}{2}t$. Using Firm B's reaction function and the demand function in (2.8), we obtain the equilibrium characterization of the competitive benchmark case in which Firm A does not provide a price guarantee:

$$p_A^p = \frac{3}{2}t, \quad p_B = \frac{5}{4}t, \quad D_A = \frac{3}{8}, \quad D_B = \frac{5}{8}, \quad \pi_A = \frac{18}{32}t, \quad \pi_B = \frac{25}{32}t.$$

Note that Firm B is better off than Firm A in equilibrium, which results from the sequential structure of the game. Since prices are strategic complements, Firm B has a second mover advantage. It can profitably undercut Firm A's price and hereby gain a higher market share as well as higher profits in equilibrium.

2.3.4 Equilibrium pricing with guarantees

In this subsection we assume that Firm A provides a guarantee with a non-negative markup on the competitor's price.[10] This includes, if m is zero, also a perfect price-matching guarantee.

In the second stage Firm B maximizes its profit function

$$\pi_B^{PG}(p_B, p_A(p_A^p, p_B)) = \begin{cases} \pi_B^{No\ PG}(p_B, p_A^p) & \text{if} \quad p_B \geq p_A^p - m\ , \\ \pi_B^{PG-Active}(p_B, p_B + m) & \text{else.} \end{cases}$$

That is, only if it undercuts the price of Firm A by no more than m, Firm A's guarantee will not be activated and profits are defined by $\pi_B^{No\ PG}$. For any lower p_B, the guarantee will be activated and the profits of Firm B are defined by (given the demand function (2.8)):

$$\pi_B^{PG-Active}(p_B, p_B + m) = \begin{cases} p_B \cdot \left[\frac{1}{2} + \frac{m}{2t}\right] & \text{if} \quad p_B \leq v - \frac{t+m}{2}, \\ p_B \cdot \left[\frac{v - p_B}{t}\right] & \text{if} \quad v - \frac{t+m}{2} < p_B < v, \\ 0 & \text{else.} \end{cases} \tag{2.11}$$

Whenever Firm A's price guarantee is active, the effective price difference between p_A and p_B equals the markup, independently of p_B. Consequently, the position of the customer being indifferent between buying at Firm A or B exists along the road, as the price difference m is by assumption smaller than t (see condition 2.4). Hence, by the demand function in (2.8), whenever this customer finds it profitable to purchase a good, i.e. if condition (2.5) holds (which is then equivalent to $p_B \leq v - \frac{t+m}{2}$), the market demands are fixed to $D_A = \frac{1}{2} - \frac{m}{2t}$ and $D_B = \frac{1}{2} + \frac{m}{2t}$. This is plausible, as customers balance the trade-off between better (effective) prices and higher transportation costs. However, if p_B exceeds $v - \frac{t+m}{2}$ (i.e. the indifferent customer prefers not to buy), the demand is calculated with the demand function of a monopolist, stated in (2.6). Thus, for $p_B \leq v - \frac{t+m}{2}$ profits are linearly increasing in p_B, whereas for higher prices profits are decreasing, so that the profits are maximized at $p_B = v - \frac{t+m}{2}$.

[10] As proven in Appendix 2.B, prices in equilibrium are identical if additionally Firm B provides a price-matching guarantee with a non-negative markup.

The following proposition derives the reaction function of Firm B maximizing π_B^{PG}:

Proposition 2. *Firm B's reaction function, when Firm A provides a price guarantee with a markup m on the competitor's price, is given by:*

$$R_B^{PG}(p_A^p) = \begin{cases} v - \dfrac{t+m}{2} & \text{if} \quad p_A^p > v - \frac{t-m}{2}, \\ p_A^p - m & \text{if} \quad t + 2m < p_A^p \leq v - \frac{t-m}{2}, \\ \dfrac{p_A^p + t}{2} & \text{if} \quad p_A^p \leq t + 2m. \end{cases} \tag{2.12}$$

Proof. See Appendix 2.B.

Thus, Firm B's reaction is dependent on p_A^p being in a specific interval. In the following paragraphs the intuition for the optimal choice of p_B is briefly discussed with the help of a graphical illustration for each of the three intervals.

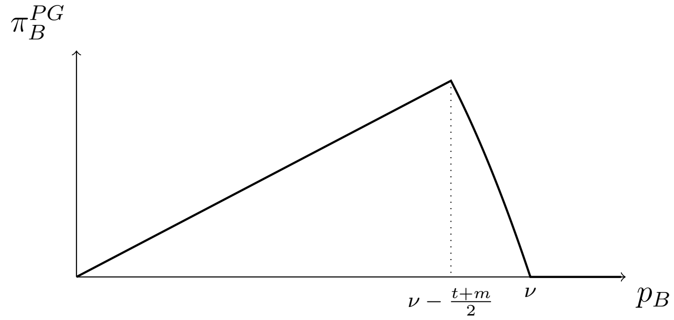

Figure 2.1: π_B^{PG} if $p_A^p > v - \frac{t-m}{2}$

Figure 2.1 depicts the profit function of Firm B for $p_A^p > v - \frac{t-m}{2}$. Whenever p_B is below $v - \frac{t+m}{2}$ Firm A's price guarantee is active while the market is fully covered. Hence, by (2.8), Firm B's market demand is $D_B = \frac{1}{2} + \frac{m}{2t}$, and thus constant. Therefore, profits are linearly increasing in this interval. For any higher p_B, condition (2.5) is violated, and thus, independently of whether p_B might activate Firm A's guarantee or not, Firm B faces monopolistic demand. Since the monopolist prefers to serve the entire road, Firm B's profits are monotonically decreasing in this segment. Consequently, it is optimal to set $p_B = v - \frac{t+m}{2}$ for any $p_A^p > v - \frac{t-m}{2}$, since any higher p_B would lead to an unprofitable loss in market share and any lower price would trigger a harmful automatic reduction of Firm A's price. The latter precludes Firm B from gaining any higher market demand.

Figure 2.2 illustrates Firm B's profits for posted prices in the interval $[t + 2m, v - \frac{t-m}{2}]$. Analogously to the reasoning above, due to the price guarantee, it can not

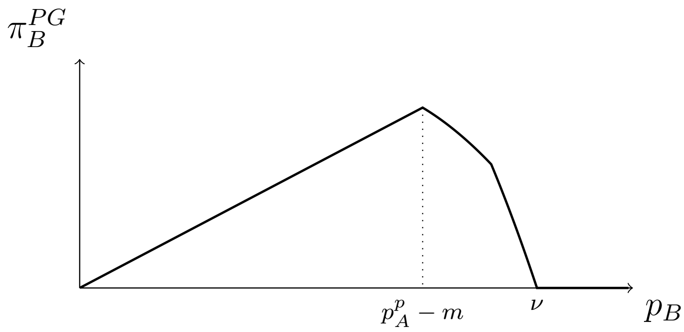

Figure 2.2: π_B^{PG} if $t + 2m < p_A^p \leq v - \frac{t-m}{2}$

be optimal to set $p_B < p_A^p - m$, since this would result in decreased profits for both firms while leaving market shares unaffected. For any higher p_B, Firm B's trade-off between charging at a higher price and gaining a higher demand is in favor of the demand, independently of whether p_B would violate condition (2.5) or not. As a result π_B^{PG} is decreasing in this segment. In summary, p_A^p is still sufficiently high so that Firm B has an incentive to undercut Firm A's price just to the extent of the markup.

Figure 2.3 finally refers to the states where Firm A posted a price lower or equal $2m + t$. Here, the posted price of Firm A is so low, that Firm B would not want to undercut it by more than m, even if it could effectively do so. Thus, the optimal reaction for these posted prices is, similar to the competitive benchmark case, to set $p_B = \frac{p_A^p + t}{2}$.

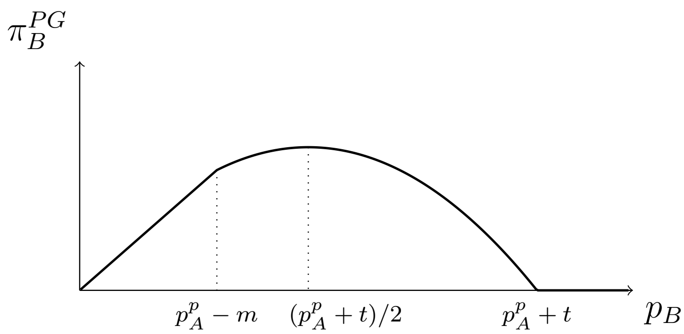

Figure 2.3: π_B^{PG} if $p_A^p \leq t + 2m$

In summary, Firm B ensures in all cases that the market is fully covered and shared with Firm A, with a maximal market share of Firm B of $\frac{1}{2} + \frac{m}{2t}$.

Given Firm B's reaction, given by Proposition 2, and the demand function in (2.8), Firm A faces the following maximization problem:

$$\underset{p_A^p}{\text{argmax}}\ \pi_A(p_A^p)|R_B^{PG} = \begin{cases} \left[v - \dfrac{t-m}{2}\right] \cdot \left[\dfrac{1}{2} - \dfrac{m}{2t}\right] & \text{if} \quad p_A^p > v - \frac{t-m}{2}, \\ p_A^p \cdot \left[\dfrac{1}{2} - \dfrac{m}{2t}\right] & \text{if} \quad t + 2m < p_A^p \leq v - \frac{t-m}{2}, \\ p_A^p \cdot \left[\dfrac{1}{2} + \dfrac{t - p_A^p}{4t}\right] & \text{if} \quad p_A^p \leq t + 2m. \end{cases} \tag{2.13}$$

That is, for any posted price higher than $t + 2m$, Firm A will serve a market demand of $\frac{1}{2} - \frac{m}{2t}$, since Firm B will either undercut just to the extent of the markup or activate Firm A's price guarantee (see Proposition 2). Moreover, its profits strictly increase in the interval $[t+2m, v-\frac{t-m}{2}]$ because its effective price will be the posted price as p_B will be set to just $p_A^p - m$. All posted prices higher than $v - \frac{t-m}{2}$ will result in an effective price of Firm A of $v - \frac{t-m}{2}$, due to the activation of the price guarantee. Only for $p_A^p \leq t + 2m$ the maximization problem is identical to the problem of the competitive benchmark case.

The following proposition shows the optimal price of Firm A:

Proposition 3. *In equilibrium, Firm A will set*

$$p_A^p = \begin{cases} p_A^p \geq v - \dfrac{t-m}{2} & \textit{if} \quad m < \phi, \\ \dfrac{3}{2}t & \textit{if} \quad m \geq \phi. \end{cases} \tag{2.14}$$

with $\phi = \frac{1}{2}\sqrt{4v^2 - 9t^2} - v + t$.

Proof. See Appendix 2.B.

According to Proposition 3 Firm A's optimal price depends on the markup being above or below the critical threshold value ϕ. Whenever $m < \phi$, Firm A can maximize its profits by setting any collusive arbitrary high price which is at least $v - \frac{t-m}{2}$, since Firm B will then take care, that the market is jointly covered with the highest possible prices. For $m \geq \phi$ Firm A's optimal price coincides with the equilibrium price in the competitive benchmark case.

Figure 2.4 shows an example of Firm A's profit function if m is below the critical threshold value. Here, the local profit maximum in the competitive section, reached with the competitive price $p_A^p = \frac{3}{2}t$ in the example, is clearly below the maximum which can be achieved by setting a collusive price. This argument also holds if the

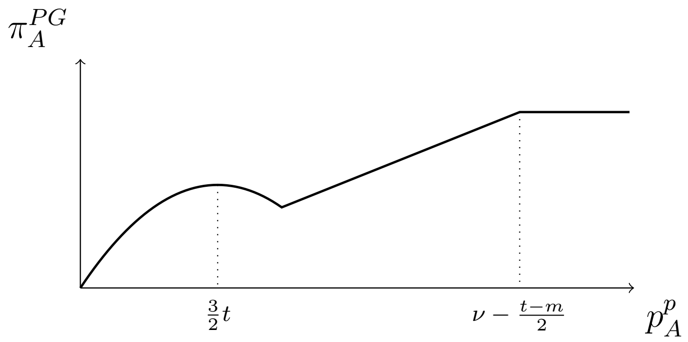

Figure 2.4: π_A^{PG} if $m < \phi$

local maximum of the parabola is to the right of the competitive section, i.e. if $\frac{3}{2}t < 2m + t$.

Figure 2.5 portrays Firm A's profit function when m exceeds the critical threshold. Here, the profits from collusion are lower than the profits which can be achieved in the competitive segment. This results from the fact that the market division with collusion is increasingly disadvantageous for Firm A when m gets larger.

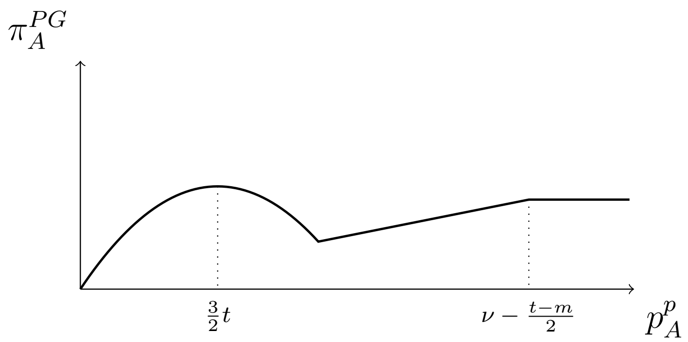

Figure 2.5: π_A^{PG} if $m \geq \phi$

Finally, Proposition 2 and Proposition 3 together imply the following result, fully characterizing the effective prices in equilibrium.

Proposition 4. *If Firm A offers a price guarantee with a non-negative markup of*

(a) $m < \phi$, the effective price of Firm A is $v - \frac{t-m}{2}$ and the effective price of Firm B is $v - \frac{t+m}{2}$, and hence prices equal on average the monopoly price of $v - \frac{t}{2}$.

(b) $m \geq \phi$, the effective price of Firm A is $\frac{3}{2}t$, and the effective price of Firm B is $\frac{5}{4}t$, and hence prices are the same as in the competitive benchmark case where no firm provides a guarantee.

Proof. See Appendix 2.B.

The intuition for Proposition 4 is simply that Firm A's market share is decreasing in the size of the markup. Hence, if m exceeds ϕ, Firm A's profit from setting a collusive price would be too small, so that it prefers to post the competitive price. In contrast, if m is below ϕ, the guarantee induces a collusive outcome.

2.3.5 Summary of results

Table 2.1 summarizes the results and compares equilibrium market outcomes across different kinds of competition.

It shows that whenever Firm A offers perfect price-matching, the market outcome is identical to a case where both firms are owned by a monopolist. This type of price guarantee is most attractive for Firm A, because it neutralizes the second mover advantage of Firm B, i.e. both firms share the monopoly profit of $v - \frac{t}{2}$ equally.

Table 2.1: Equilibrium Prices and Consumer Rent

	p_A	p_B	Consumer rent
Monopoly, *Perfect price-matching* $(m = 0)$	$v - \frac{t}{2}$	$v - \frac{t}{2}$	$\frac{1}{4}t$
Price-matching with $m \in (0, \phi]$	$v - \frac{t-m}{2}$	$v - \frac{t+m}{2}$	$\frac{1}{4}t + \frac{m^2}{4t}$
Price-matching with $m \geq \phi$, *No price-matching*	$\frac{3}{2}t$	$\frac{5}{4}t$	$v - \frac{81}{64}t$

According to Proposition 4, whenever Firm A is offering a price guarantee with a positive small markup, the average price level of both firms is still the monopoly price. However, due to the unequal market division, the profit of Firm A decreases when the markup gets bigger, whereas the profits of Firm B increase. The consumer rent in this case is slightly higher in comparison with perfect price-matching, as customers close to Firm B benefit from its lower prices and their gains overcompensate the losses of customers close to Firm A.

If Firm A offers a price guarantee with a high markup, the guarantee will be virtually ignored. Both firms set prices as in the competitive benchmark case, and accordingly rents and profits are unaffected by the guarantee.

2.4 Experiment

We conducted a laboratory experiment using the model-framework discussed in the previous section. We aim to investigate the collusive effects of guarantees with different maximum markups on the competitor's price.

Background information. All treatments were programmed with the software z-Tree (Fischbacher, 2007) and all sessions were conducted in the *Cologne Laboratory for Economic Research* at the University of Cologne in August 2016. Participants were randomly recruited from a sample of 1,500 students, enrolled in business administration or economics, via email with the *Online Recruitment System ORSEE* (Greiner, 2015). We conducted in total six sessions with 30 participants each. Each subject was only allowed to participate in one session. The share of males and females, 53.3% and 46.7% respectively, was almost equal. The average age was 24.7 years. Payments to subjects consisted of a 4 Euro lump-sum payment for showing up, another 4 Euro for completing a short questionnaire and additional money which could be earned in every period, based on achieved profits. The currency used was *Experimental Currency Units (ECU)*, which was converted to Euro at the end of the experiment at an exchange rate of 1 EUR per 14,000 ECU. Average individual payments including the lump-sum payments were 13.56 Euro. Each session took about one hour.

2.4.1 Design and hypotheses

The lab experiment was designed to test the extend of tacit collusion in the presence of guarantees. Three treatments were conducted: A baseline treatment without a price guarantee, a treatment with a markup below and a treatment with a markup above the threshold value ϕ, which determines whether a guarantee is expected to lead to collusive prices or not. In each treatment subjects were in role of either Firm A or Firm B and faced a computerized equilibrium demand function.

Besides the markup, all parameters were kept constant across treatments. The valuation of customers for a good was set to $v = 200$ and the transportation costs were set to $t = 35$. Given these parameters, the threshold value ϕ predicts that a price guarantee with a markup below 27.99 results in collusive prices, whereas guarantees with higher markups are expected to result in competitive prices. Additionally, potential customers along the road were set to a mass of 100 instead of 1 in the previous section. This does not qualitatively change theoretical predictions, but scales up demand and profits and thus makes the experiment less artificial and easier to explain in the instructions. In order to gain sufficient statistical power for the analysis, all treatments consisted of two sessions with 30 participants each. Since we used a matching group size of six, this resulted in 10 independent observations for each role in every treatment.

Table 2.2 summarizes the treatment design and states theoretical point predictions for posted as well as effective prices, and the corresponding equilibrium profits.

Table 2.2: Treatment Design and Point Predictions

	Treatment 1 *(No guarantee)*	Treatment 2 *(Small markup)*	Treatment 3 *(High markup)*
m	—	2	33
p_A^p	52.50	≥ 183.50	52.50
p_A	52.50	183.50	52.50
p_B	43.75	181.50	43.75
π_A	$1,968.75$	$8,650.71$	$1,968.75$
π_B	$2,734.38$	$9,593.57$	$2,734.38$

All values are stated in ECU.

In Treatment 1 (T1) Firm A has no price guarantee. This treatment serves as the competitive benchmark. In equilibrium Firm A sets a price of 52.50. Firm B, due to its second mover advantage undercuts this by setting a price of 43.75. Consequently, Firm A's price exceeds Firm B's price by 20%, leading to a market coverage of 37.5% for Firm A compared to 62.5% for Firm B. Due to the higher market share, Firm B gets a profit of 2,734.38, which exceeds Firm A's profit of 1,968.25 .

In Treatment 2 (T2) Firm A has a price guarantee with a markup of $m = 2$. Since this markup is below the threshold value ϕ, it induces a collusive market outcome in theory. In any equilibrium of T2, Firm A posts the collusive price of 183.50 or higher. Firm B undercuts the posted price but only to the extent of m plus the amount by which Firm A's price exceeds 183.50. Put differently, Firm B sets 181.50 in any equilibrium and thus assures that the effective price of Firm A is 183.50. Consequently, effective prices are close to another and equilibrium market shares and profits are only in slight favor of Firm B, which serves 52.86% of the market and earns 9,593.57 compared to 47.14% and 8,650.71 for Firm A.

In Treatment 3 (T3) Firm A has a price guarantee with a markup of $m = 33$. Since the markup is higher than ϕ, theory predicts that the guarantee does not affect effective prices, market shares and profit levels compared to a setting where no guarantee is in place. Thus, chosen price levels in this treatment are expected to coincide with the price levels of T1.

Hypotheses. In summary, we get two hypotheses from the treatment comparisons. First, we expect the price guarantee with the small markup in T2 to lead to a collusive market outcome. That is, we expect Firm A and Firm B to set higher prices in T2 compared to T1. Second, we do not expect the price guarantee with the high markup to have any effect on competition. Consequently, the prices of Firm A and Firm B in T3 are expected not to differ compared to T1 but to be lower than in T2.

Procedures within the experiment. All treatments consisted of an individual trial stage, followed by an interaction stage consisting of 15 periods of the sequential pricing game.

Prior to the start of the experiment, subjects were randomly allotted to computer terminals. Then they received identical written instructions, explaining general lab rules, all treatment specific information, including the equilibrium demand function as well as the matching procedure in the interaction stage.[11] Whenever subjects had questions, these were answered privately by referring to the relevant section in the instructions.

The trial stage, which lasted approximately five minutes, started roughly ten minutes after the instructions were distributed. This stage was not payoff relevant, did not involve any interaction between subjects and consisted of a simple scenario-calculator which used continuous posted prices as inputs and showed resulting effective prices, market shares and profit levels as outputs. This calculator was identical for all subjects within a treatment, independently of the role a subject was assigned to in the subsequent interaction stage, where it was also accessible. The purpose for providing the calculator was to allow subjects to deal with complex demand and profit calculations. By using a calculator with empty default values, it could be avoided to set anchoring points in contrast to providing payoff tables or examples, which inevitably put focus on certain price combinations. The scenario calculator could be used for any continuous price combination between 0 and 200.[12]

Finally, subjects proceeded to the interaction stage, consisting of 15 identical periods of the sequential pricing game. Each subject was assigned to a specific role, either Firm A or Firm B, and a matching group consisting of 6 subjects. These

[11]The instruction in English language can be found in Appendix 2.C. The original German instructions are available upon request.

[12]Imposing an upper bound for posted prices was necessary, due to a technical reason: Subjects entered prices via a slider bar, which requires a lower and an upper bound. Thus, we have chosen to set the upper bound to the prohibitive price level of 200, since all posted prices higher than 200 are at least weakly dominated. Thus, this restriction does not affect the equilibrium point predictions stated in Table 2.2.

assignments remained constant for the course of the experiment. In order to avoid reciprocal behavior, a stranger matching was used to determine pairs of Firm A and Firm B. That is, in every period each subject was randomly rematched within its matching group, while we ensured that the same pair was never matched in two consecutive periods. This matching procedure was clearly stated in the instructions. Only the size of the matching group was not mentioned. At the beginning of each period Firm A chooses its posted price. Thereafter Firm B, being aware of the posted price, chooses its effective price. Afterwards subjects received complete feedback on posted and effective prices, market shares and profit levels and proceeded to the next period.

Once the experiment was over, a short questionnaire appeared on the screen asking subjects for their age, field of study and gender. In addition to the collection of demographic data, the questionnaire justified the higher than usual total lump-sum payment of 8 Euro. The latter was needed for easing equilibrium payoff differences across treatments, as the exchange rate of ECU to EUR was identical across treatments.

2.4.2 Results

Table 2.3 summarizes the descriptive results of the experiment.

Table 2.3: Average Price and Profit Levels

	Treatment 1 (no guarantee)		Treatment 2 (small markup)		Treatment 3 (high markup)	
	Prediction	*Experiment*	*Prediction*	*Experiment*	*Prediction*	*Experiment*
p_A^p	52.50	79.82	$\geq$ 183.50	180.52	52.50	73.86
		(21.88)		(3.42)		(27.63)
p_A	52.50	79.82	183.50	178.96	52.50	73.81
		(21.88)		(3.93)		(27.59)
p_B	43.75	68.99	181.50	177.17	43.75	62.63
		(18.38)		(3.90)		(23.21)
π_A	1,968.75	1,875.39	8,650.71	8,540,33	1,968.75	1,597.21
		(506,87)		(172.19)		(340.23)
π_B	2,734.38	5,096.05	9,593.57	9,330.95	2,734.95	4,779.08
		(1,682.57)		(207.42)		(2,331.18)

All values are stated in ECU. Standard deviations are reported in parentheses and calculated at the matching group level.

In Treatment 1 the average price level for Firm A (Firm B) was 79.82 (68.99), which is higher than the predicted equilibrium price of 52.50 (43.75). In a sense, this could be interpreted as a form of collusion, although these price levels are far from perfect collusion.[13] A closer look at the data reveals that Firm A sometimes attempted to establish (almost) perfect collusion, by posting prices higher than 180, in 76 out of 450 observations, often in early periods. However, in 39 of these cases the posted price was undercut such that Firm A was not able to sell any good. Only in 24 cases the collusive attempt was profitable in the sense that the resulting profit exceeded the equilibrium profit. As a consequence, only Firm B benefited from the higher than predicted price levels and received on average higher profits than in equilibrium.

In Treatment 2 Firm A posted on average a price of 180.52, slightly below the equilibrium price of $p_A^p \geq 183.5$. More precisely, in 100 out of 450 observations an equilibrium strategy was played, either by posting a price of 183.5 (23 obs.) or higher (77 obs.), in 312 cases the posted prices were between 180 and 183.5 and in 38 cases a price lower than 180 was posted. Firm B set on average prices of 177.17. That is, in the 100 observations where an equilibrium price was posted, Firm B reacted on average by setting a price of 181.08 which is close to the predicted value of the reaction function of 181.5 for those cases. Firm B's average undercutting of 1.89 in the 371 observations where Firm A's posted price was between 70 and 183.5 is also close to the prediction of 2 for this interval of p_A^p. Hence, the descriptive data suggests that Firm A's price guarantee prevented Firm B from harsh undercutting. Consequently, the resulting effective prices of 178.96 (177.17) for Firm A (Firm B) and the hereby resulting profit levels were close to the point predictions of Table 2.2 .

In Treatment 3 the posted price of Firm A was on average 73.86, which is, similar like to T1, a bit higher than the predicted 52.50. An attempt for (almost) perfect collusion was observed in 61 of 450 cases, but only in 6 observations this attempt was profitable. The average undercutting of Firm B for posted prices in the interval [70,199] was 27.63 compared to the prediction of 33 for these cases (132 obs.). The average price of Firm B was 62.63 and, since the Firm A's price guarantee was almost never activated, the average effective price of Firm A rarely differed from the posted price.[14] In terms of profit Firm B was better off than in equilibrium because it could benefit from Firm A's attempts for collusion whereas Firm A was worse off.

[13]Perfect collusion is reached when both firms have an effective price of 182.50. This is the only price combination which extracts the full rent of the indifferent consumer and minimizes overall transportation costs at the same time.

[14]The price guarantee in T3 was activated in 17 observations. In none of these cases Firm B undercut by more than 36.

Test of hypotheses. In order to test the hypotheses, price levels across treatments are compared on the matching group level by using the non-parametric Mann-Whitney-Wilcoxon test (MWW test, all hereafter stated p-values refer to the two-sided version of the test).

The first hypothesis states that the price guarantee with the small markup of 2 has a collusive effect. This hypothesis can be confirmed, as we find that the posted price of Firm A as well as the price of Firm B are significantly higher in T2 compared to T1 ($p < 0.001$ in both comparisons).

In addition, the experiment data is also consistent with the second hypothesis, which states that the price guarantee with a high markup of 33 does not lead to collusion. The comparison of T3 with T1 cannot detect any significant differences neither for the price of Firm A ($p = 0.4057$) nor the price of Firm B ($p = 0.4983$), whereas both prices are lower compared to T2 ($p < 0.001$ for both comparisons).

Dynamic effects. For robustness, we control for dynamic effects. To this end, Table 2.4 provides the results of a random-effects GLS regression with the posted price of Firm A as the dependent variable and Treatment 2, where collusion is predicted, as baseline.

Table 2.4: Determinants of Firm A's posted price

	(1)	(2)
Constant	180.5***	174.2***
	(1.044)	(3.600)
Treatment 1	-100.7***	-82.68***
	(6.761)	(8.780)
Treatment 3	-106.7***	-86.42***
	(8.502)	(9.160)
Period		0.794*
		(0.358)
Treatment 1 $\times$ Period		-2.251**
		(0.855)
Treatment 3 $\times$ Period		-2.530*
		(0.995)
Observations	1,350	1,350

The table shows the results of Random-Effects GLS model. Robust standard errors clustered on the level of experimental cohorts are listed in parentheses. ***, ** and * indicate significance on the 1‰, 1% and 5%-level, respectively.

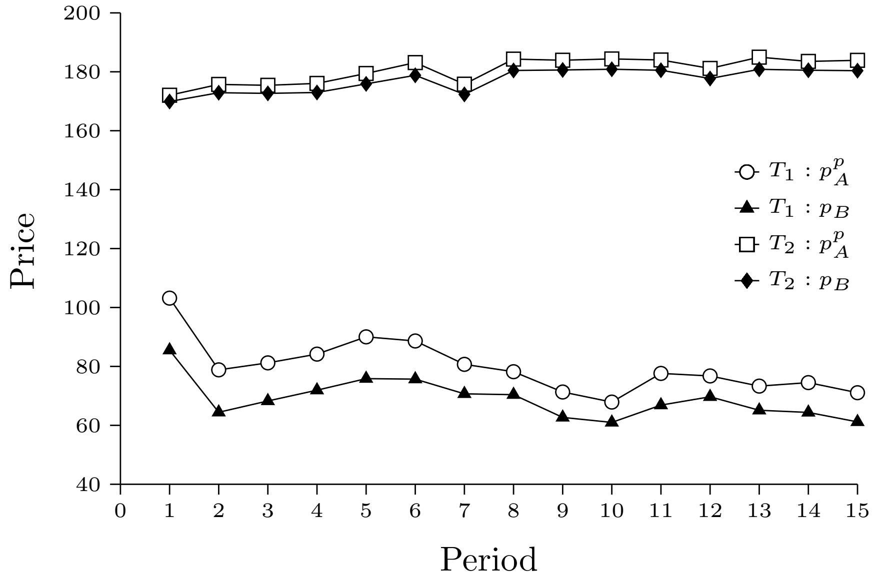

Figure 2.6: Price development across treatments

The regression results show that the coefficients for Treatment 1 and Treatment 3 are negative compared to Treatment 2, i.e. posted prices are lower in these treatments. The effects are highly statistically significant, independent of whether it is controlled for period effects or not, which reconfirms the results of the non-parametric analysis of a collusive price level in T2. Only the size of the (initial) treatment effect varies slightly, once period is taken into account. That is in T1 (T3) the size changes from -100.7 (-106.7) to -82.68 (-86.42). The coefficients on period and corresponding interaction terms show that subjects refrain over time from making collusive offers in T1 and T3 whereas the period effect in T2 goes in the opposite direction. More precisely posted prices decrease per period on average by 1.457 in T1 and 1.736 in T3 whereas posted prices increase slightly by 0.794 in T2.[15] This indicates that subjects behave in line with the theoretical predictions more frequently over time. Finally, Figure 2.6 illustrates the development for posted prices of Firm A and Firm B for T1 and T2.

[15]The numbers stated refer to the overall treatment specific period effect. For T1 and T3 the effect is the sum of the treatment unspecific period effect and the interaction effect.

2.5 Conclusion

This paper studies whether a price-matching guarantee with a markup on the lowest competing price has the potential to induce tacit collusion. It shows both theoretically and experimentally that in a Hotelling duopoly framework with fixed locations and sequential pricing this can be indeed the case. Thus, these kind of price guarantees should be reviewed by antitrust authorities with the same skepticism as perfect price-matching guarantees.

In particular, whenever the guaranteed maximum markup on the lowest competing price does not exceed a threshold value, the guarantee leads to on average monopoly pricing. If instead the markup exceeds this threshold, the market outcome is unaffected. For the former results it suffices that the price leader, i.e. the first moving firm, offers a guarantee. However, if the level of the markup would be endogenously chosen by the first moving firm, it would offer the smallest possible markup, in other words, a perfect price-matching guarantee. The reason is that the latter neutralizes the second mover advantage of its competitor completely.

Apart from studying the role of the markup, the paper connects to the existing literature on perfect price-matching guarantees. It shows that even in a setting where competitors are symmetric with regard to their cost structure, a collusive market outcome can result. The reason is, that with sequential price competition the first mover has a disadvantageous position, similar to a firm which is disadvantaged by its cost structure in a simultaneous move game. Thus, it extends the findings of Logan and Lutter (1989).

With regard to the motivating example of Shell, which, to the best of the author's knowledge, is the first to use the considered type of guarantee, the paper does not claim to provide a final answer on whether their conduct intends to establish tacit collusion. One reason is that the model setup used does not cover all characteristics of the German gasoline retail market, e.g. it does not take repeated interaction or the heterogeneity of customers into account. Yet, it is an open question why Shell, which possesses price leadership according to Bundeskartellamt (2011, 2014), adopted a guarantee with a theoretically suboptimal markup of 2 Cents. A rationale for this could be to avoid suspicion about anti-competitive conduct, as perfect price-matching guarantees have been criticized extensively in the economics and law literature. At the same time, a recent empirical paper of Dewenter and Schwalbe (2015) found that Shell's prices increased after the introduction of its guarantee. This finding, in combination with the paper's result that such a guarantee in general has the potential to induce tacit collusion, suggest that Shell's conduct should be carefully monitored.

2.A References

Arbatskaya, M., Hviid, M., and Shaffer, G. (2004). On the Incidence and Variety of Low-Price Guarantees. *Journal of Law and Economics*, 47:307–332.

Arbatskaya, M., Hviid, M., and Shaffler, G. (2006). On the Use of Low-Price Guarantees to Discourage Price Cutting. *International Journal of Industrial Organization*, 24:1139–1156.

Bundeskartellamt (2011). Sektoruntersuchung Kraftstoffe - Abschlussbericht gemäß § 32e GWB. Bonn.

Bundeskartellamt (2014). Ein Jahr Markttransparenzstelle für Kraftstoffe (MTS-K): Eine erste Zwischenbilanz. Bonn.

Bundeskartellamt (2015). Das 2. Jahr Markttransparenzstelle für Kraftstoffe (MTS-K). Bonn.

Chen, Y., Narasimhan, C., and Zhang, Z. J. (2001). Consumer Heterogeneity and Competitive Price-Matching Guarantees. *Marketing Science*, 20(3):300–314.

Corts, K. S. (1995). On the Robustness of the Argument that Price-Matching is Anti-Competitive. *Economic Letters*, 47:417–421.

Corts, K. S. (1996). On the Competitive Effects of Price-Matching Policies. *International Journal of Industrial Organization*, 15:283–299.

Dewenter, R. and Schwalbe, U. (2015). Preisgarantien im Kraftstoffmarkt. Helmut Schmidt University - Economics Working Paper No. 161.

Doyle, C. (1988). Different Selling Strategies in Bertrand Oligopoly. *Economics Letters*, 28:387–390.

Dugar, S. (2007). Price-Matching Guarantees and Equilibrium Selection in a Homogenous Product Market: An Experimental Study. *Review of Industrial Organization*, 30(2):107–119.

Edlin, A. (1997). Do Guaranteed-Low-Price Policies Guarantee High Prices, and Can Antitrust Rise to the Challenge? *Harvard Law Review*, 111:528–575.

Edlin, A. and Emch, E. (1999). The Welfare Losses from Price-Matching Policies. *The Journal of Industrial Economics*, 47(2):145–167.

Fatas, E., Georgantzis, N., Manez, J., and Sabater-Grande, G. (2005). Pro-Competitive Price Beating Guarantees: Experimental Evidence. *Review of Industrial Organization*, 26:115–136.

Fatas, E., Georgantzis, N., Manez, J. A., and Sabater, G. (2013). Experimental Duopolies under Price Guarantees. *Applied Economics*, 45(1):15–35.

Fatas, E. and Manez, J. A. (2007). Are Low-Price Promises Collusion Guarantees? An Experimental Test of Price Matching Policies. *Spanish Economic Review*, 9(1):59–77.

Fischbacher, U. (2007). z-Tree: Zurich Toolbox for Ready-Made Economic Experiments. *Experimental Economics*, 10(2):171–178.

Greiner, B. (2015). Subject Pool Recruitment Procedures: Organizing Experiments with ORSEE. *Journal of the Economic Science Association*, 1(1):114–125.

Hay, G. A. (1982). Oligopoly, Shared Monopoly and Antitrust Law. *Cornell Law Review*, 67(3):439–481.

Hess, J. D. and Gerstner, E. (1991). Price-Matching Policies: An Empirical Case. *Managerial and Decision Economics*, 12(4):305–315.

Hotelling, H. (1929). Stability in Competition. *The Economic Journal*, 39:41–57.

Hviid, M. (2010). Summary of the Literature on Price Guarantees. Working Paper, ESRC Center for Competition Policy and UEA Law School.

Hviid, M. and Schaffer, G. (1994). Do-Low-Price Guarantees Facilitate Tacit Collusion. Working Paper 94-02, University of Michigan.

Hviid, M. and Schaffer, G. (1999). Hassle Costs: The Achilles' Heel of Price-Matching Guarantees. *Journal of Economics and Management Strategy*, 8(4):489–521.

Kaplan, T. R. (2000). Effective Price-Matching: A Comment. *International Journal of Industrial Organization*, 18:1291–1294.

Logan, J. W. and Lutter, R. W. (1989). Guaranteed Lowest Prices: Do They Facilitate Collusion? *Economics Letters*, 31:189– 192.

Mago, S. D. and Pate, J. G. (2009). An Experimental Examination of Competitor-Based Price Matching Guarantees. *Journal of Economic Behavior & Organization*, 70:342–360.

Mao, W. (2005). Price-Matching Policy with Imperfect Information. *Managerial and Decsion Economics*, 26:367–372.

Moorthy, S. and Winter, R. A. (2006). Price-Matching Guarantees. *The RAND Journal of Economics*, 37(2):449–465.

Moorthy, S. and Zhang, X. (2006). Price Matching by Vertically Differentiated Retailers: Theory and Evidence. *Journal of Marketing Research*, 43(2):156–167.

Salop, S. C. (1986). Practices that (Credibly) Facilitate Oligopoly Co-ordination. In Stiglitz, J. E. and Mathewson, G. F., editors, *New Developments in the Analysis of Market Structure: Proceedings of a conference held by the International Economic Association in Ottawa, Canada*, pages 265–294. Palgrave Macmillan UK, London.

Sargent, M. (1993). Economics Upside-Down: Low-Price Guarantees as Mechanisms for Facilitating Tacit Collusion. *University of Pennsylvania Law Review*, 141:2055–2118.

Shell Deutschland Oil GmbH (2016). Shell ClubSmart Promotion Website. https://www.shellsmart.com/smart/index.html (retrieved 10/12/2016).

2.B Proofs

Proof of Proposition 1

Let us consider all possible cases of p_A, and derive separately the best responses of Firm B. Since Firm B's profit function is piecewise defined, it is important to check which interval of p_B, for a given p_A^p, refers to which segment of the profit function $\pi_B^{No\,PG}$. The four segments are therefore labeled with capital roman numbers, i.e.

$$\pi_B^{No\,PG} = \begin{cases} I \quad : p_B & \text{if}\, p_B \leq v - t \,\wedge\, p_B < p_A^p - t\,, \\ II \quad : p_B \cdot \left[\dfrac{1}{2} + \dfrac{p_A^p - p_B}{2t}\right] & \text{if}\, p_B < 2v - t - p_A^p \,\wedge\, p_B \in [p_A^p - t, p_A^p + t]\,, \\ III : p_B \cdot \left[\dfrac{v - p_B}{t}\right] & \text{if}\, p_B \geq 2v - t - p_A^p \,\wedge\, p_B \in \,]v - t, v[\,, \\ IV \quad : 0 & \text{else.} \end{cases}$$

In the following cases we never check for IV, since the zero profit is always strictly dominated by other segments (with at least one of these segments being nonempty for any p_A^p, as shown below).

Case 1 – Firm A sets $p_A^p > v$.

Segment I is equivalent to $p_B \in [0, v - t]$. This follows from $p_A^p - t > v - t > 0$, where the first inequality is by assumption on p_A^p, and the second follows from our parametric assumption $t < \frac{v}{3}$. Consequently, the highest reachable profit level in segment I is $v - t$, independently of p_A^p, which is reached by setting $p_B = v - t$.

Segment II is empty in the considered case. Assume by contradiction that it is non empty. Then there exists a p_B such that

$$p_B < 2v - t - p_A^p \;\wedge\; p_B \geq p_A^p - t$$

$$\Rightarrow p_A^p - t < 2v - t - p_A^p$$

$$\Leftrightarrow p_A^p < v,$$

which is a contradiction to the considered interval of p_A^p.

Segment III is equivalent to $p_B \in]v - t, v[$. This follows from

$$p_B \geq 2v - t - p_A^p \;\wedge\; p_B \in]v - t, v[$$

$$\Leftrightarrow p_B \in]v-t, v[,$$

since $v - t > 2v - t - p_A^p$ by $p_A^p > v$. The highest reachable profit in this segment is in the limit $v - t$, because

$$\frac{\partial (p_B \cdot \frac{v-p_B}{t})}{\partial p_B} = \frac{v - 2p_B}{t} < 0 \text{ since } p_B \geq v - t \wedge t < \frac{v}{3}.$$

Best response – Case 1: Thus, the best response to $p_A^p > v$ is to set $p_B = v - t$.

Case 2 – Firm A sets p_A^p in the interval $]v - t, v]$.

Segment I is, given that $p_A^p < v - t$, defined in the interval equivalent to $p_B < p_A^p - t$. Since $t < \frac{v}{3}$, the interval $[0, p_A^p - t[$ is non-empty for the given interval of p_A^p. Then, the highest reachable profit level in I is in the limit $p_A^p - t$.

Segment II is defined for

$$p_B < 2v - t - p_A^p \ \wedge \ p_B \in [p_A^p - t, p_A^p + t]$$

$$\Leftrightarrow p_B \in [p_A^p - t, 2v - t - p_A^p[,$$

because $2v - t - p_A^p < p_A^p + t$ due to assumed $p_A^p > v - t$. This interval of p_B is non-empty, since $p_A^p - t < 2v - t - p_A^p$ is equivalent to $p_A^p < v$ which is satisfied in the considered interval of p_A^p.

The highest reachable profit level in II is dependent on p_A^p. For $p_A^p > 3t$ it is $p_A^p - t$, and is reached with $p_B = p_A^p - t$. For $p_A^p \leq 3t$ it is $\frac{(p_A^p+t)^2}{8t}$, and is reached with $p_B = \frac{p_A^p+t}{2}$. The reason is, that the profit function in segment II has a parabolic shape, but the maximum at $p_B = \frac{1}{2}(p_A^p + t)$ can be to the left of the interval of p_B allowed by II, which is the case if:

$$\frac{1}{2}(p_A^p + t) < p_A^p - t$$

$$\Leftrightarrow p_A^p > 3t.$$

At the same time, the right boundary of the interval of p_B equal to $2v - t - p_A^p$ is always above $\frac{p_A^p+t}{2}$ within the considered interval of p_A^p. Thus, when $p_A^p > 3t$, the lower bound of the interval of p_B, i.e. $p_A^p - t$, is the best response, whereas if $p_A^p \leq 3t$ the best response is $\frac{p_A^p+t}{2}$.

Segment III is defined if the following conditions are met

$$p_B \geq 2v - t - p_A^p \ \wedge \ p_B \in]v - t, v[$$

$$\Leftrightarrow v > p_B \geq 2v - t - p_A^p$$

because $2v - t - p_A^p \geq v - t$ due to $p_A^p \leq v$. This interval of p_B is non-empty, because $v > 2v - t - p_A^p$ is equivalent to $p_A^p > v - t$ which is satisfied in the considered interval of p_A^p.

The highest reachable profit level in III is $\frac{(p_A^p + t - v)(2v - t - p_A^p)}{t}$ reached with the lowest p_B within the interval, i.e. $2v - t - p_A^p$. The reason is, that the profit function in III has a parabolic shape, but the price maximizing the parabola $p_B = \frac{v}{2}$ is always to the left of the interval $[2v - t - p_A^p, v[$:

$$\frac{v}{2} < 2v - t - p_A^p$$

$$\Leftrightarrow p_A^p < \frac{3}{2}v - t$$

which holds for the considered interval of p_A^p since $t \leq \frac{v}{3}$.

Best response – Case 2: In summary, the best response to $p_A^p \in \,]v - t, v]$ is to set $p_B = p_A^p - t$ if $p_A^p > 3t$ and $p_B = \frac{p_A^p + t}{2}$ if $p_A^p \leq 3t$.
The reason is, that the highest profit in II is always at least as high as the highest profit in I and III. The former comparison directly follows from the analysis of segments I and II above, given that the profit level $p_A^p - t$ is always achievable in II. The latter comparison results from the following:
(a) $p_A^p > 3t$*:*

$$\frac{(p_A^p + t - v)(2v - t - p_A^p)}{t} \leq p_A^p - t$$
$$\Leftrightarrow (p_A^p + t - v)(2v - t - p_A^p) - t^2 - p_A^p \cdot t \leq 0.$$

The left hand side is a parabola in t, with a global maximum. Thus, for the claim to be true the inequality needs to hold for the maximum at $t^* = \frac{3}{4}(p_A^p - v)$. Plugging t^* into the inequality gives:

$$\frac{1}{8}((p_A^p)^2 + 6p_A^p \cdot v - 7v^2) \leq 0$$

which is fulfilled as long as $p_A^p \leq v$, which holds in the considered case.
(b) $p_A^p \leq 3t$*:*

$$\frac{(p_A^p + t - v)(2v - t - p_A^p)}{t} \leq \frac{(p_A^p + t)^2}{8t}$$
$$\Leftrightarrow \frac{(3p_A^p + 3t - 4v)^2}{t} \geq 0$$

which is fulfilled since $t > 0$.

Case 3 – Firm A sets p_A^p in the interval $]t, v - t]$.

Segment I is defined when the following conditions are met

$$p_B \leq v - t \ \wedge p_B < p_A^p - t$$

$$\Leftrightarrow p_B < p_A^p - t$$

because p_A^p is smaller than v in the considered interval of p_A^p. This interval of p_B is non-empty since $p_A^p > t$. The highest reachable profit level in I is in the limit $p_A^p - t$.

Segment II is defined under the conditions

$$p_B < 2v - t - p_A^p \ \wedge \ p_B \in [p_A^p - t, p_A^p + t]$$

$$\Leftrightarrow p_B \in [p_A^p - t, p_A^p + t]$$

because $p_A^p + t \leq 2v - t - p_A^p$, which equals $\Leftrightarrow p_A^p \leq v - t$ and is fulfilled for the given interval of p_A^p. The interval of p_B stated above is non-empty because $p_A^p > t$ and $t \geq 0$. The highest reachable profit level in II is dependent on p_A^p. For $p_A^p > 3t$ it is $p_A^p - t$, and is reached with $p_B = p_A^p - t$. For $p_A^p \leq 3t$ it is $\frac{(p_A^p+t)^2}{8t}$, and is reached with $p_B = \frac{p_A^p+t}{2}$. The reasoning is identical to Case 2.

Segment III is not defined for the given interval of p_A^p. This is shown by contradiction. For III to be defined the following conditions have to be satisfied:

$$p_B > 2v - t - p_A^p \ \wedge \ p_B \in]v - t, v[$$

$$\Rightarrow v > 2v - t - p_A^p$$

$$\Leftrightarrow p_A^p > v - t,$$

which is a contradiction.

Best response – Case 3: In summary, the best response to $p_A^p \in]t, v - t]$ is $p_B = p_A^p - t$ if $p_A^p \geq 3t$ and $p_B = \frac{p_A^p+t}{2}$ if $p_A^p < 3t$. This is true because in the considered case the highest profit of II always exceeds the highest profit in I. Indeed, for $p_A^p > 3t$ the profit maximum of I is only in the limit as high as the profit maximum of II. For $p_A^p \leq 3t$ the profit of II is at least as high as in I, because:

$$\frac{(p_A^p + t)^2}{8t} \geq p_A^p - t$$

$$\Leftrightarrow (p_A^p)^2 - 6p_A^p \cdot t + 9t^2 \geq 0.$$

The left hand side is a parabola with a global minimum of 0 at $p_A^p = 3t$. Thus the condition is always met.

Case 4 – Firm A sets p_A^p in the interval $[0, t]$.

Segment I does not exist. Assume by contradiction there exists $p_B < p_A^p - t$. This however cannot be true since $p_A^p \leq t$ is assumed in the considered case.

Segment II has the following conditions

$$p_B < 2v - t - p_A^p \ \wedge \ p_B \in [p_A^p - t, p_A^p + t]$$

$$\Leftrightarrow p_B \in [p_A^p - t, p_A^p + t],$$

since $2v - t - p_A^p > p_A^p + t$, which is in turn equivalent to $p_A^p < v - t$ and hence fulfilled in the given interval of p_A^p due to the parametric assumption $t < \frac{v}{3}$. But since p_B has to be non-negative by assumption, II is eventually equivalent to

$$0 \leq p_B \leq p_A^p + t,$$

which is clearly a non-empty interval, because $p_A^p \geq 0$ and $t > 0$.
The highest reachable profit level in II is $\frac{(p_A^p+t)^2}{8t}$, which is achieved by setting $p_B = \frac{p_A^p+t}{2}$, which in turn is always within the allowed boundaries of p_B, i.e. in $[0, p_A^p + t]$.

Segment III is not defined for the given interval of p_A^p. The argumentation is analogous to Case 3.

Best response – Case 4: In summary, the best response to $p_A^p \in [0, t]$ is $\frac{p_A^p+t}{2}$.

Best response function – Summary of the four cases:

Let us now sum up the best responses for the considered intervals of p_A^p together. This yields

$$R_B^{No\,PG}(p_A^p) = \begin{cases} v - t & \text{if} \quad p_A^p > v, \\ p_A^p - t & \text{if} \quad 3t \leq p_A^p \leq v, \\ \frac{p_A^p+t}{2} & \text{if} \quad p_A^p < 3t. \end{cases}$$

■

Proof of Continuity of π_B^{PG}

Lemma 2. *π_B^{PG} is continuous in p_B.*

Proof. The proof consists of three parts: First we prove that $\pi_B^{No\ PG}$ is continuous, second we show that $\pi_B^{PG-Active}$ is continuous and finally the continuity of π_B^{PG}, which is a combination of $\pi_B^{No\ PG}$ and $\pi_B^{PG-Active}$, is proven.

1.) Continuity of $\pi_B^{No\ PG}$.

Here it is sufficient to show, that D_B is continuous with respect to p_B for any given $p_A = p_A^p$. The reason is that $\pi_B^{No\ PG} = p_B \cdot D_B(p_A = p_A^p, p_B)$ and p_A is not a function of p_B since the price guarantee is inactive.
We first reformulate the demand function in the following way. From the argumentation of Cases 1 and 2 on page 12 it follows that whenever condition (2.5) is not satisfied, the firm with a lower price faces a monopolistic demand function given by (2.6). At the same time, since for the firm with the higher price it should hold that $p_i \geq v$ (which follows from $p_B \geq 2v - t - p_A$ and $p_i > p_-i + t$), the monopolistic demand function is formally applicable to this firm as well in the considered case. Hence,

$$D_B(p_A, p_B) = \min\left\{\max\left\{\frac{v - p_B}{t}, 0\right\}, 1\right\} \quad \text{if} \quad p_B > 2v - t - p_A \, . \tag{2.15}$$

Next, note that $\frac{1}{2} + \frac{p_A - p_B}{2t} > 1$ iff $p_A > p_B + t$, and that $\frac{1}{2} + \frac{p_A - p_B}{2t} < 0$ iff $p_A < p_B - t$. This implies that whenever condition (2.5) is satisfied (given the argumentation in Case 3 and Case 4 on page 12), the demand function can be represented as

$$D_B(p_A, p_B) = \min\left\{\max\left\{\frac{1}{2} + \frac{p_A - p_B}{2t}, 0\right\}, 1\right\} \quad \text{if} \quad p_B \leq 2v - t - p_A \, . \tag{2.16}$$

Summing up (2.15) and (2.16) together, we obtain

$$D_B(p_A, p_B) = \begin{cases} \min\left\{\max\left\{\frac{1}{2} + \frac{p_A - p_B}{2t}, 0\right\}, 1\right\} & \text{if} \quad p_B \leq 2v - t - p_A \, , \\ \\ \min\left\{\max\left\{\frac{v - p_B}{t}, 0\right\}, 1\right\} & \text{else.} \end{cases} \tag{2.17}$$

Because both sections of the demand function are continuous in p_B for any $p_B > 0$, it remains to show that at $p_B = 2v - t - p_A$ both sections of the demand function yield the same level of demand. Indeed, at this value of p_B:

$$\frac{1}{2} + \frac{p_A - p_B}{2t} = \frac{t + 2v - t - p_B - p_B}{2t} = \frac{v - p_B}{t}.$$

2.) Continuity of $\pi_B^{PG-Active}$.

Since under an active price guarantee $p_A = p_B + m$, we have

$$\pi_B^{PG-Active} = p_B \cdot D_B(p_B + m, p_B).$$

Given (2.17), the former demand function can be rewritten as

$$D_B(p_B + m, p_B) = \begin{cases} \min\left\{\max\left\{\frac{1}{2} + \frac{m}{2t}, 0\right\}, 1\right\} & \text{if} \quad p_B \leq v - \frac{t+m}{2}\ , \\ \\ \min\left\{\max\left\{\frac{v - p_B}{t}, 0\right\}, 1\right\} & \text{else.} \end{cases} \tag{2.18}$$

Because both sections of the demand function are continuous in p_B for any $p_B > 0$, it remains to show that at $p_B = v - \frac{t+m}{2}$ both sections yield the same demand. Indeed at this value of p_B

$$\frac{v - p_B}{t} = \frac{v - v + \frac{t+m}{2}}{t} = \frac{1}{2} + \frac{m}{2t}.$$

3.) Continuity of π_B^{PG}.

The combined profit function π_B^{PG} is defined as

$$\pi_B^{PG}(p_A^p, p_B) = \begin{cases} \pi_B^{No\ PG}(p_A^p, p_B) & \text{if} \quad p_B \geq p_A^p - m\ , \\ \\ \pi_B^{PG-Active}(p_B) & \text{else.} \end{cases}$$

Since $\pi_B^{PG-Active}$ and $\pi_B^{No\ PG}$ are both continuous in p_B for any $p_B > 0$, as proven above, it only needs to be shown that at $p_B = p_A^p - m$ both functions give the same profit. Indeed, for this posted price

$$\pi_B^{No\ PG} = p_B \cdot D_B(p_A = p_B + m, p_B)$$

and hence coincides with $\pi_B^{PG-Active}$. Consequently, π_B^{PG} is continuous in p_B. ∎

Proof that π_B^{PG} is hump-shaped

Lemma 3. *There exists a p_B^* such that $\pi_B^{PG}(p_B)$ is increasing for $p_B < p_B^*$ and decreasing for $p_B \geq p_B^*$.*

Proof. The proof has three parts. First, we prove that $\pi_B^{PG-Active}$ is hump-shaped. Second, we show that $\pi_B^{No\,PG}$ is hump-shaped. Finally, it is proven that the combined profit function $\pi_B^{PG}$is hump-shaped.

1.) $\pi_B^{PG-Active}(p_B)$ is hump-shaped.

It is easy to see, that $\pi_B^{PG-Active}$ is linearly increasing in p_B for values of p_B smaller than $v - \frac{t+m}{2}$ (see (2.11)). For higher values, it has a parabolic shape up to $p_B = v$ and then stays flat at 0. However, the maximum of the parabola is located at $p_B = \frac{1}{2}v$ which is lower than the left border of the parabolic interval $v - \frac{t+m}{2}$ since $t + m < v$, because $m < t \leq \frac{v}{3}$. Hence, $\pi_B^{PG-Active}(p_B)$ is decreasing in p_B for $p_B > v - \frac{t+m}{2}$. Consequently, given that $\pi_B^{PG-Active}(p_B)$ is continuous (see proof of Lemma 2), it is hump-shaped with respect to p_B with a global maximum at $p_B = v - \frac{t+m}{2}$.

2.) $\pi_B^{No\,PG}(p_B)$ is hump-shaped.

Since the composition of $\pi_B^{No\,PG}(p_B)$ is dependent on p_A^p, the proof is given separately for each of the four cases of intervals of p_A^p described in the proof of Proposition 1. In what follows, we refer to the results of the analysis in the proof of Proposition 1 in each of these four cases. We also rely on the fact that $\pi_B^{No\,PG}(p_B)$ is continuous (see proof of Lemma 2).

Case 1 – Firm A sets $p_A^p > v$.

For $p_B \leq v - t$ the profit function is defined by Segment I of $\pi_B^{No\,PG}$, and thus linearly increasing in p_B.

For $v - t < p_B < v$, the profit function is defined by Segment III of $\pi_B^{No\,PG}$, which is a parabola with the maximum at $\frac{v}{2}$. Since this maximum is reached with a lower price than $v - t$, because $t < \frac{v}{3}$, the profit function is decreasing for $p_B \in]v - t, v[$. For any higher p_B the profit is zero. Hence, for $p_A^p > v$ the function $\pi_B^{No\,PG}(p_B)$ is hump-shaped with respect to p_B with a global maximum at $p_B = v - t$.

Case 2 – Firm A sets p_A^p in the interval $]v - t, v]$.

For $p_B < p_A^p - t$ the profit function is defined by Segment I of $\pi_B^{No\,PG}(p_B)$, and thus linearly increasing in p_B.

For $p_A^p - t \leq p_B < 2v - t - p_A^p$ the profit function is defined by Segment II of $\pi_B^{No\,PG}$, which is a parabola with the maximum at $\frac{p_A^p+t}{2}$. If additionally $p_A^p > 3t$ this maximum is located at a price lower than the left interval border $p_A^p - t$ and the profit function is hence decreasing for $p_B \in [p_A^p - t, 2v - t - p_A^p[$. Otherwise, i.e. if

$p_A^p \leq 3t$, the profit function is increasing in $p_B \in [p_A^p - t, \frac{p_A^p+t}{2}[$ and decreasing in $p_B \in [\frac{p_A^p+t}{2}, 2v - t - p_A^p[$.

For $2v - t - p_A^p \leq p_B < v$ the profit function is defined by Segment III of $\pi_B^{No\,PG}$, which is a parabola with the maximum at $p_B = \frac{v}{2}$. Since this maximum is reached with a lower price than the left border of the interval $2v - t - p_A^p$, because $t < \frac{v}{3}$ and $p_A^p \leq v$, the profit function is decreasing for $p_B \in [2v - t - p_A^p, v[$.

For any higher p_B the profit is zero.

Hence, for $v - t < p_A^p \leq v$ the function $\pi_B^{No\,PG}(p_B)$ is hump-shaped with a global maximum at $p_B = p_A^p - t$ if $p_A^p > 3t$ and at $p_B = \frac{p_A^p+t}{2}$ if $p_A^p \leq 3t$.

Case 3 – Firm A sets p_A^p in the interval $]t, v - t]$.

For $p_B < p_A^p - t$ the profit function is defined by Segment I of $\pi_B^{No\,PG}$, and thus linearly increasing in p_B.

For $p_A^p - t \leq p_B \leq p_A^p + t$ the profit function is defined by Segment II of $\pi_B^{No\,PG}$, which is a parabola with the maximum at $\frac{p_A^p+t}{2}$. Whether this maximum is in the given interval for p_B depends on p_A^p. If p_A^p is larger than $3t$ the maximum is located at p_B lower than the left border of the interval $p_A^p - t$, and hence the profit function is decreasing for $p_B \in [p_A^p - t, p_A^p + t]$. If $p_A^p \leq 3t$ the maximum is reachable, and the profit function is increasing for $p_B \in [p_A^p - t, \frac{p_A^p+t}{2}[$ and decreasing for $p_B \in]\frac{p_A^p+t}{2}, p_A^p + t]$.

For any higher p_B the profit is zero.

Hence, for $p_A^p \in]t, v - t]$ function $\pi_B^{No\,PG}(p_B)$ is hump-shaped with a global maximum at $p_B = \frac{p_A^p+t}{2}$ if $t < p_A^p \leq 3t$ and at $p_B = p_A^p - t$ if $3t < p_A^p \leq v - t$.

Case 4 – Firm A sets p_A^p in the interval $[0, t]$.

For $p_B < p_A^p + t$ the profit function is defined by Segment II of $\pi_B^{No\,PG}$, which is a parabola with the maximum at $\frac{p_A^p+t}{2}$, which is within the given interval of p_B.

For any higher p_B the profit is zero.

Hence, for $p_A^p \leq t$ the function $\pi_B^{No\,PG}(p_B)$ is hump-shaped with a global maximum at $p_B = \frac{p_A^p+t}{2}$.

Summing up all four cases.

In summary, $\pi_B^{No\,PG}(p_B)$ is hump-shaped with respect to p_B for any value of p_A^p.

3.) $\pi_B^{PG}(p_B)$ is hump-shaped.

The function $\pi_B^{PG}(p_B)$ consists of $\pi_B^{PG-Active}(p_B)$ for $p_B < p_A^p - m$ and of $\pi_B^{No\,PG}(p_B)$ for any higher p_B. Since it is already proven that $\pi_B^{PG-Active}(p_B)$ and $\pi_B^{No\,PG}(p_B)$ are both hump-shaped, while $\pi_B^{PG}(p_B)$ is continuous by Lemma 2, it is sufficient to show that whenever $\pi_B^{PG-Active}(p_B)$ is hump-shaped on the interval $p_B \in [0, p_A^p - m[$, the slope of $\pi_B^{No\,PG}(p_B)$ is negative at $p_A^p - m$. Indeed, if $\pi_B^{PG-Active}(p_B)$ is hump-shaped on the interval $p_B \in [0, p_A^p - m[$, then, given that it has a global maximum at $p_B = v - \frac{t+m}{2}$ as shown above, we must have

$$p_A^p - m > v - \frac{t+m}{2}. \tag{2.19}$$

This yields $p_A^p > v - t$. Consequently, given the arguments in Case 1 and Case 2 in the proof above, $\pi_B^{No\,PG}(p_B)$ is hump-shaped with a global maximum at $p_B = \min\{v-t, p_A^p - t\}$ if $p_A^p > 3t$ and at $p_B = \frac{p_A^p+t}{2}$ if $p_A^p \leq 3t$. Let us show that both of these maximum points are below $p_A - m$ once (2.19) holds, in which case the slope of $\pi_B^{No\,PG}(p_B)$ must be negative at $p_B = p_A^p - m$. For the first possible point, we have that $\min\{v-t, p_A^p - t\} \leq p_A^p - t$ is always below $p_A - m$ since $m < t$. Consider the second possible maximum point and assume by contradiction

$$\frac{p_A^p + t}{2} > p_A^p - m \Leftrightarrow p_A^p < t + 2m.$$

Given (2.19), we then have

$$t + 2m > m + v - \frac{t+m}{2} \Leftrightarrow 3t + 3m > 2v,$$

which is a contradiction given that $m < t$ and $t < \frac{v}{3}$.

Thus, whenever $\pi_B^{PG-Active}(p_B)$ is hump-shaped on the interval $p_B \in [0, p_A^p - m[$, the slope of $\pi_B^{No\,PG}(p_B)$ is negative at $p_B = p_A^p - m$.

Consequently, $\pi_B^{PG}(p_B)$ is hump-shaped with respect to p_B for any value of p_A^p. ■

Proof of Proposition 2

Firm B's profit function π_B^{PG} is given by $\pi_B^{PG-Active}$ for $p_B < p_A^p - m$, whereas for higher p_B it is defined by $\pi_B^{No\,PG}$. The proof is split in three different cases and uses the fact that π_B^{PG} is continuous by Lemma 2, and is hump-shaped by Lemma 3. Hence, whenever either $\pi_B^{No\,PG}$ or $\pi_B^{PG-Active}$ are hump-shaped on the corresponding interval, their peaks are the global maximum of π_B^{PG}. If none of them are hump-shaped on the corresponding interval, the maximum of π_B^{PG} is located at the intersection of both functions, i.e. at $p_B = p_A^p - m$.

Case 1 – Firm A sets $p_A^p \geq v - \frac{t-m}{2}$.

Then, function $\pi_B^{PG-Active}(p_B)$ is hump-shaped on the corresponding interval, i.e., its peak, which is located at $p_B = v - \frac{t+m}{2}$ (see proof of Lemma 3) is reachable within $p_B \in [0, p_A^p - m[$. Indeed, $v - \frac{t+m}{2} < p_A^p - m$ is equivalent to $p_A^p > v - \frac{t-m}{2}$ which is fulfilled in the given interval of p_A^p.

Hence, the best response to $p_A^p \geq v - \frac{t-m}{2}$ is $p_B = v - \frac{t+m}{2}$.

Case 2 – Firm A sets p_A^p in the interval $]t+2m, v-\frac{t-m}{2}]$.

The maximum of $\pi_B^{PG-Active}(p_B)$ is not reachable on the corresponding interval $p_B \in [0, p_A^p - m[$. Indeed, $v - \frac{t+m}{2} \geq p_A^p - m$ is equivalent to $p_A^p \leq v - \frac{t-m}{2}$ which is fulfilled in the given interval of p_A^p. Hence, $\pi_B^{PG-Active}(p_B)$ monotonically increases in p_B for $p_B \in [0, p_A^p - m]$ (given that it is hump-shaped over the whole interval of p_B, see proof of Lemma 3).

The maximum of $\pi_B^{No\ PG}$ is also not reachable on the corresponding interval $p_B \in [p_A^p - m, \infty[$. Indeed, given that $p_A^p \in]t, v[$ in the considered case, the maximum is located either at $p_B = \frac{p_A^p+t}{2}$ or $p_B = p_A^p - t$ (see Cases 2 and 3 in the proof of Lemma 3). Both values are smaller than $p_A^p - m$, since $\frac{p_A^p+t}{2} < p_A^p - m$ is equivalent to $p_A^p > t+2m$ and $p_A^p - t < p_A^p - m$ is equivalent to $m < t$. The former is true for the given interval of p_A^p and the latter is true due to the parametric assumption $m < t$. Since the maximum of $\pi_B^{No\ PG}$ is to the left of $p_A^p - m$ and $\pi_B^{No\ PG}$ is hump-shaped (see proof of Lemma 3), π_B^{PG} has a decreasing slope to the right of $p_A^p - m$, where it is defined by $\pi_B^{No\ PG}$. Since to the left of $p_A^p - m$ the function π_B^{PG} is defined by $\pi_B^{PG-Active}$, which monotonically increases in p_B for $p_B \in [0, p_A^p - m]$ in the considered case as shown above, the maximum of π_B^{PG} is located at $p_B = p_A^p - m$.

Hence, the best response to $p_A^p \in]t+2m, v-\frac{t-m}{2}]$ is $p_B = p_A^p - m$.

Case 3 – Firm A sets p_A^p in the interval $[0, t+2m]$.

Since $p_A^p < 3t$ (due to $m < t$), the maximum of $\pi_B^{No\ PG}$ is reachable in the relevant interval of p_B with $p_B = \frac{p_A^p+t}{2}$ (see Cases 2-4 in the proof of Lemma 3).

Hence, the best response to $p_A^p \in [0, t+2m]$ is $p_B = \frac{p_A^p+t}{2}$.

Best response function – Summary of the three cases.

In summary of all three cases the reaction function is given by

$$R_B^{PG}(p_A^p) = \begin{cases} v - \dfrac{t+m}{2} & \text{if} \quad p_A^p > v - \frac{t-m}{2}, \\ p_A^p - m & \text{if} \quad t+2m < p_A^p \leq v - \frac{t-m}{2}, \\ \dfrac{p_A^p + t}{2} & \text{if} \quad p_A^p \leq t+2m. \end{cases}$$

■

Proof of Proposition 3

From (2.13) one can see that Firm A, in order to maximize its profits, chooses either p_A^p from the "collusive" interval $]v - \frac{t-m}{2}, \infty]$ or from the "competitive" interval $[0, t + 2m]$. The reason is, that the profit of Firm A, if p_A^p is set in the interval $]t + 2m, v - \frac{t-m}{2}]$, is strictly dominated by the constant profit level which results when p_A^p is in the collusive interval.
In the competitive interval Firm A's profit function is defined by a parabola which reaches a maximum of $\frac{9}{16}t$ at $p_A^p = \frac{3}{2}t$. Now, we consider two cases depending on whether this maximum is reachable within the corresponding interval $p_A^p \in [0, t + 2m]$.

Case 1: $\frac{3}{2}t \leq t + 2m$.

In this case, the maximum of the parabola is reached in the competitive interval. In this case, Firm A finds it only optimal to set a collusive p_A^p if the constant collusive profit level is at least $\frac{9}{16}t$:

$$\frac{9}{16}t \leq \left[v - \frac{t-m}{2}\right] \cdot \left[\frac{1}{2} - \frac{m}{2t}\right]$$

$$\Leftrightarrow \frac{9t^2}{16t} - \left[\frac{8mt - 8mv + 8tv - 4m^2 - 4t^2}{16t}\right] \leq 0,$$

$$\Leftrightarrow m^2 - 2m(t - v) - 2tv + \frac{13}{4}t^2 \leq 0.$$

The left-hand side is a parabola with respect to m. It has a global minimum, and only one positive root equal to $\frac{1}{2}\sqrt{4v^2 - 9t^2} - v + t$. Hence, the condition above is met whenever

$$m \leq \frac{1}{2}\sqrt{4v^2 - 9t^2} - v + t.$$

In this case, Firm A's profit is maximized at any collusive price, i.e. at any $p_A^p \geq v - \frac{t-m}{2}$. Otherwise, the profit is maximized at the competitive price $p_A^p = \frac{3}{2}t$.

Case 2: $\frac{3}{2}t > t + 2m$.

Here, the maximum of Firm A's profit is to the right of the competitive interval. Consequently, the slope of the profit function is positive at $p_A^p = t + 2m$. Since the profit function is monotonically increasing for $p_A^p > t + 2m$, while being continuous over the whole domain (see (2.13)), a collusive p_A^p (i.e., any p_A^p above $v - \frac{t-m}{2}$) yields the highest profit.

Summary of both cases.

Firm A's profit is maximized at any $p^p_A \geq v - \frac{t-m}{2}$ whenever

$$m \leq \frac{1}{2}\sqrt{4v^2 - 9t^2} - v + t \;\vee\; (\frac{3}{2}t > t + 2m \Leftrightarrow m < \frac{t}{4}).$$

Since $\frac{t}{4} < \frac{1}{2}\sqrt{4v^2 - 9t^2} - v + t$ for $t \leq \frac{v}{3}$, the condition is equivalent to:

$$m \leq \frac{1}{2}\sqrt{4v^2 - 9t^2} - v + t.$$

Otherwise, Firm A's profit is maximized under competitive price $p^p_A = \frac{3}{2}t$. ■

Proof of Proposition 4

(a) In this case, by Propositions 2 and 3 it follows that $p^p_A \geq v - \frac{t-m}{2}$ while $p_B = v - \frac{t+m}{2}$. Hence, $p^p_A - p_B \geq v - \frac{t-m}{2} - (v - \frac{t+m}{2}) = m$. Consequently, the guarantee is activated and the effective price of Firm A is $p_B + m = v - \frac{t-m}{2}$.
(b) From Proposition 3 it follows that $p^p_A = \frac{3}{2}t$ in the considered case. Consider the best response of Firm B described in Proposition 2. Let us show that the condition for a competitive reaction from Firm B, i.e. $p^p_A \leq t + 2m$, is fulfilled. Given that $m \geq \phi$, the sufficient condition for this is $p^p_A \leq t + 2\phi$, which is equivalent to $\phi \geq \frac{1}{4}t$. One can show that this always holds for $t \leq \frac{v}{3}$. Consequently, by Proposition 2, $p_B = \frac{p^p_A + t}{2} = \frac{5}{4}t$. Then we have, $p^p_A - p_B = \frac{3}{2}t - \frac{5}{4}t = \frac{1}{4}t \leq \phi \leq m$. Consequently, the effective price of Firm A is equal to its posted price: $p_A = p^p_A = \frac{3}{2}t$. ■

Proof that Firm B's guarantee does not affect equilibrium prices

It is to show, that in comparison to a game where only Firm A offers a price guarantee with an arbitrary non-negative markup on the competitors' price (*1PG-game*), a game in which both firms offer such a price guarantee does not change equilibrium prices (*2PG-game*). In order to show this, it is important to recall that in any equilibrium of the *1PG-game* Firm B undercuts Firm A.

In the *2PG-game* Firm B is restricted in overbidding the price of Firm A by more than m. This restriction is binding for the best response function of Firm B in the *1PG-game* only off the equilibrium path. Hence, it is sufficient to show that Firm A's optimal strategy does not change between the *1PG-game* and the *2PG-game*.

Since Firm A's profit is weakly increasing in the price of Firm B, all posted prices of Firm A which lead to a less drastic overbidding of Firm B in the *2PG-game* compared to the *1PG-game* are becoming less attractive. However, all other profits, including the profit of the equilibrium action of the *1PG-game*, are identical to the *2PG-game*. Consequently, Firm A posts the same prices in equilibrium in both games, and Firm B reacts by undercutting to the same extent.[16] ■

[16]Note that this reasoning holds only for the sequential game with otherwise symmetric firms considered in the theory section, as it relies on Firm B setting the lower price in the equilibrium of the *1PG Game*. This reasoning may not hold if firms are asymmetric, for example if Firm B has a disadvantageous cost structure.

2.C English Instructions (translated)

The following pages contain a translated version of the instructions. Curley brackets indicate the treatment variation of the instructions. Naturally subjects only saw their treatment variation.

Instructions — Experiment Rules

Welcome to the experiment!

In this experiment you can earn money. How much you will earn, depends on your decisions and on the decisions of other participants. Irrespectively of the decisions during the experiment, you will additionally receive an amount of 4.00 Euro for your appearance as well as another 4.00 Euro for the completion of a questionnaire at the end of the experiment.

During the experiment the currency "Experimental Currency Units" (ECU) is used. At the end of the experiment all ECU amounts, which you earned during the experiment, are converted into Euro and are paid to you in cash. The exchange rate for 14,000 ECU is 1 Euro.

All decisions during the experiment are anonymous. The payments at the end of the experiment are treated confidentially.

From now on, please do not communicate with other participants. If you have any questions, now or during the experiment, please raise your hand. We will come to you and answer your question. Moreover, during the experiment we ask you to switch off your mobile phone. Documents (books, lecture script, etc.), which are not related to the experiment, may not be used during the experiment. In case of offense against these rules we may exclude you from the experiment and all payments.

Instructions — General Part

At the beginning of the experiment each participant is assigned to a role, either *Competitor A* or *Competitor B*. This assignment remains constant during the whole experiment and each participant is informed individually about his role on the screen.

Competitor A and Competitor B sell arbitrarily divisible goods in a market. Each competitor can produce up to 100 units. The production will create no costs. {T2+T3: Competitor A is bound to a price guarantee, which guarantees, that his final price will not exceed the price of Competitor B by more than {T2:2; T3:33} ECU.}

The sales prices are determined in the following order:

1. Competitor A sets his {T2+T3: posted} price first.

2. Competitor B sees the {T2+T3: posted} price of Competitor A and sets his price. {T2+T3: This price is his final price.

3. The final price of Competitor A is determined:

   - If Competitor B sets a price which is at least {T2: 2; T3: 33} ECU lower than the posted price of Competitor A, the price guarantee of Competitor A is activated. The final price of Competitor A equals the price of Competitor B plus a markup of {T2: 2; T3: 33} ECU.

   - If Competitor B sets a higher price than Competitor A, or undercuts his price by less than {T2: 2; T3: 33} ECU, the price guarantee of Competitor A is not activated. The final price of Competitor A equals his posted price.}

The sales volume of each competitor depend on the {T2 + T3: final} price of Competitor A (p_A) and the {T2 + T3: final} price of Competitor B (p_B). In the experiment they are calculated by the computer as follows:

$$\text{Sales Volume Competitor A} = \begin{cases} \dfrac{p_B - p_A + 35}{70} \cdot 100 & \text{if} \quad p_A + p_B < 365 \\ \dfrac{200 - p_A}{35} \cdot 100 & \text{else.} \end{cases}$$

$$\text{Sales Volume Competitor B} = \begin{cases} \dfrac{p_A - p_B + 35}{70} \cdot 100 & \text{if} \quad p_A + p_B < 365 \\ \dfrac{200 - p_B}{35} \cdot 100 & \text{else.} \end{cases}$$

A sales volume cannot be less than 0 units or greater than 100 units. If the formulas above generate a sales volume smaller than 0, the sales volume is set to 0. If the formulas above generate a sales volume higher than 100, the sales volume is set to 100.

The sales volumes and {T2 + T3: final} prices lead to the competitors' profits:

Profit of a Competitor (in ECU) = His {T2+T3:Final} Price · His Sales Volume

Instructions — Scenario Calculator

At the beginning of the experiment a scenario calculator will be provided. With the help of this calculator you can calculate the sales volumes and profits of both competitors for any price combination. The scenario calculator is available during the whole experiment.

The scenario calculator uses the {T2 + T3: posted} price of Competitor A and the {T2 + T3: final} price of Competitor B as inputs:

- You can enter any value between 0 and 200 for each competitor.
- The input is either entered in an input field or by using a slider-bar.
- Inputs via the input field can have any number of decimal places and must be confirmed with the button next to it.

Note: Consider in your simulations that Competitor B makes his decision after Competitor A and therefore knows Competitor A's {T2 + T3: posted} price.

After both prices are entered, the scenario calculator displays:

- **{T2+T3: whether the price guarantee is activated:**
  - This is the case when the final price of Competitor B is at least {T2: 2; T3: 33} ECU lower than the posted price of Competitor A.
  - If the price guarantee is activated, the following applies:
    Final Price Competitor A = Final Price Competitor B + {T2:2; T3:33} ECU}
- **the sales amounts of every competitor:**
  - {T2+T3: The calculation is based on the final prices.}
  - Sales volumes can vary between 0 and 100 units.
- **{T2+T3: the final prices of both competitors:**
  - The final price of Competitor A equals his posted price, if the price guarantee is not activated, or equals the price of Competitor B plus {T2: 2; T3: 33} ECU if the price guarantee is activated.
  - The final price of Competitor B is always his entered price because Competitor B is not restricted by a price guarantee.}
- **the profits of both competitors:**
  - The profits of both competitors are the respective {T2+T3: final} price multiplied by the respective sales volume:
    Profit = {T2+T3: Final} Price $\cdot$ Sales Volume [in ECU]

Familiarize yourself with the calculations and use the scenario calculator as often as you like. Your entries in the scenario calculator will not affect your payoff at the end of the experiment.

Instructions — Decision Stage

In this stage of the experiment you interact with other competitors which will be matched to you. The interaction takes place in the setting you already know from the scenario calculator.

The decision stage consists of 15 independent periods. The course in each period is identical. However, the competitor matched to you differs from period to period. The matching procedure is as follows:

- Your competitor will be randomly determined each period. However, it is assured that you are never matched with the same competitor in two consecutive periods.
- Your competitor will differ from you in the assigned role, in other words a Competitor A always competes with a Competitor B.

Timing within a period:

1. At the beginning of every period, Competitor A sets his {T2+T3: posted} price.
   Meanwhile, Competitor B sees a waiting screen.
2. After Competitor A has set his {T2+T3: posted} price, Competitor B sees it and sets his {T2+T3: final} price.
   Meanwhile, Competitor A sees a waiting screen.
3. Finally, the computer calculates {T2+T3: the final price of Competitor A and} the sales volumes. These are displayed, in addition to the profits of both competitors, in the period summary.

After completing 15 periods, your profits of all periods will be displayed and summed up in a final summary. The total sum is then converted into Euro to the exact cent and paid to you in cash at the end of the experiment. The payment additionally includes a premium of 4.00 Euro for showing up and another premium of 4.00 Euro for completing the questionnaire. The exchange rate is €1 per ECU 14,000.

Once the experiment ended, a short questionnaire appears on your screen. Please fill out this questionnaire, while the experimenters prepare your payoff. Afterwards, you will be called by your cabin number for your payment.

Thank you for your participation!

2.D German Instructions (original)

Instruktionen — Allgemeine Experimentregeln

Herzlich Willkommen zum Experiment!

In diesem Experiment können Sie Geld verdienen. Wie viel Sie verdienen werden, hängt von Ihren Entscheidungen beziehungsweise den Entscheidungen anderer Experimentteilnehmer ab. Unabhängig von den Entscheidungen während des Experimentes erhalten Sie zusätzlich 4,00 Euro für Ihr Erscheinen sowie weitere 4,00 Euro für das Ausfüllen eines Fragebogens am Ende des Experimentes.

Während des Experimentes wird die Währung ECU (Experimental Currency Units) verwendet. Am Ende des Experimentes werden alle ECU-Beträge, welche Sie im Laufe des Experimentes verdienen, in Euro umgerechnet und Ihnen ausgezahlt. Der Umrechnungskurs beträgt 1 Euro für 14 000 ECU.

Alle Entscheidungen, die Sie während des Experimentes treffen, sind anonym. Ihre Auszahlung am Ende des Experimentes wird vertraulich behandelt.

Bitte kommunizieren Sie ab sofort nicht mehr mit den anderen Teilnehmern. Falls Sie jetzt oder während des Experimentes eine Frage haben, heben Sie bitte die Hand. Wir werden dann zu Ihnen kommen und Ihre Frage beantworten. Während des Experimentes bitten wir Sie außerdem, Ihr Mobiltelefon auszuschalten. Unterlagen (Bücher, Vorlesungsskripte, etc.), die nichts mit dem Experiment zu tun haben, dürfen während des Experimentes nicht verwendet werden. Bei Verstößen gegen diese Regeln können wir Sie vom Experiment und allen Auszahlungen ausschließen.

Instruktionen — Allgemeiner Teil

Zu Beginn des Experimentes wird jedem Experimentteilnehmer eine Rolle zugeteilt, entweder *Wettbewerber A* oder *Wettbewerber B*. Diese Zuteilung bleibt das gesamte Experiment über bestehen und wird jedem Experimentteilnehmer individuell auf dem Bildschirm mitgeteilt.

Wettbewerber A und Wettbewerber B verkaufen am Markt beliebig teilbare Güter. Sie können jeweils bis zu 100 Einheiten produzieren. Bei der Produktion fallen keine Kosten an. {T2+T3: Beim Verkauf ist Wettbewerber A an eine Preisgarantie gebunden, welche garantiert, dass sein endgültiger Preis den Preis von Wettbewerber B um nicht mehr als {T2: 2; T3: 33} ECU überschreitet.}

Die Festlegung der Verkaufspreise geschieht in folgender Reihenfolge:

1. Wettbewerber A legt zuerst seinen {T2+T3: vorläufigen} Preis fest.
2. Wettbewerber B sieht den {T2+T3: vorläufigen} Preis von Wettbewerber A und legt seinen Preis fest. **{**T2+T3: Dieser Preis ist zugleich sein endgültiger Preis.
3. Der endgültige Preis von Wettbewerber A wird bestimmt:
   - Sollte Wettbewerber B den vorläufigen Preis von Wettbewerber A um mindestens {T2: 2; T3: 33} ECU unterbieten, so wird dessen Preisgarantie aktiviert. Der endgültige Preis von Wettbewerber A entspricht dann dem Preis von Wettbewerber B zuzüglich {T2: 2; T3: 33} ECU.
   - Sollte Wettbewerber B einen höheren Preis festlegen als Wettbewerber A oder dessen vorläufigen Preis um weniger als {T2: 2; T3: 33} ECU unterbieten, so wird die Preisgarantie von Wettbewerber A nicht aktiviert. Der endgültige Preis von Wettbewerber A entspricht dann seinem vorläufigen Preis.**}**

Die Absatzmengen der Wettbewerber hängen von dem {T2 + T3: endgültigen} Preis von Wettbewerber A (p_A) und dem {T2 + T3: endgültigen} Preis von Wettbewerber B (p_B) ab. Sie werden im Experiment durch den Computer wie folgt berechnet:

$$\text{Absatzmenge Wettbewerber A} = \begin{cases} \dfrac{p_B - p_A + 35}{70} \cdot 100 & \text{falls} \quad p_A + p_B < 365 \\ \dfrac{200 - p_A}{35} \cdot 100 & \text{sonst.} \end{cases}$$

$$\text{Absatzmenge Wettbewerber B} = \begin{cases} \dfrac{p_A - p_B + 35}{70} \cdot 100 & \text{falls} \quad p_A + p_B < 365 \\ \dfrac{200 - p_B}{35} \cdot 100 & \text{sonst.} \end{cases}$$

Eine Absatzmenge kann niemals kleiner als 0 Einheiten oder größer als 100 Einheiten sein. Falls sich aus den obigen Formeln eine kleinere Absatzmenge als 0 Einheiten ergibt, so wird die Absatzmenge auf 0 Einheiten gesetzt. Falls sich aus den obigen Formeln eine Absatzmenge von mehr als 100 Einheiten ergibt, so wird die Absatzmenge auf 100 Einheiten gesetzt.

Aus den Absatzmengen und den {T2+T3: endgültigen} Preisen ergeben sich die Gewinne der Wettbewerber:

Gewinn eines Wettbewerbers (in ECU) = Sein {T2+T3: endgültiger} Preis · seine Absatzmenge

<u>Instruktionen — Szenario–Rechner</u>

Zu Beginn des Experimentes wird Ihnen ein Szenario-Rechner bereitgestellt. Mit Hilfe dieses Rechners können Sie für beliebige Preiskombinationen die Absatzmengen und Gewinne beider Wettbewerber berechnen. Der Szenario-Rechner steht Ihnen während des gesamten Experimentes zur Verfügung.

Als Eingabe benötigt der Szenario-Rechner den {T2 + T3: vorläufigen} Preis von Wettbewerber A und den {T2 + T3: endgültigen} Preis von Wettbewerber B:

- Sie können für jeden Wettbewerber beliebige Werte zwischen 0 und 200 eingeben.
- Die Eingabe erfolgt entweder über eine Schiebeleiste oder ein Eingabefeld.
- Eingaben über das Eingabefeld können beliebig viele Nachkommastellen haben und müssen mit dem nebenstehenden Knopf bestätigt werden.

Hinweis: Berücksichtigen Sie bei Ihren Simulationen, dass Wettbewerber B nach Wettbewerber A entscheidet und zum Zeitpunkt seiner Entscheidung dessen {T2 + T3: vorläufigen} Preis kennt.

Nachdem beide Preise eingegeben sind, wird angezeigt,

- **{T2+T3: ob die Preisgarantie aktiviert wird:**
  - Dies ist immer der Fall, wenn der endgültige Preis von Wettbewerber B den vorläufigen Preis von Wettbewerber A um mehr als {T2: 2; T3: 33} ECU unterschreitet.
  - Sofern die Preisgarantie aktiviert wird, gilt:
    Endgültiger Preis Wettbewerber A = Endgültiger Preis Wettbewerber B
    + {T2: 2; T3: 33} ECU **}**
- **welche Absatzmenge jeder Wettbewerber hat:**
  - {T2+T3: Die Berechnung erfolgt auf Basis der endgültigen Preise.}
  - Die Absatzmengen können zwischen 0 und 100 Einheiten betragen.
- **{T2+T3: wie die endgültigen Preise beider Wettbewerber lauten:**
  - Der endgültige Preis von Wettbewerber A ist sein vorläufiger Preis, falls die Preisgarantie nicht aktiviert wird, beziehungsweise der Preis von Wettbewerber B zuzüglich {T2: 2; T3: 33} ECU, falls die Preisgarantie aktiviert wird.

- Der endgültige Preis von Wettbewerber B ist immer sein eingegebener Preis, da Wettbewerber B an keine Preisgarantie gebunden ist.**}**

- **wie hoch die Gewinne beider Wettbewerber sind:**
  - Die Gewinne beider Wettbewerber ergeben sich aus der Multiplikation des jeweiligen {T2 + T3: endgültigen} Preises und der jeweiligen Absatzmenge: Gewinn ={T2 + T3: Endgültiger} Preis · Absatzmenge [in ECU]

Machen Sie sich mit den Berechnungen vertraut und nutzen Sie den Szenario-Rechner. Sie können ihn beliebig oft verwenden. Ihre Eingaben im Szenario-Rechner haben keinen Einfluss auf Ihre Auszahlungen am Ende des Experimentes.

Instruktionen — Entscheidungsstufe

Nachdem Sie sich nun mit dem Szenario-Rechner vertraut gemacht haben, interagieren Sie in diesem Teil des Experimentes mit Ihnen zugeteilten anderen Wettbewerbern in dem Ihnen aus dem Szenario-Rechner bekannten Setting.

Die Entscheidungsstufe besteht aus insgesamt 15 Runden, wobei jede Runde vom Ablauf identisch ist. Von Runde zu Runde unterschiedlich ist, mit welchem Wettbewerber sie konkurrieren. Hierbei gilt:

- Ihr Wettbewerber wird jede Runde zufällig neu bestimmt. Es wird sichergestellt, dass Sie in zwei aufeinanderfolgenden Runden niemals demselben Wettbewerber zugeordnet sind.
- Ihr Wettbewerber hat immer eine von Ihnen unterschiedliche Rolle, sodass immer ein Wettbewerber A mit einem Wettbewerber B konkurriert.

Ablauf einer Runde:

1. Zu Beginn jeder Runde setzt Wettbewerber A zuerst seinen {T2+T3: vorläufigen} Preis.
   Wettbewerber B sieht währenddessen einen Wartebildschirm.
2. Nachdem Wettbewerber A seinen {T2+T3: vorläufigen} Preis gesetzt hat, wird dieser Wettbewerber B angezeigt, welcher nun seinen {T2+T3: endgültigen} Preis setzt.
   Wettbewerber A sieht währenddessen einen Wartebildschirm.
3. Anschließend werden vom Computer {T2+T3: der endgültige Preis von Wettbewerber A und} die Absatzmengen bestimmt. Diese werden zusammen mit den Gewinnen beider Wettbewerber in der abschließenden Rundenzusammenfassung angezeigt.

Nach Abschluss der 15 Runden wird eine Auflistung Ihrer sämtlichen Rundengewinne angezeigt und aufsummiert. Die Gesamtsumme wird am Ende des Experimentes zum Umrechnungskurs von 1 € pro 14 000 ECU auf den Cent genau umgerechnet und zuzüglich zu der Prämie von 4 € für das Erscheinen und der 4 € - Prämie für das Ausfüllen des Fragebogens Ihnen in bar ausbezahlt.

Nach der Rundenübersicht erscheint der kurze Fragebogen auf dem Bildschirm. Bitte füllen Sie diesen aus, während die Experimentatoren Ihre Auszahlungen vorbereiten. Im Anschluss werden Sie anhand Ihrer Kabinennummer zur Auszahlung aufgerufen und das Experiment ist beendet.

Vielen Dank für Ihre Teilnahme!

Chapter 3

Strategic Disclosure of Demand Information by Duopolists: Theory and Experiment*

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Abstract

We study the strategic disclosure of demand information and product-market strategies of duopolists. In a setting where both firms receive information with some probability, we show that firms selectively disclose information in equilibrium in order to influence their competitor's product-market strategy. Subsequently, we analyze the firms' behavior in a laboratory experiment. We find that subjects often use selective disclosure strategies, and this finding appears to be robust to changes in the information structure, the mode of competition, and the degree of product differentiation. Moreover, in our experiment, subjects' product-market conduct is largely consistent with theoretical predictions.

Keywords: duopoly, Cournot competition, Bertrand competition, information disclosure, incomplete information, common value, product differentiation, asymmetry, skewed distribution, laboratory experiment

JEL Codes: C92, D22, D82, D83, L13, M4

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3.1 Introduction

This paper studies strategies of firms that may not have complete information about the demand for their goods. The market demand may be affected by exogenous shocks, such as the business cycle or the weather. For example, a firm may not know whether its market demand remains depressed (booming) or a recovery (recession) is imminent. In addition, the firm may not be fully informed about how well product characteristics match with consumers' tastes if those tastes are subject to change. Alternatively, a firm may not have complete information on a common cost of production. For example, prices of common inputs may fluctuate in an unpredictable way. In all those cases, a firm can obtain information to learn about the market, and if it does, it can use this information to gain a strategic advantage. First, the firm can manage the beliefs of a competitor by disclosing or concealing its information. Second, the firm can use the information to make better-informed choices in the product market. In this paper, we study these strategic uses of a firm's demand information both theoretically as well as experimentally.

The analysis of the firms' disclosure incentives is relevant as starting point for developing antitrust policy and accounting rules. An antitrust authority is better equipped to determine how much information firms should be allowed to share, by understanding the non-cooperative disclosure strategies of competing duopolists (e.g., Kühn and Vives, 1995, and Kühn, 2001). Likewise, it is helpful to know how much information firms share voluntarily when one designs accounting rules that stipulate how much information firms are required to disclose (e.g., Verrecchia, 2001, and Dye, 2001). In other words, the effects of disclosure regulation can only be properly assessed if the unregulated disclosure strategies and their effects on product-market competition are well understood.

If there are no verification and disclosure costs, and if it is known that firms have information, then often firms will disclose all information. Firms do so, since they cannot credibly conceal unfavorable news. This phenomenon is called the unraveling result (Milgrom, 1981, Milgrom and Roberts, 1986, Okuno-Fujiwara et al., 1990, and Milgrom, 2008).[1] In the experimental literature, King and Wallin (1991a), and Jin et al. (2015) find support for the unraveling result if receivers get enough feedback.

By contrast, if a firm can fail to become informed, it is no longer known whether this firm is informed. Although information is verifiable, it is not verifiable whether or not a firm is informed. In such an environment the unraveling result may fail to hold since firms can credibly conceal unfavorable news by claiming to be uninformed,

[1]The assumption that information is verifiable, which we adopt in this paper, is consistent with some empirical findings (e.g., see Jansen, 2008).

e.g., see Dye (1985), Farrell (1986), Jung and Kwon (1988), and Sankar (1995). In these models of unilateral disclosure, a Cournot oligopolist has an incentive to disclose bad news (low demand), and conceal good news (high demand) to discourage its rivals. A Bertrand oligopolist only discloses good news (high demand) to induce the competitors to choose high prices. Ackert et al. (2000) give experimental support for unilateral, selective information disclosure of a common cost parameter in Cournot duopoly. They confirm that a firm discloses bad news more often than good news.[2]

Theoretical studies of multilateral information disclosure typically focus on symmetric models.[3] Darrough (1993) analyzes a symmetric model, and Jansen (2008) focuses on symmetric equilibria. These papers show that the optimal unilateral disclosure strategy is also an equilibrium strategy in symmetric settings of multilateral disclosure. That is, symmetric Cournot duopolists disclose low demand intercepts and conceal high intercepts, whereas Bertrand duopolists disclose only high intercepts. As far as we know, there are no experiments on multilateral disclosure in duopoly models.

Although the literature focuses on unilateral disclosure and multilateral information exchange between symmetric firms, there exist important differences between firms in practice (e.g., established firms differ from new firms, and firms have different sizes and capabilities). Our paper intends to address this issue.

We contribute to the literature in two ways. First, we contribute to the theoretical literature on multilateral information disclosure by analyzing the disclosure and product-market strategies of firms in asymmetric duopolies. Second, we contribute to experimental work on strategic information disclosure by studying multilateral disclosure, by analyzing the behavior of Bertrand duopolists, and by studying disclosure behavior of duopolists with differentiated goods in a laboratory.

A firm's disclosure of common demand information in a Cournot duopoly has two conflicting effects. First, the disclosure informs the firm's competitor about his payoff from the product market. In particular, if the firm discloses that demand is low (high), then its competitor learns that a relatively low (high) output level is profitable. Therefore, this effect gives the firm an incentive to disclose a low demand intercept and conceal a high intercept in order to discourage supply by its competitor.

[2] King and Wallin (1991b) obtain results consistent with selective disclosure in an asset market. In a labor market, costly disclosure to an automated receiver is selective too (Benndorf et al., 2015).

[3] With multilateral disclosure, both firms in a duopoly make (simultaneous) disclosure choices.

However, there is an additional effect of demand disclosure. A firm that discloses information also informs its competitor about its conduct in the product market. In particular, if the firm discloses that it learned that demand is low (high), then it signals to the competitor that it will have a less (more) "aggressive" output strategy than an uninformed firm. This effect gives the firm an incentive to disclose a high demand intercept and conceal a low demand intercept. Such a disclosure strategy makes the firm's competitor pessimistic about the competitive pressure, and thereby discourages him to supply to the market (strategic substitutes).

Our paper derives precise conditions under which the former effect outweighs the latter. In particular, if the demand distribution is not too skewed towards low demand, or if firms do not differ too much from each other, then there exists an equilibrium in which both firms disclose low demand and conceal high demand. Hence, we extend the aforementioned literature by allowing for asymmetry and multilateral disclosure.

In addition, we characterize situations where the latter effect of disclosure dominates the former, and a firm reverses its disclosure strategy. This happens if demand is sufficiently skewed towards low demand (e.g., in periods of economic recession), and if one firm is likely to be informed while the other firm is unlikely to be informed. In this case, the former firm discloses only a low intercept whereas the latter firm discloses only a high demand intercept. If it is unlikely that a firm is informed and it is likely that the demand is low, then this firm is expected to be a soft competitor, since it is likely that the firm is uninformed and pessimistic. Disclosure of good news by this firm makes the competitor less "aggressive," since the news makes the competitor realize that the firm will be less soft than expected.[4] Hence, if the firms' probabilities of receiving information are sufficiently different, then the firms' information disclosure choices may differ from the choices by identical firms.[5]

In a Bertrand duopoly, the effects from disclosing information about a common demand intercept are aligned. As before, the disclosure of high (low) demand information makes the competitor of a firm optimistic (pessimistic) about his product-market opportunities. In addition, the firm's disclosure of a high (low) demand intercept signals to the firm's competitor that it will have a less (more) "aggressive"

[4]This happens for the following reasons. First, the competitor drastically updates his belief about the firm's conduct in the product market, and thereby expects fiercer competition. Moreover, the average competitor becomes only slightly more optimistic about his own opportunities in the product market, since it is very likely that the competitor was already informed about the size of the market.

[5]This observation is consistent with the observations in Hwang (1993, 1994). Hwang analyzes the information sharing incentives of precommitting firms (Kühn and Vives, 1995, Raith, 1996, and Vives, 1999), whereas we study the incentives for strategic disclosure.

pricing strategy than if it were uninformed. Both belief updates give the competitor the incentive to set a relatively high (low) price. Therefore, the firm discloses a high demand intercept and conceals a low intercept to encourage a high price by its competitor.

Our laboratory experiment analyzes the strategic information disclosure and product market choices of firms in several duopolistic settings. In particular, we vary the mode of competition, the information structure (i.e., from unilateral to bilateral disclosure, and from symmetric to asymmetric models), and the degree of product differentiation across seven treatments.

We find that subjects often use selective disclosure strategies. The subjects in our treatments with Cournot (Bertrand) competition disclose information on low (high) demand intercepts significantly more often than information on high (low) demand intercepts. These observed tendencies suggest that subjects understand that disclosed information informs their competitor about demand, and they use their information strategically. The observed selective disclosure strategies give the subjects' competitor pessimistic (optimistic) beliefs about the market with Cournot (Bertrand) competition, and thereby make the competitor less "aggressive" in the product market if this were the only effect of information disclosure. Our finding appears to be robust to changes in the information structure, and the degree of product differentiation.

Finally, the subjects in our experiment display product-market conduct that is largely consistent with our theoretical predictions. Their product-market choices tend to be responsive to information, and (weakly) to the precision of information.

3.2 The model

Consider an industry where two risk-neutral firms interact in a three-stage game. Firms have symmetric demand functions, with intercept θ. This demand intercept is unknown to the firms.[6] The intercept is either low or high, i.e., $\theta \in \{\underline{\theta}, \overline{\theta}\}$ with $0 < \underline{\theta} < \overline{\theta}$, and θ is drawn with probability $q(\theta)$ where $0 < q(\theta) < 1$ and $q(\underline{\theta}) + q(\overline{\theta}) = 1$.

In stage 1, the firms can learn the demand realization from imperfect signals, (Θ_1, Θ_2). With probability a_i, firm i learns the true demand intercept, $\Theta_i = \theta$, but with probability $1 - a_i$ the firm receives the uninformative signal $\Theta_i = \varnothing$, where $0 < a_i < 1$ and $i = 1, 2$. These signals are independent, conditional on θ.

[6] This model is conceptually identical to a model with incomplete information about a common shock to a constant marginal production costs. Hence, all results hold for such a model as well.

In stage 2, each firm chooses whether to disclose or conceal its signal. If a firm receives information about the demand intercept, then this information is verifiable. However, the fact whether or not a firm is informed is not verifiable. If firm i receives information $\Theta_i = \theta$, it chooses the probability with which it discloses this information, $s_i(\theta) \in [0,1]$ for $i = 1,2$. In particular, firm i discloses θ with probability $s_i(\theta)$, while it sends uninformative message $\varnothing$ with probability $1 - s_i(\theta)$ for $i = 1,2$. An uninformed firm can only send message $\varnothing$. In other words, $\left[s_i(\underline{\theta}), s_i(\overline{\theta})\right]$ denotes firm i's disclosure strategy for $i = 1,2$. Firms choose their disclosure strategies simultaneously.

In the final stage, firms simultaneously choose their output levels of substitutable goods, $x_i \geq 0$ for firm i (i.e., Cournot competition).[7] Firm i's inverse demand function is $\mathcal{P}_i^d(x_i, x_j) \equiv \theta - x_i - \delta x_j$, for $i, j \in \{1,2\}$ with $i \neq j$, and $0 < \delta \leq 1$. Parameter δ stands for the degree of product substitutability.[8] Firm i has the constant unit cost of production $c_i \geq 0$. We assume that the firms' costs do not differ too much, and thereby we focus on accommodating output strategies. Firm i's profit for output levels (x_i, x_j) and demand intercept θ is (for $i, j \in \{1,2\}$ with $i \neq j$):

$$\pi_i(x_i, x_j; \theta) = (\theta - c_i - x_i - \delta x_j)\, x_i. \tag{3.1}$$

We solve the model backwards and use the perfect Bayesian equilibrium concept.

3.3 Theoretical analysis

This section analyzes the equilibrium quantities for given disclosure choices, and characterizes the equilibrium disclosure strategies. In addition, we characterize the equilibrium strategies of Bertrand competitors. These analyses yield testable hypotheses.

3.3.1 Equilibrium outputs

First, we study the equilibrium outputs under complete information. Whenever one of the firms discloses the information θ, both firms know that the demand intercept is θ. Firm i's first-order condition of profit maximization with respect to x_i, given

[7] In Section 3.3, we extend the model by considering price competition (i.e., Bertrand competition).

[8] For example, if $\delta = 1$ then the firms' goods are perfect substitutes, and if $\delta \to 0$ then in the limit the firms supply to independent markets.

$\theta \in \{\underline{\theta}, \overline{\theta}\}$, is as follows (for $i, j = 1, 2$ and $i \neq j$):

$$2x_i(\theta) = \theta - c_i - \delta x_j(\theta) \tag{3.2}$$

The first-order conditions give the following equilibrium output and profit for firm i:

$$\begin{aligned} x_i^f(\theta) &= \frac{\theta - c_i}{2 + \delta} + \frac{\delta(c_j - c_i)}{4 - \delta^2} \text{ and} && (3.3) \\ \pi_i^f(\theta) &= x_i^f(\theta)^2, && (3.4) \end{aligned}$$

respectively, with $\theta \in \{\underline{\theta}, \overline{\theta}\}$ and $i, j \in \{1, 2\}$ with $i \neq j$. This is a standard result.

Second, we consider the equilibrium after no firm disclosed any information. In that case, an informed firm i with $\Theta_i = \theta$ assigns probability $A_j(\theta; s_j)$ to competing with an informed rival j ($\Theta_j = \theta$), and probability $1 - A_j(\theta; s_j)$ to facing an uninformed rival ($\Theta_j = \varnothing$), where:

$$A_j(\theta; s_j) \equiv \frac{a_j \left[1 - s_j(\theta)\right]}{1 - a_j s_j(\theta)}. \tag{3.5}$$

After an uninformative signal ($\Theta_i = \varnothing$), firm i expects the demand intercept:

$$E_j\{\theta | \varnothing; s_j\} \equiv Q_j(\underline{\theta}; s_j)\underline{\theta} + Q_j(\overline{\theta}; s_j)\overline{\theta}, \tag{3.6}$$

with posterior belief

$$Q_j(\theta; s_j) \equiv \frac{q(\theta)\left[1 - a_j s_j(\theta)\right]}{q(\underline{\theta})\left[1 - a_j s_j(\underline{\theta})\right] + q(\overline{\theta})\left[1 - a_j s_j(\overline{\theta})\right]}. \tag{3.7}$$

The uninformed firm i assigns probability $Q_j(\theta; s_j)A_j(\theta; s_j)$ to competing with an informed firm j with $\Theta_j = \theta$ for $\theta \in \{\underline{\theta}, \overline{\theta}\}$. With the remaining probability, $1 - E_j\{A_j(\theta; s_j)|\varnothing; s_j\}$, firm j is believed to be uninformed. Hence, if the beliefs of firm i are consistent with disclosure strategy s_j, then firm i's first-order conditions are as follows (for $i, j = 1, 2$ with $i \neq j$, and $\Theta_i \in \{\underline{\theta}, \overline{\theta}, \varnothing\}$ where $E_j\{\theta|\theta; s_j\} = \theta$):

$$2x_i^*(\Theta_i) = E_j\{\theta|\Theta_i; s_j\} - c_i - \delta E_j\left\{ A_j(\theta; s_j)x_j^*(\theta) + \left[1 - A_j(\theta; s_j)\right] x_j^*(\varnothing) \middle| \, \Theta_i; s_j \right\}. \tag{3.8}$$

Equation (3.8) implies that the equilibrium output of an uninformed firm equals the conditionally expected output of an informed firm:

$$x_i^*(\varnothing; s_i, s_j) = E_j\left\{ x_i^*(\theta; s_i, s_j) \middle| \, \varnothing; s_j \right\}. \tag{3.9}$$

After we define the function $\mathcal{D}$ as follows

$$\begin{aligned}\mathcal{D}(s_i, s_j) \quad &\equiv \quad 4 - \delta^2 \left[A_j(\underline{\theta}; s_j)Q_i(\overline{\theta}; s_i) + A_j(\overline{\theta}; s_j)Q_i(\underline{\theta}; s_i)\right] \\ &\qquad \cdot \left[A_i(\underline{\theta}; s_i)Q_j(\overline{\theta}; s_j) + A_i(\overline{\theta}; s_i)Q_j(\underline{\theta}; s_j)\right], \end{aligned} \tag{3.10}$$

we derive the equilibrium output from (3.8) and (3.9), by using (3.5)–(3.7).

Proposition 1. *If no firm disclosed information, and firms i and j have beliefs consistent with s_j and s_i, respectively, then the following holds for $i, j = 1, 2$ with $i \neq j$. The equilibrium output of firm i with information $\Theta_i = \theta$ equals*

$$x_i^*(\theta; s_i, s_j) \equiv x_i^f(\theta) + \frac{\frac{\delta}{4-\delta^2} q(\widehat{\theta}) \left(\theta - \widehat{\theta}\right) \psi_i(s_i, s_j)}{\mathcal{D}(s_i, s_j) \prod_{h=1}^{2} \left[1 - a_h s_h(\theta)\right] E\{1 - a_h s_h(\theta)\}}, \tag{3.11}$$

where

$$\begin{aligned}\psi_i(s_i, s_j) \quad \equiv \quad & \delta(1 - a_i)(1 - a_j)E\left\{\left[1 - a_i s_i(\theta)\right]\left[1 - a_j s_j(\theta)\right]\right\} \\ & +2(1 - a_j)\left[1 - a_i s_i(\underline{\theta})\right]\left[1 - a_i s_i(\overline{\theta})\right] E\{1 - a_j s_j(\theta)\} \\ & -\delta(1 - a_i)\left[1 - a_j s_j(\underline{\theta})\right]\left[1 - a_j s_j(\overline{\theta})\right] E\{1 - a_i s_i(\theta)\}, \end{aligned} \tag{3.12}$$

and $\mathcal{D}(s_i, s_j) > 0$ for $\theta, \widehat{\theta} \in \{\underline{\theta}, \overline{\theta}\}$ with $\theta \neq \widehat{\theta}$. In equilibrium, firm i with signal $\Theta_i \in \{\underline{\theta}, \overline{\theta}, \varnothing\}$ expects to earn the profit $\pi_i^*(\Theta_i; s_i, s_j) \equiv x_i^*(\Theta_i; s_i, s_j)^2$.

The sign of $\left(\widehat{\theta} - \theta\right) \cdot \psi_i(s_i, s_j)$ determines the sign of $x_i^f(\theta) - x_i^*(\theta; s_i, s_j)$, since all other terms are positive for $i = 1, 2$. This observation is important for the firm's incentive to disclose information, which we analyze in the next subsection.

3.3.2 Equilibrium disclosure strategies

Now we analyze the firms' incentives to strategically disclose information. That is, we look for strategies (s_i^*, s_j^*) that are optimal given beliefs consistent with (s_i^*, s_j^*).

Suppose that firm i's beliefs are consistent with strategy s_j^*, and firm j has beliefs that are consistent with s_i^*. Given these beliefs, the expected profit of firm i with $\Theta_i = \theta$ from disclosure probability $s_i(\theta)$ equals:

$$\Pi_i(\theta, s_i; s_i^*, s_j^*) = \pi_i^f(\theta) + \left[1 - s_i(\theta)\right]\left[1 - a_j s_j^*(\theta)\right] \left(\pi_i^*(\theta; s_i^*, s_j^*) - \pi_i^f(\theta)\right). \tag{3.13}$$

Hence, the sign of firm i's marginal expected profit from changing $s_i(\theta)$ depends on the sign of the profit difference $\pi_i^f(\theta) - \pi_i^*(\theta; s_i^*, s_j^*)$. In turn, the sign of the output difference $x_i^f(\theta) - x_i^*(\theta; s_i, s_j)$ determines the sign of this profit difference, and thereby the incentive of firm i to disclose information θ.

We illustrate the firms' disclosure incentives in two extreme information disclosure constellations. First, we consider full disclosure (i.e., $s_i(\underline{\theta}) = s_i(\overline{\theta}) = 1$ for $i = 1, 2$). Firm i has the incentive to unilaterally deviate from full disclosure by concealing high-demand information. Such concealment reduces the competitor's output from $x_j^f(\overline{\theta})$ to $E\{x_j^f(\theta)\}$ if the competitor is uninformed, whereas it does not affect an informed competitor. The competitor's output reduction is profitable for firm i.

Second, we consider full concealment (i.e., $s_i(\underline{\theta}) = s_i(\overline{\theta}) = 0$ for $i = 1, 2$). With prior beliefs and *ex ante* symmetric firms (i.e., $a_i = a_j$), a firm has the incentive to unilaterally deviate from full concealment by disclosing a low demand intercept.[9] This relaxes competitive pressure from the competitor, and increases the disclosing firm's profit. By contrast, if the firms are asymmetric, i.e., a_i is low and a_j is high, firm i may want to deviate by disclosing a high demand intercept.[10] Yet, firm j has the incentive to unilaterally deviate from full concealment by disclosing a low intercept.[11]

These examples suggest that there is always a firm with an incentive to disclose only low demand information. This disclosure incentive is also present in equilibrium.

Proposition 2. *For any equilibrium, there exists a firm, i, such that this firm chooses the disclosure strategy $\left[s_i(\underline{\theta}), s_i(\overline{\theta})\right] = (1, 0)$.*

Hence, it is without loss of generality to restrict attention to equilibria in which one of the firms discloses only a low demand intercept. This simplifies the equilibrium analysis, and it yields the following characterization.

Proposition 3. ***(a)*** *There exists an equilibrium with symmetric disclosure choices (i.e., $\left[s_i^*(\underline{\theta}), s_i^*(\overline{\theta})\right] = (1, 0)$ for $i = 1, 2$) if and only if $q(\underline{\theta})a_j\left[2 + \delta\left(1 - a_i\right)\right] \leq 2$ for $i, j = 1, 2$ with $i \neq j$;*
(b) *For some $i, j = 1, 2$ with $i \neq j$, there exists an equilibrium with $\left[s_i^*(\underline{\theta}), s_i^*(\overline{\theta})\right] = (0, 1)$ if and only if $q(\underline{\theta})a_j(2 + \delta) \geq 2$;*

[9] It follows from (3.12) that $\psi_i([0, 0], [0, 0]) = 2(1 - a_j) - \delta(1 - a_i)a_j$ which is positive if $a_i = a_j$.

[10] For example, if $\theta = \overline{\theta}$, a_j is close to 1, and a_i is close to 0 (and both firms conceal all information), then firm j expects an output close to $E\{x_i^f(\theta)\}$ from firm i. In turn, firm i expects that firm j is informed and will set its output approximately according to the best reply $x_j(\overline{\theta}) = [\overline{\theta} - c_i - \delta E\{x_i^f(\theta)\}]/2$. This output is higher than the output which firm j sets after disclosure of high demand information by firm i (i.e., $x_j^f(\overline{\theta})$). In other words, the unilateral disclosure of $\Theta_i = \overline{\theta}$ allows firm i to set a higher output, and thereby to reach a higher profit level.

[11] Subsequently, firm i supplies the output $x_i^f(\underline{\theta})$ instead of the higher output $E\{x_i^f(\theta)\}$.

(c) *For some $i, j = 1, 2$ with $i \neq j$, there exists an equilibrium with $0 \leq s_i^*(\underline{\theta}) \leq 1$ and*

$$s_i^*(\overline{\theta}) = \frac{1}{a_i}\left(1 - \frac{\delta(1-a_i)q(\underline{\theta})a_j}{2\left[1 - q(\underline{\theta})a_j\right]}\right) \tag{3.14}$$

if and only if $2/(2+\delta) \leq q(\underline{\theta})a_j \leq 2/\left[2 + \delta(1-a_i)\right]$;
(d) *No other equilibrium exists.*

Proposition 2 implies that the equilibrium of Proposition 3(a) is the only symmetric disclosure equilibrium that can exist. In this equilibrium, the incentive to make a competitor pessimistic about the size of the market dominates. Proposition 3(a) gives two conditions for the existence of this equilibrium. In particular, the conditions hold if the distribution is not too skewed towards a low demand intercept (e.g., $q(\underline{\theta}) \leq \frac{2}{3}$).[12] Alternatively, if firms are symmetric (i.e., $a_i = a_j$), then Proposition 3(a) applies too.[13] Finally, product differentiation is favorable for the existence of the symmetric disclosure equilibrium. In particular, there exists a critical degree of substitutability, $\delta^* > 0$, such that the conditions of Proposition 3(a) are satisfied for all $\delta \leq \delta^*$.[14]

Conversely, the proposition shows that the equilibrium with symmetric disclosure choices need not always exist. In particular, if (i) the distribution of θ is skewed towards low intercepts (i.e., $q(\underline{\theta})$ is high), (ii) goods are close substitutes (i.e., δ is high), and (iii) it is very likely that one of the firms receives information while it is unlikely that the other firm receives information (e.g., a_j is high while a_i is low), then the symmetric disclosure equilibrium does not exist. Under those conditions, firm i has an incentive to unilaterally disclose good (conceal bad) news to make its rival realize (believe) that firm i will compete "aggressively" in the product market.

For intuition of these observations, suppose that the firms have beliefs consistent with the strategies $\left[s_i^*(\underline{\theta}), s_i^*(\overline{\theta})\right] = \left[s_j^*(\underline{\theta}), s_j^*(\overline{\theta})\right] = (1, 0)$, and firm j chooses the strategy $\left[s_j^*(\underline{\theta}), s_j^*(\overline{\theta})\right] = (1, 0)$. It is convenient to consider the extreme situation where $q(\underline{\theta}) = 1 - \varepsilon$, and $a_i = \varepsilon$, $a_j = 1 - \varepsilon$, with $\varepsilon > 0$ small. In this situation, an uninformed firm i would expect a demand intercept of approximately $\frac{1}{2}\left(\underline{\theta} + \overline{\theta}\right)$, and the firm would consider it approximately equally likely to compete with an informed

[12] In the rewritten condition $q(\underline{\theta}) \leq 2/\left(a_j\left[2 + \delta\left(1 - a_i\right)\right]\right)$, the right-hand side is decreasing in a_j and δ, and increasing in a_i. This implies that $2/\left(a_j\left[2 + \delta\left(1 - a_i\right)\right]\right) > 2/3$.

[13] For $a_i = a_j = a$, the conditions reduce to $q(\underline{\theta})a\left[2 + \delta\left(1 - a\right)\right] \leq 2$. This condition holds, since its left-hand side is increasing in a for $0 < a < 1$ and therefore $q(\underline{\theta})a\left[2 + \delta\left(1 - a\right)\right] < 2q(\underline{\theta}) < 2$.

[14] The condition's left-hand side is increasing in δ, and it is smaller than 2 for $\delta = 0$.

rival ($\Theta_j = \overline{\theta}$) as with an uninformed rival ($\Theta_j = \varnothing$).[15] Consequently, an uninformed firm i would supply approximately the amount $x_i^f\left(\frac{1}{2}\left(\underline{\theta}+\overline{\theta}\right)\right)$.[16]

First, we consider the incentive for firm i with $\Theta_i = \overline{\theta}$ to unilaterally deviate by *disclosing a high demand intercept.* If firm i were to conceal its information, then firm j would expect to compete almost surely with an uninformed rival (since a_i is small), who supplies $x_i^f\left(\frac{1}{2}\left(\underline{\theta}+\overline{\theta}\right)\right)$ units. By contrast, the disclosure of the high demand intercept makes firm j realize that it faces a strong competitor, who sets the output $x_i^f(\overline{\theta})$. Clearly, firm i's expected output from disclosure is greater than the expected output from concealment, i.e., $x_i^f(\overline{\theta}) > x_i^f\left(\frac{1}{2}\left(\underline{\theta}+\overline{\theta}\right)\right)$. Now, irrespective of whether firm i discloses or conceals, the competitor's best reply is approximately $2x_j \approx \overline{\theta} - c_j - \delta x_i$, since it is extremely likely that firm j is informed in the latter case (i.e., a_j is big). Whereas disclosure does not greatly affect firm j's beliefs about the demand, it has a substantial effect on firm j's beliefs about firm i's product market conduct. This gives firm j an incentive to contract its output. Hence, the unilateral disclosure of $\Theta_i = \overline{\theta}$ is profitable for firm i, given the proposed equilibrium beliefs.

Under the same conditions, firm i with bad signal $\Theta_i = \underline{\theta}$ has the incentive to *conceal bad news.* Here, firm i's strategy can only have an effect on the firms' product-market conduct, if firm j is uninformed. In this case, a similar intuition applies as before. Although firm i's strategy has a negligible effect on firm j's beliefs about demand, it has a substantial effect on the firm's beliefs about the competitive pressure from firm i.[17] Concealment makes uninformed firm j expect fierce quantity competition, and firm j reduces its output as a consequence. Firm j's lower output enables firm i to expand its output, and thereby increase its expected profit.

Proposition 3(b) shows that the deviation strategies from above can be equilibrium strategies. An asymmetric equilibrium can only exist if the intercept dis-

[15]This is due to the fact that both a_j and $q(\underline{\theta})$ are high. In particular, the posterior probability $Q_j(\overline{\theta};1,0)$ in (3.7) equals $1/(2-\varepsilon)$, and $A_j(\theta;1,0)$ in (3.5) gives $A_j(\underline{\theta};1,0) = 0$ and $A_j(\overline{\theta};1,0) = 1-\varepsilon$. Clearly, for $\varepsilon \to 0$, these probabilities converge to $Q_j(\overline{\theta};1,0) \to 1/2$ and $Q_j(\overline{\theta};1,0)A_j(\overline{\theta};1,0) \to 1/2$.

[16]An informed rival would know that the intercept is $\overline{\theta}$, whereas an uninformed rival would expect approximately the low intercept $\underline{\theta}$, since $q(\underline{\theta})$ is high and the concealment by firm i generates almost no additional information (a_i is low). Approximately, this gives the best reply functions: $2x_j(\overline{\theta}) \approx \overline{\theta} - c_j - \delta x_i(\varnothing)$ and $2x_j(\varnothing) \approx \underline{\theta} - c_j - \delta x_i(\varnothing)$ for firm j, and $2x_i(\varnothing) \approx (\underline{\theta}+\overline{\theta})/2 - c_i - \delta\left[x_j(\overline{\theta}) + x_j(\varnothing)\right]/2$ for firm i. Solving this system of equations gives $x_i^*(\varnothing; s_i^*, s_j^*) \approx x_i^f(\frac{1}{2}\left(\underline{\theta}+\overline{\theta}\right))$ for firm i.

[17]With or without disclosure by firm i, the competitor's best reply is approximately $2x_j \approx \underline{\theta} - c_j - \delta x_i$. This is due to the fact that a_i is low and $q(\underline{\theta})$ is high. In particular, the posterior probability $Q_i(\overline{\theta};1,0)$ in (3.7) equals $\varepsilon/\left[(1-\varepsilon)^2+\varepsilon\right]$, and $A_i(\theta;1,0)$ in (3.5) gives $A_i(\underline{\theta};1,0) = 0$ and $A_i(\overline{\theta};1,0) = \varepsilon$. Clearly, for $\varepsilon \to 0$, these probabilities converge to $Q_i(\overline{\theta};1,0) \to 0$ and $Q_i(\overline{\theta};1,0)A_i(\overline{\theta};1,0) \to 0$. Whereas firm j anticipates the competitor's output $x_i^f(\underline{\theta})$ after disclosure, it expects approximately the output $x_i^f\left(\frac{1}{2}\left(\underline{\theta}+\overline{\theta}\right)\right)$ after concealment.

tribution is skewed towards the low demand (i.e., $q(\underline{\theta}) > 2/(2+\delta)$ is a necessary condition).

Finally, Proposition 3(c) shows that there can exist equilibria in mixed strategies. As in part (b), an equilibrium in mixed strategies can only exist if the distribution of θ is skewed towards low intercepts (i.e., $q(\underline{\theta}) > 2/(2+\delta)$). Moreover, Proposition 3(c) implies that an equilibrium with full disclosure or full concealment by firm i only exists in special cases (respectively, if $q(\underline{\theta})a_j = 2/(2+\delta)$ or $q(\underline{\theta})a_j = 2/\left[2+\delta\left(1-a_i\right)\right]$).

Proposition 3 has the following implication for the uniqueness of an equilibrium.

Corollary 1. ***(a)*** *For $q(\underline{\theta})\max\{a_1, a_2\} < 2/(2+\delta)$, the firms choose symmetric disclosure strategies (i.e., $\left[s_i^*(\underline{\theta}), s_i^*(\overline{\theta})\right] = (1,0)$ for $i = 1, 2$) in the unique equilibrium.*
(b) *For $q(\underline{\theta})a_i < 2/(2+\delta)$ and $q(\underline{\theta})a_j > 2/\left[2+\delta\left(1-a_i\right)\right]$ where $i, j = 1, 2$ with $i \neq j$, the firms choose the strategies $\left[s_i^*(\underline{\theta}), s_i^*(\overline{\theta})\right] = (0,1)$ and $\left[s_j^*(\underline{\theta}), s_j^*(\overline{\theta})\right] = (1,0)$ in the unique equilibrium.*

Corollary 1(a) confirms the result of Darrough (1993). For the symmetric distribution (i.e., $q(\underline{\theta}) = \frac{1}{2}$) and symmetric probabilities of receiving an informative signal ($a_i = a_j$), the symmetric equilibrium is unique. In our setting with a binary type space, symmetry of the distribution is already sufficient for uniqueness.

In the setting where only one firm can become informed, we confirm Sankar (1995).

Corollary 2 (Sankar, 1995)**.** *If $a_j = 0$, then firm i chooses strategy $\left[s_i(\underline{\theta}), s_i(\overline{\theta})\right] = (1,0)$ in the unique equilibrium for $i, j = 1, 2$ with $i \neq j$.*[18]

In the context of a model with a symmetric distribution, Sankar (1995) argues that this result extends to settings with $a_j > 0$. Our contribution is to show that this argument depends on the symmetry of the distribution. In particular, if the distribution is sufficiently skewed towards a low intercept, then the equilibrium with symmetric disclosure choices may not be unique or may not exist (Corollary 1(b)).

3.3.3 Bertrand competition

This subsection analyzes the incentives of firms that compete in prices. Inverting the system of inverse demand functions gives the following direct demand function:

$$D_i(p_i, p_j; \theta) \equiv \frac{1}{1-\delta^2}\Bigg((1-\delta)\theta + \delta p_j - p_i\Bigg) \tag{3.15}$$

[18]Corollary 2 follows from the fact that (3.12) reduces to $\psi_i(s_i) = 2\left[1 - a_i s_i(\underline{\theta})\right]\left[1 - a_i s_i(\overline{\theta})\right] > 0$ for $a_j = 0$. Consequently, there only exists an equilibrium with $\left[s_i(\underline{\theta}), s_i(\overline{\theta})\right] = (1,0)$.

for $i, j = 1, 2$ with $i \neq j$. Maximizing the expected profit $\pi_i = (p_i - c_i)\, D_i(p_i, p_j; \theta)$ and solving for the equilibrium gives the following result by focusing on accommodating pricing strategies (i.e., the substitutability parameter δ is sufficiently low).

Proposition 4. *If a firm disclosed θ, then firm i sets the equilibrium price:*

$$p_i^f(\theta) \equiv \frac{(1-\delta)\theta + c_i}{2-\delta} + \frac{\delta(c_j - c_i)}{4-\delta^2}. \tag{3.16}$$

If no firm disclosed information, and firms i and j have beliefs consistent with s_j and s_i, respectively, then the equilibrium price of firm i with information $\Theta_i = \theta$ equals:

$$p_i^*(\theta; s_i, s_j) \equiv p_i^f(\theta) - \frac{\delta \frac{1-\delta}{2-\delta} p(\widehat{\theta}) \left(\theta - \widehat{\theta}\right) \psi_i^b(s_i, s_j)}{\mathcal{D}(s_i, s_j) \prod_{h=1}^{2} [1 - a_h s_h(\theta)]\, E\{1 - a_h s_h(\theta)\}} \tag{3.17}$$

where $\psi_i^b(\bullet) > 0$ and $\mathcal{D}(\bullet) > 0$ for $\theta, \widehat{\theta} \in \{\underline{\theta}, \overline{\theta}\}$ with $\theta \neq \widehat{\theta}$, and $i, j = 1, 2$ with $i \neq j$. The equilibrium price of an uninformed firm equals $p_i^*(\varnothing; s_i, s_j) = E_j\left\{p_i^*(\theta; s_i, s_j) | \varnothing; s_j\right\}$ for $i, j = 1, 2$ with $i \neq j$. Firm i chooses the strategy $\left[s_i(\underline{\theta}), s_i(\overline{\theta})\right] = (0, 1)$ in the unique equilibrium for $i = 1, 2$.

The intuition for this result is straightforward. The effects of information disclosure by Bertrand competitors reinforce each other, whereas demand disclosure by a Cournot competitor yields two conflicting effects. Disclosure of good news about the market size increases the competitor's price for two reasons. First, the competitor becomes more optimistic about the market opportunities (i.e., the demand), and raises its price. In addition, the competitor learns that the disclosing firm is informed about the fact that demand is high, and is therefore less "aggressive" than expected. Also this makes the competitor a softer price setter in the product market (strategic complements). The intuition for concealing bad news is analogous.

3.3.4 Hypotheses

Our theoretical results yield some hypotheses which we test afterwards. First, we derive the following testable hypothesis from Corollary 1 and Proposition 4.

Hypothesis 1. ***(a)*** *If demand is uniformly distributed ($q(\underline{\theta}) = \frac{1}{2}$) and firms compete in quantities (prices), then firms disclose information on low (high) demand intercepts more often than high (low) intercepts.*

(b) *If firms compete in quantities and the conditions of Corollary 1(b) are satisfied, then firm i (firm j) discloses information on high (low) demand intercepts more often than low (high) intercepts.*

Hypothesis 1(a) gives testable predictions for settings in which firms choose symmetric disclosure strategies in the unique equilibrium. Hypothesis 1(b) covers the settings in which the disclosure strategies differ in the unique equilibrium.

Second, we develop two testable hypotheses about the effects of information on the firms' product-market strategies.[19] If firms compete in quantities and the demand distribution is uniform (i.e., $q(\underline{\theta}) = \frac{1}{2}$), then firms choose the disclosure strategy $s_1 = s_2 = [1, 0]$ in the unique equilibrium (Proposition 3), and Proposition 1 gives:

$$x_i^*(\underline{\theta}; [1,0], [1,0]) < x_i^f(\underline{\theta}) < x_i^*(\varnothing; [1,0], [1,0]) < x_i^f(\overline{\theta}) < x_i^*(\overline{\theta}; [1,0], [1,0]) \quad (3.18)$$

for $i = 1, 2$. A firm's incentive to conceal $\overline{\theta}$ follows from the last inequality of (3.18). By contrast, under the conditions of Corollary 1(b), firm i discloses only high demand intercepts in the unique equilibrium, and its equilibrium outputs compare as follows:

$$x_i^f(\underline{\theta}) < x_i^*(\underline{\theta}; [0,1], [1,0]) < x_i^*(\varnothing; [0,1], [1,0]) < x_i^*(\overline{\theta}; [0,1], [1,0]) < x_i^f(\overline{\theta}). \quad (3.19)$$

Firm i's incentive to conceal $\underline{\theta}$ follows from the first inequality in (3.19). Similarly, if firms compete in prices, then Proposition 4 shows that both firms disclose only high demand intercepts in the unique equilibrium (i.e., $s_1 = s_2 = [0, 1]$), and prices can be ranked as follows (for $i = 1, 2$):

$$p_i^f(\underline{\theta}) < p_i^*(\underline{\theta}; [0,1], [0,1]) < p_i^*(\varnothing; [0,1], [0,1]) < p_i^*(\overline{\theta}; [0,1], [0,1]) < p_i^f(\overline{\theta}). \quad (3.20)$$

Firm i's incentive to conceal a low demand intercept follows from the first inequality in (3.20). We summarize these observations in the following hypothesis.

Hypothesis 2. *Consider firm i with an informative signal ($\Theta_i = \theta$).*
(a) *If demand is high ($\theta = \overline{\theta}$) and it is drawn from the uniform distribution ($q(\underline{\theta}) = \frac{1}{2}$), and firms compete in quantities, then the firm's output without information disclosure is greater than the output with information disclosure.*
If demand is low ($\theta = \underline{\theta}$), and ***(b)*** *firms compete in quantities and the conditions of Corollary 1(b) are satisfied, or* ***(c)*** *firms compete in prices, then firm i's product market choice without information disclosure is greater than the choice with disclosure.*

The inequalities (3.18)-(3.20) relate the equilibrium product-market strategy of an uninformed firm to the strategies under complete information in the following way.

[19] See the Mathematical Appendix for details on formal derivations.

Hypothesis 3. *The product-market choice of uninformed firm i is greater (smaller) than the choice of a firm with complete information about a low (high) demand, if:* ***(a)*** *firms compete in quantities and demand is uniformly distributed ($q(\underline{\theta}) = \frac{1}{2}$), or* ***(b)*** *firms compete in quantities and the conditions of Corollary 1(b) are satisfied, or*
(c) *firms compete in prices.*

The product-market choice of an uninformed firm is greater than the choice of a firm with complete information about a low demand intercept for the following reason. On the one hand, an uninformed firm is more optimistic about the demand than a firm that knows that demand is low. This gives an uninformed firm an incentive to choose a higher product-market variable. On the other hand, an uninformed firm expects tougher quantity (softer price) competition than a firm that faces a pessimistic competitor who knows that demand is low. This gives the uninformed firm an incentive to set a lower output (higher price). Under the conditions of Hypothesis 3(a)-(b), the former effect outweighs the latter, which yields $x_i^f(\underline{\theta}) < x_i^*(\varnothing; \cdot)$. Under Bertrand competition (Hypothesis 3(c)), the two effects reinforce each other, and give $p_i^f(\underline{\theta}) < p_i^*(\varnothing; \cdot)$. The comparison of the product-market choice of an uninformed firm with the choice of a firm with complete information about high demand is analogous.

Finally, we generate a testable hypothesis which relates to the effect of the likelihood of receiving information on a firm's equilibrium product-market choice.

Hypothesis 4. *For $i = 1, 2$, the product-market choice of firm i under incomplete information is decreasing in the firm's likelihood of receiving information, a_i, in the following instances.* ***(a)*** *Firms compete in quantities, demand is uniformly distributed ($q(\underline{\theta}) = \frac{1}{2}$), and the firm is uninformed ($\Theta_i = \varnothing$) or the firm received high-demand information ($\Theta_i = \overline{\theta}$) and $a_i \geq 0.3$.* ***(b)*** *Firms compete in prices.*

The likelihood a_i affects the beliefs of firm i's competitor. In particular, for beliefs consistent with the equilibrium strategy and information concealment, an increase of a_i has two effects. On the one hand, an uninformed Cournot (Bertrand) competitor becomes more optimistic (pessimistic) about the size of demand in the market, since it is more likely that firm i is informed and conceals good (bad) news. This gives the Cournot (Bertrand) competitor an incentive to expand his output (reduce his price). On the other hand, in a Cournot (Bertrand) duopoly, firm i's competitor expects that firm i is relatively more "aggressive," since it is more likely that firm i is informed about a high (low) demand intercept. This gives the competitor an incentive to reduce his output or price. If firms compete in quantities, and demand is uniformly distributed, the former effect dominates the latter effect, and firm i reduces its output in response to the competitor's output expansion. Under Bertrand competition, the two effects on the competitor's beliefs reinforce each other. Firm i's best reply to its competitor's lower price is to decrease its price as well.

3.4 Experimental analysis

We conduct a lab experiment in which participants play variants of the duopoly games from Sections 3.2 and 3.3.3. All sessions of our experiment were conducted in the *Cologne Laboratory for Economic Research* at the University of Cologne. The experiment has been programmed with the experimental software *z-Tree* (Fischbacher, 2007).

Participants were recruited via e-mail from a preselected subsample of 1,900 students with a considerable background in business administration or economics.[20] We used the *Online Recruitment System ORSEE* (Greiner, 2015) to randomly invite participants for the experiment. We held seven sessions with 30 participants each. The share of male (110) and female (100) participants was almost equal and the average age was 24.7 years. Each subject was allowed to participate in one session only.

We paid each subject € 2.50 for showing up. During the course of the experiment, subjects could earn additional money, dependent on their decisions. In the experiment, we used an experimental currency (ECU), which was converted to Euros (€) and paid in cash at the end of the experimental sessions. Average individual payments were approximately € 21 (including participation fee). Each session took about two hours.

We describe and motivate the experimental design before discussing the results.

3.4.1 Design

In the experiment, we simplify the model by imposing zero production costs ($c_1 = c_2 = 0$), we set $\underline{\theta} = 240$ and $\overline{\theta} = 300$, and we truncate the inverse demand function

[20] We invited students who were at least in their third semester and had been enrolled in one of the following courses of studies towards a Bachelor's, Master's or other comparable degree: business administration, business arithmetics, business informatics, economics, social sciences. The preselection from the pool of about 5,000 registered subjects has the following motivation. First, students with these backgrounds may be more representative of the business community than the general student population. Second, students with this background may have a greater ability to deal with the complexity of this game.

to avoid negative profits.[21] In contrast to the models of Sections 3.2 and 3.3.3, we restrict disclosure decisions to pure strategies (i.e., $s_i(\theta) \in \{0,1\}$ for any θ and i).[22]

Treatments. Each treatment has 30 participants, i.e., 15 subjects with the role of firm 1 and 15 subjects as firm 2. Subjects in each treatment of the experiment are randomly assigned to matching groups of six individuals. In each period, a subject is randomly assigned to another subject within his matching group, but the same pair is never matched in two consecutive periods. Subjects are made aware of the random matching, but they do not know the matching group size. This is done to avoid reciprocal behavior.[23]

We vary the strategic product-market variables, the degree of substitutability (δ), firm 1's likelihood of receiving information (a_1), the prior demand probability $q(\underline{\theta})$, and the exchange rate of ECU/€ across treatments, to test our hypotheses. The exchange rates vary such that the subjects' expected earnings remain constant across treatments. We keep $a_2 = 0.9$ across treatments. Table 3.1 lists the different variables and parameter values in our seven treatments. By using these parameter values, we focus on settings with unique equilibria.

Table 3.1: Treatment overview – parameter values

	Strategic variable	δ	a_1	a_2	$q(\underline{\theta})$	Exchange Rate	Date
Treatment 1 (T1)	output	1	0	0.9	0.5	28,000 ECU/€	12/04/2012
Treatment 2 (T2)	output	1	0.9	0.9	0.5	28,000 ECU/€	12/04/2012
Treatment 3 (T3)	output	1	0.3	0.9	0.5	28,000 ECU/€	12/05/2012
Treatment 4 (T4)	output	1	0.3	0.9	0.9	23,000 ECU/€	12/05/2012
Treatment 5 (T5)	output	$\frac{1}{2}$	0	0.9	0.5	40,000 ECU/€	22/07/2013
Treatment 6 (T6)	price	$\frac{1}{2}$	0	0.9	0.5	56,000 ECU/€	22/07/2013
Treatment 7 (T7)	price	$\frac{1}{2}$	0.9	0.9	0.5	56,000 ECU/€	22/07/2013

Treatments 1-4 adopt Cournot competition with homogeneous goods ($\delta = 1$). In Treatment 1, we use the uniform demand distribution (i.e., $q(\underline{\theta}) = 0.5$) and set

[21] That is, $\mathcal{P}_i^d(x_i, x_j) = \max\{\theta - x_i - \delta x_j, 0\}$. Since $\underline{\theta}$ and $\overline{\theta}$ are sufficiently close to each other, this restriction has no effect on the equilibrium, and it was only rarely binding in the experiment (<1%).

[22] This does not restrict the equilibrium strategies, since we aim to test the emergence of unique equilibria in pure strategies for all treatments. For the parameter choices of our treatments, mixed strategies affect the firm's choices neither along the equilibrium path, nor off the equilibrium path.

[23] With this matching procedure we especially aim to prevent collusion, since collusion is most likely in small groups with repeated interaction, e.g., see Huck et al. (2004).

$a_1 = 0$. This gives a model of unilateral disclosure, which is similar to one of the settings in Ackert et al. (2000).[24] With T1, we aim to replicate the findings of Ackert et al., and thereby test Hypotheses 1(a for quantity competition), 2(a) and 3(a).

In Treatment 2, we modify T1 such that both firms have the same likelihood of learning the demand intercept, i.e., $a_1 = 0.9$ and $q(\underline{\theta}) = 0.5$. In this *ex ante* symmetric setting, we aim to test whether multilateral selective disclosure occurs as predicted by Hypothesis 1(a). In addition, it allows us to compare quantities between different treatments, and study the effects of changing a_1 (Hypothesis 4(a)).

In Treatment 3, we set $a_1 = 0.3$ while everything else remains as in T1 and T2. With this treatment we can test whether multilateral selective disclosure of low demand occurs in asymmetric settings with uniformly distributed demand (Hypothesis 1(a)). Moreover, the comparisons with T1 and T2 give further insights in the effects of varying a_1 (Hypothesis 4(a)). T1-T3 allow us to test Hypotheses 2(a) and 3(a) too.

In Treatment 4, we modify T3 by setting $q(\underline{\theta}) = 0.9$, i.e., we introduce skewness of the demand distribution. This changes the unique equilibrium disclosure strategy of firm 1. Hypothesis 1(b) predicts that firm 1 discloses only a high demand intercept in T4, which we aim to verify. Further, we can test Hypotheses 2(b) and 3(b) by T4.

Treatments 5-7 adopt product differentiation ($\delta = \frac{1}{2}$). In Treatment 5, we modify T1 by introducing product differentiation (i.e., $a_1 = 0$, $q(\underline{\theta}) = 0.5$, and $\delta = \frac{1}{2}$). This allows us to verify whether the results from T1 are robust to a change in the degree of product substitutability (Hypotheses 1(a), 2(a) and 3(a)). In addition, T5 serves as a link between T1-T4 and T6-T7.

Treatments 6 and 7 adopt competition in prices (Bertrand competition) with differentiated goods. Here, we use the direct demand function $D_i(p_i, p_j; \theta) \equiv \theta + p_j - 2p_i$ for $i, j = 1, 2$ and $i \neq j$ (i.e., $\delta = \frac{1}{2}$). As in T5, Treatment 6 assumes unilateral disclosure. By comparing behavior in T6 with behavior in T5, we are able to study the effects of changing the strategic variable in the product market (Hypothesis 1(a)).

Finally, Treatment 7 extends T6 by adopting multilateral disclosure, i.e., $a_1 = 0.9$, and $q(\underline{\theta}) = 0.5$. In other words, a_1 increases from 0 to 0.9 by moving from T6 to T7, and thereby T7 is the Bertrand counterpart of T2 (Hypothesis 4(b)). In addition, T6-T7 yield data for testing Hypotheses 1(a for price competition), 2(c) and 3(c).

[24] Incentives in T1 and Ackert et al. (2000) are identical. Though, framing and procedures differ, e.g., Ackert et al. hold a Pen&Paper experiment and subjects learn about an industry-wide cost with three possible realizations.

Parts within each treatment. Each treatment consists of three different parts which are all slight modifications of the models from Sections 2 and 3.3. The three parts have different levels of complexity, as they introduce random variables and strategy choices step by step.

In Part I, subjects compete in a duopolistic market with full information (i.e., $a_1 = a_2 = 1$), and subjects make no disclosure choices (i.e., $s_1 = s_2 = 1$). This part consists of 20 independently repeated periods and is identical across treatments with the same intensity of competition.[25] At the beginning of each period, both subjects are informed about the realization of the random demand intercept θ. Subsequently, they simultaneously choose output levels (T1-T5) or prices (T6-T7) from the interval $[0, 300]$. At the end of each period, we give feedback concerning chosen outputs (prices), the subject's price (demand), and the subject's profit. To start each treatment with this simple part has several advantages. First, participants familiarize themselves with the duopoly game. This is important, since subjects are not equipped with calculators, payoff tables or other auxiliary means in our experiment.[26] Therefore, we expect more noisy and suboptimal behavior in initial periods. Second, we can use observations from Part I for investigations of general interest, e.g., it allows us to examine the intensity of competition and learning in a complete-information setting.

In Part II, we introduce incomplete information about the demand intercept, and we allow subjects to make disclosure choices. At the beginning of each period in this part, subjects 1 and 2 independently learn the intercept with probability a_1 and a_2, respectively, which varies across treatments. Subsequently, both subjects simultaneously make their disclosure decisions. Finally, subjects simultaneously set their output levels or prices and receive feedback as in Part I. We repeat this procedure for 50 independent periods, in order to increase the likelihood for all subjects to experience all possible states of information at least once.[27] Part II constitutes the core of our experiment, as it allows us to observe disclosure decisions and product-market choices for various realizations of random variables.

Part III consists of a single period. Here, subjects have to make a conditional disclosure decision prior to receiving their signal. That is, they formulate a full

[25] In T1-T3, Part I is *ex ante* identical. Part I of T4 is only strategically identical to Part I of T1-T3, since it has a different demand distribution. Part I of T6 is *ex ante* identical to Part I of T7.

[26] Requate and Waichman (2011), and Gürerk and Selten (2012) explore the effects of the provision of payoff tables in experimental oligopolies. They find that provision has a considerable effect on initial behavior and it makes collusion more likely to occur.

[27] The likelihood for specific informational settings is quite low in some treatments, due to a low a_1 or $q(\overline{\theta})$, since the demand intercept and signals are randomly drawn within all treatments.

disclosure strategy, $\left[s_i(\underline{\theta}), s_i(\overline{\theta})\right] \in \{0,1\} \times \{0,1\}$, indicating whether or not any particular demand intercept will be disclosed.[28] After posting the strategies, the intercept is drawn and messages are transferred. Finally, subjects simultaneously make their product-market choices, and receive feedback as in Parts I and II. The observed strategies of this part allow a deeper inquiry into the subjects' disclosure behavior.

3.4.2 Results

In this section, we make a descriptive analysis of the data generated by our experiment, and we test the hypotheses from the previous section.

Each treatment and subject role give 5 independent observations, since the 30 subjects are randomly matched in groups of 6 subjects. That is, an observation is the average of choices by subjects with a specific role over time in their matching group.[29]

As we only have a small number of observations we do not make normality assumptions. Instead, we analyze our data by using non-parametric tests. For comparisons within treatments, we use the Wilcoxon-Matched-Pairs-Signed-Rank test (Wilcoxon test), while we use the Mann-Whitney-Wilcoxon test (MWW test) for between-treatment comparisons.[30] Typically, we test directional hypotheses, and thus we use the one-sided version of the previous tests in those cases.

Observations from Part I – Complete information. In Part I of our experiment, the firms have complete information. Table 3.2 summarizes the equilibrium product-market choices under complete information for all treatments. Similarly, Table 3.3 lists the average product-market choices in Part I across treatments.

Table 3.2: Equilibrium product-market choices under complete information

	T1	T2	T3	T4	T5	T6	T7
low demand ($\theta = \underline{\theta}$)	80	80	80	80	96	80	80
high demand ($\theta = \overline{\theta}$)	100	100	100	100	120	100	100

Note: The choices in T1-T5 (T6-T7) are output levels (prices).

First, we test whether there are exogenous variations across treatments which are strategically identical in Part I (i.e., T1-T4 for Cournot competition with homogeneous goods, and T6-T7 for Bertrand competition with differentiated goods).

[28]The strategy method was initially used by Selten (1967).

[29]Hence, all product-market choices reported below refer to average levels of matching groups.

[30]For descriptions of the Wilcoxon and MWW tests, see, e.g., Siegel and Castellan (1988).

Table 3.3: Average product-market choices in Part I

	T1	T2	T3	T4	T5	T6	T7
low demand ($\theta = \underline{\theta}$)	85.8 (15.9)	86.2 (22.2)	86.9 (22.7)	87.9 (21.3)	94.6 (4.2)	76.1 (2.7)	83.8 (11.4)
high demand ($\theta = \overline{\theta}$)	108.4 (16.8)	107.6 (24.3)	111.5 (22.8)	114.2 (40.0)	127.9 (10.6)	102.6 (13.9)	112.0 (15.0)

Note: Standard deviations are reported in parentheses.
The choices in T1-T5 (T6-T7) are output levels (prices).

The choices in Table 3.3 are relatively close to the predictions of Table 3.2, and they do not differ much across strategically identical treatments. By using one-on-one treatment comparisons with the two-sided MWW test, we find no statistically significant differences between choices in any two strategically equivalent treatments. Hence, we attribute differences between treatments in Parts II and III solely to the parameter variations.

Next, we investigate the choices in Part I, by using pooled data from the *ex ante* identical Cournot treatments T1-T3, and the Bertrand treatments T6-T7. For the Cournot treatments, we can reject the hypothesis that chosen output levels are lower (i.e., less competitive) than the respective equilibrium outputs in Table 3.2.[31] In fact, the chosen outputs tend to be a bit more competitive than predicted.[32] For Bertrand competition with low demand, we do not find significant differences between chosen and predicted prices.[33] For high demand draws, we can reject the hypothesis that price choices are lower (i.e., more competitive) than predicted with weak statistical significance.[34] The latter result is mainly driven by initial periods, as we see next.

Finally, we examine the extent to which learning takes place. One reason for having Part I is to familiarize subjects with the product-market game. Therefore, we expect deviations from the Nash equilibria to diminish over time. To our surprise, the initial product-market choices of subjects are on average already close to the predictions of Table 3.2. For T1-T3, subjects choose an average output level of 86.7 (SD:10.9) in the first five instances with low demand, which significantly decreases to 84.11 (SD:7.9) in the later periods of Part I.[35] For high demand in T1-T3, subjects

[31] Wilcoxon tests, one-sided: p=0.0234 for low demand, p=0.0013 for high demand.

[32] Holt (1985) finds slighty more competitive behavior than predicted in his Cournot duopoly experiment too. Some subjects gave a "rivalistic" explanation, i.e., they are willing to take a small loss in order to harm the competitor. Huck et al. (1999) observe the same, especially when providing feedback about the competitors' quantities. Rivalistic behavior may explain our observations too.

[33] Wilcoxon test, two-sided (non-directional null-hypothesis), p=0.5751.

[34] Wilcoxon test, one-sided, p=0.0697.

[35] Wilcoxon test, one-sided, p=0.0219.

start with 109.4 units (SD:9.5) on average, and continue with 108.6 units (SD:9.1) in the subsequent periods. Those two output levels do not differ significantly. In T6-T7 with low demand, subjects start with average price 84.0 (SD:11.7) which is significantly higher than 75.8 (SD:7.9) in the subsequent periods.[36] With high demand, the average initial price 112.8 (SD:16.5) is significantly higher than the average price 101.7 (SD:13.2) in later instances.[37] Thus, the price (output) choices of Bertrand (Cournot) competitors become slightly more (less) "aggressive" in the course of Part I. The choices tend to converge to the predicted levels for both modes of competition.

Observations on Disclosure Choices (H1). Table 3.4 summarizes the unique equilibrium disclosure choices for T1-T7. Below we test whether the disclosure choices in our experiment are in line with these predictions.

Table 3.4: Disclosure frequencies in the unique equilibrium (in %)

	T1	T2	T3	T4	T5	T6	T7
Firm 1:							
low demand ($\Theta_1 = \underline{\theta}$)	—	100	100	0	—	—	0
high demand ($\Theta_1 = \overline{\theta}$)	—	0	0	100	—	—	100
Firm 2:							
low demand ($\Theta_2 = \underline{\theta}$)	100	100	100	100	100	0	0
high demand ($\Theta_2 = \overline{\theta}$)	0	0	0	0	0	100	100

Disclosure choices in Part II. Table 3.5 gives the average disclosure frequencies of the subjects who received an informative signal from nature in Part II of the experiment.[38] A pairwise comparison of the frequencies from the first and second rows, and from the third and fourth rows, suggests that firms in T1-T5 disclose a low demand intercept more frequently than a high demand intercept. By contrast, firms in T6-T7 appear to disclose a high demand intercept more frequently than a low intercept, as the theory predicts (Table 3.4). The following statistical results are in line with these qualitative observations.

[36] Wilcoxon test, one-sided, p=0.0184.

[37] Wilcoxon test, one-sided, p=0.0026.

[38] We also analyze whether subjects change their disclosure behavior over time. We compare the subjects' average disclosure frequency in the first five instances where the subjects received a particular informative signal with the frequency in the last five instances where they observed this signal. Although the disclosure frequencies appear to increase, the changes are not statistically significant in most cases. For details, see Tables 3.12-3.14 in Appendix 3.C.

Table 3.5: Disclosure frequencies in Part II (in %)

	T1	T2	T3	T4	T5	T6	T7
Firm 1:							
low demand ($\Theta_1 = \underline{\theta}$)	—	85.5 (17.5)	87.7 (9.9)	93.5 (13.3)	—	—	41.9 (13.9)
high demand ($\Theta_1 = \overline{\theta}$)	—	56.1 (25.4)	56.5 (19.5)	36.6 (30.9)	—	—	84.5 (21.2)
Firm 2:							
low demand ($\Theta_2 = \underline{\theta}$)	97.8 (1.6)	85.5 (17.5)	87.9 (9.3)	84.7 (16.5)	81.8 (11.1)	38.9 (22.3)	41.9 (13.9)
high demand ($\Theta_2 = \overline{\theta}$)	46.4 (9.9)	56.1 (25.4)	34.4 (27.8)	32.6 (22.1)	13.6 (14.1)	94.7 (4.0)	84.5 (21.2)

Note: Standard deviations are reported in parentheses.
In T2 and T7 we do not distinguish between firms as they are ex ante identical.

Result 1. ***(a)*** *In Cournot (Bertrand) markets with uniformly distributed demand, there is evidence that subjects disclose low (high) demand intercepts significantly more often than high (low) intercepts.*
(b) *In Cournot markets with skewed demand distribution and asymmetric signal distributions (T4), subjects with a high-demand signal show a lower than predicted frequency of disclosure.*

Hypothesis 1(a) predicts that Cournot (Bertrand) competitors with a uniform demand distribution disclose low (high) demand intercepts more frequently than high (low) intercepts. In line with this hypothesis, we find in the Cournot treatments T1-T3 and T5 significantly higher disclosure frequencies for subjects with low-demand information.[39] This result is consistent with a finding by Ackert et al. (2000) who examine a unilateral disclosure setting. In addition, we extend their finding to a setting with differentiated goods (T5), and to multilateral settings for symmetric (T2) as well as asymmetric signaling technologies (T3). Further, we find in T6-T7 that the frequencies of disclosing a high demand intercept are significantly higher than the frequencies of disclosing low demand.[40] This is in line with Hypothesis 1(a) too.

Hypothesis 1(b) predicts that firm 1 (firm 2) in T4 discloses high (low) demand intercepts more frequently than low (high) intercepts. We find that firm 1 discloses a low demand intercept significantly more often than a high intercept, and we obtain

[39]We used one-sided Wilcoxon tests. The p-value in each treatment comparison is 0.0215, which is the best possible value attainable given the number of independent observations.
[40]Wilcoxon tests, one-sided, p-values=0.0215.

a similar result for firm 2.[41] The latter result is consistent with Hypothesis 1(b), whereas the former result is not.

Result 1(a) suggests that the subjects understand that their disclosure reveals information to their competitor about the size of the market. That is, the subjects seem to understand the strategic value of managing the competitor's belief about the market. In addition, it gives experimental support for the theoretical finding that the disclosure behavior of Cournot competitors differs from that of Bertrand competitors (e.g., Darrough, 1993). However, there is no evidence that subjects understand that their disclosure reveals information about their own conduct, as Result 1(b) implies. These observations are consistent with the observations by Ackert et al. (2000). Also they find that subjects adjust their disclosure choices if they inform the competitor about the market (industry-wide information), whereas they do not adjust if disclosure informs the competitor about the discloser's conduct (firm-specific information). Ackert et al. make this observation in a model with unilateral disclosure of independently distributed costs, whereas we make our observation in a model with bilateral disclosure of a common demand intercept.

Disclosure choices in Part III. For a deeper inquiry of the disclosure behavior, we asked the participants in Part III of each treatment for a complete disclosure strategy. Table 3.6 gives the frequencies of the individual disclosure-strategy choices for each treatment and role in Part III. Out of the 90 participants who had to make a disclosure decision in the Cournot treatments T1-T3 and T5, 42 subjects choose to disclose only if demand is low, which is the equilibrium disclosure strategy. Another 39 (7) subjects choose to disclose all (no) demand intercepts. The high frequency of full-disclosure choices is in line with Cai and Wang (2006), who find that senders in a cheap-talk game tend to overcommunicate.[42] Just 2 subjects choose to disclose only a high demand intercept. In short, 90% of the subjects in Part III of T1-T3 and T5 disclose a low demand intercept, whereas less than 46% disclose a high intercept. This is in line with Hypothesis 1(a). Also the frequencies from the Bertrand treatments T6-T7 are in line with the aggregate disclosure predictions from Hypothesis 1(a), and they are consistent with our findings from Part II.[43]

[41] Wilcoxon tests, one-sided: p=0.0339 for firm 1, p=0.0215 for firm 2.

[42] Subjects may disclose all information if they lack sophistication to recognize the strategic role of information (Cai and Wang, 2006). Alternatively, subjects may have an aversion to deception (e.g., Gneezy, 2005), and they may interpret concealment as lying about the fact that they are informed. Finally, risk-averse subjects may disclose all information to eliminate strategic uncertainty.

[43] Out of the 45 subjects in T6-T7 who choose a disclosure strategy, 28 subjects choose to disclose only a high demand intercept, whereas no subject chooses to do the reverse. Further, 14 (3) subjects choose to disclose all (no) demand information. In other words, more than 93% of the subject choose to disclose a high demand intercept, whereas about 31% disclose a low intercept.

Table 3.6: Frequencies of disclosure choices in Part III (in %)

	T1	T2	T3	T4	T5	T6	T7
Firm 1's strategy							
"disclose nothing"	—	6.7	6.7	6.7	—	—	10
"disclose only low"	—	40	26.7	66.7	—	—	0
"disclose only high"	—	3.3	0	13.3	—	—	63.3
"disclose all"	—	50	66.7	13.3	—	—	26.7
Firm 1's disclosure frequency							
low demand	—	90	93.3	80	—	—	26.7
high demand	—	53.3	66.7	26.7	—	—	90
Firm 2's strategy							
"disclose nothing"	0	6.7	26.7	6.7	0	0	10
"disclose only low"	46.7	40	60	66.7	66.7	0	0
"disclose only high"	0	3.3	0	0	6.7	60	63.3
"disclose all"	53.3	50	13.3	26.7	26.7	40	26.7
Firm 2's disclosure frequency							
low demand	100	90	73.3	93.3	93.3	60	26.7
high demand	53.3	53.3	13.3	26.7	33.3	100	90

Note: In T2 and T7 we do not distinguish between firms as they are ex ante identical.

For T4, Hypothesis 1(b) predicts that firm 1 discloses a high demand intercept more frequently than a low intercept, whereas firm 2 does the reverse. However, Table 3.6 indicates that firm 1 chooses to disclose low-demand information more often (i.e., in 80% of the cases) than high-demand information (by less than 27% of the subjects).[44] Hence, the behavior of subjects in the role of firm 1 is inconsistent with the predicted behavior, whereas the behavior of firm 2 in T4 is consistent with our prediction.[45]

Observations on product-market choices.

Tables 3.7 and 3.8 summarize the average product-market choices in Part II of firm 1 and firm 2, respectively. These choices are output levels in T1-T5, whereas they are prices in T6-T7. We distinguish settings in which no messages were sent from settings of complete information. In the former situation, firms did neither send nor

[44]From the 15 subjects with the role of firm 1, there are 2 subjects who choose to disclose only high demand, whereas 10 subjects choose to do the reverse. There are 2 (1) subjects with the role of firm 1 who commit to disclosing all (no) information.

[45]Out of the 15 subjects with the role of firm 2, 10 subjects commit to disclosing only low demand intercepts, whereas no-one commits to the opposite strategy. Further, 4 (1) subjects in the role of firm 2 commit to disclose all (no) information. Hence, low demand intercepts are disclosed by 93% of the subjects, whereas high intercepts are disclosed by less than 27% of the subjects.

Table 3.7: Average product-market choices of Firm 1 in Part II

	Incomplete Information			Complete Information	
	$\Theta_1 = \underline{\theta}$	$\Theta_1 = \varnothing$	$\Theta_1 = \overline{\theta}$	$\theta = \underline{\theta}$	$\theta = \overline{\theta}$
T1	—	105.3 (7.7)	—	85.2 (7.8)	108.5 (10.8)
T2	too few obs.	95.0 (11.4)	108.0 (6.1)	81.6 (2.6)	101.8 (4.1)
T3	too few obs.	99.9 (3.9)	112.7 (1.6)	80.9 (3.4)	104.3 (5.3)
T4	too few obs.	90.9 (11.0)	107.3 (10.3)	79.6 (11.1)	99.9 (11.7)
T5	—	120.5 (12.5)	—	95.9 (6.6)	125.1 (7.6)
T6	—	79.2 (3.9)	—	74.3 (7.2)	105.7 (6.9)
T7	75.8 (7.4)	82.5 (9.2)	too few obs.	78.3 (6.7)	106.5 (6.0)

Note: Standard deviations are reported in parentheses.
In T2 and T7 we do not distinguish between firms as they are ex ante identical.
The choices in T1-T5 (T6-T7) are output levels (prices).

receive any informative message but they received a particular signal by nature. We list the average product-market choices for this setting in the first three columns of Tables 3.7 and 3.8.[46] We list the average product-market choices under complete information in the last two columns of Tables 3.7 and 3.8. Here, we pool data from instances in which firm 1, firm 2, and both firms sent an informative message.

Product-market choice of privately informed firms (H2). First, we analyze the effect of incomplete information on the product-market choices of informed firms. Our statistical analysis gives the following result.

Result 2. *In Cournot markets, there is evidence that subjects who are privately informed about high demand supply significantly more than subjects with complete information about high demand. In Bertrand markets, there is no significant difference between prices of subjects with private and complete information about low demand.*

The pairwise comparison between the third and fifth columns of Tables 3.7 and 3.8 for T1-T3 and T5 suggests that a firm with a high-demand signal chooses a higher output level under incomplete information than under complete information. This is consistent with Hypothesis 2(a), and it suggests that a firm with high-demand

[46] We do not have enough observations to give a meaningful average for subjects who have learned that demand is low (high) and have incomplete information in T1-T5 (respectively, T6-T7).

Table 3.8: Average product-market choices of Firm 2 in Part II

	Incomplete Information			Complete Information	
	$\Theta_2 = \underline{\theta}$	$\Theta_2 = \varnothing$	$\Theta_2 = \overline{\theta}$	$\theta = \underline{\theta}$	$\theta = \overline{\theta}$
T1	too few obs.	93.8 (6.3)	111.1 (9.4)	83.5 (4.5)	101.2 (11.2)
T2	too few obs.	95.0 (11.4)	108.0 (6.1)	81.6 (2.6)	101.8 (4.1)
T3	too few obs.	98.9 (10.1)	119.0 (24.4)	82.3 (4.6)	107.1 (11.7)
T4	too few obs.	92.8 (6.0)	109.4 (7.7)	77.9 (4.5)	110.1 (9.0)
T5	too few obs.	104.6 (4.3)	129.6 (11.3)	91.6 (7.2)	122.4 (17.9)
T6	76.3 (5.8)	87.5 (6.8)	too few obs.	80.8 (3.0)	104.3 (5.1)
T7	75.8 (7.4)	82.5 (9.2)	too few obs.	78.3 (6.7)	106.5 (6.0)

Note: Standard deviations are reported in parentheses.
In T2 and T7 we do not distinguish between firms as they are ex ante identical.
The choices in T1-T5 (T6-T7) are output levels (prices).

information may have indeed an incentive to conceal its information. We also test whether there is a statistically significant difference between the product-market choices under incomplete and complete information. The tests confirm that outputs differ significantly for both firms in T2 and T3.[47]

Hypothesis 2(b) predicts that a firm 1 with a low-demand signal in T4 chooses a lower output level under complete information than under incomplete information. This requires that firm 1 did not receive an informative message by its competitor and successfully learned the market demand by nature. This situation is unlikely to occur for three reasons. First, firm 2 learns the market demand with 90% probability, and it discloses low signals in equilibrium. Second, firm 1 has only a 30% probability of learning the market demand by nature. Finally, firm 1 often disclosed a low demand in the experiment. As a result, we lack sufficient observations to test Hypothesis 2(b).

With Bertrand competition, Hypothesis 2(c) predicts that the price of a firm with low-demand information is higher with incomplete information than with complete information. The pairwise comparison between the first and fourth columns of Tables 3.7 and 3.8 for T6 and T7 suggests that the reverse holds. However, from a statistical point of view, the prices do not differ significantly in either treatment.

[47] All p-values for the one-sided Wilcoxon tests in T2 and T3 are smaller than or equal to 0.0398. By contrast, the differences between $x_2^*(\overline{\theta};\cdot)$ and $x_2^f(\overline{\theta})$ are not significant in T1 (p-value=0.1124), and T4 (p-value=0.3429). Table 3.9 in Appendix 3.C gives all the p-values for these tests.

Product-market choices of uninformed firms (H3). Next, we characterize the output choices of uninformed firms. Hypothesis 3 predicts that the product-market choice of an uninformed firm should lie between the choices under complete information for T1-T3, T4 for firm 1, and T5-T7. That is, the entries in the second column are predicted to be greater (smaller) than the corresponding entries in the fourth (fifth) column of Tables 3.7 and 3.8. The qualitative pairwise comparisons of our data are consistent with the predicted rankings in all instances. Our statistical tests on the variable differences are largely in line with these observations, as we state below.

Result 3. *There is evidence that the product-market choices of uninformed subject i are significantly higher (lower) than the choices of subject i with complete information about a low (high) demand under the conditions of Hypothesis 3.*

We test whether and how the average product-market choice of an uninformed firm differs from the average product-market choices of a firm with complete information. The first and third (second and last) columns of Table 3.10 in Appendix 3.C give the p-values for these comparisons when demand is low (high). The statistical inference yields significant results in most cases.[48] Hence, our observations are in line with Hypothesis 3 in almost all cases.

The effect of a firm's own signal precision (H4). For the uniform demand distribution, Hypothesis 4 predicts that a firm's product-market choice under incomplete information tends to be decreasing in the firm's likelihood of receiving information. This is the case for an uninformed firm. In addition, it happens if a Cournot competitor is privately informed about high demand and it receives this information with a high likelihood, or a Bertrand competitor has private low-demand information.

In T1-T3, we vary firm 1's likelihood of receiving information (a_1) for a Cournot competitor with a uniform demand distribution (see Table 3.1). There is a *ceteris paribus* increase in firm 1's likelihood by moving from T1 ($a_1 = 0\%$) via T3 ($a_1 = 30\%$) to T2 ($a_1 = 90\%$). As Hypothesis 4(a) predicts, the qualitative comparison of the incomplete-information entries in rows T1, T3 and T2 of Table 3.7 suggests a decreasing pattern. Likewise, a_1 increases from 0 to 0.9 for a Bertrand competitor by switching from T6 to T7. In contrast to the prediction of Hypothesis 4(b), the

[48]Except for two tests, our results are significant with p-values smaller than or equal to 0.0398 for the one-sided Wilcoxon tests. The two exceptions emerge for the comparisons of output choices by uninformed subjects with output choices under complete information about high demand. There, our results are not significant in T2 (p-value=0.1124), and weakly significant for firm 1 in T3 (p-value=0.0690). Table 3.10 in Appendix 3.C gives all p-values for the one-sided Wilcoxon tests.

comparison of price choices under incomplete information (i.e., the second entry) in T6 and T7 of Table 3.7 suggests that firm 1's price increases in a_1. In addition to these qualitative comparisons, we perform statistical tests. This gives the following results.

Result 4. *In Cournot markets, there is weak evidence that the output of subject i is decreasing in the subject's likelihood of receiving information, a_i, if the subject remained uninformed or concealed high demand. In Bertrand markets, there is no significant difference between the prices set by subjects with different likelihoods of receiving information.*

First, the decrease of outputs chosen by an uninformed firm 1 is weakly significant if the firm's signal precision a_1 increases from 0% to 90%.[49] For smaller increases of a_1, the decrease in output is statistically insignificant (see the first column of Table 3.11 in Appendix 3.C for details). Second, also the decrease in output of privately informed firm 1 with $\Theta_1 = \overline{\theta}$ is weakly significant.[50] Hence, the qualitative and statistical comparisons are in line with the prediction from Hypothesis 4(a), although the statistical result is weak.

Hypothesis 4(b) predicts that firm 1's prices are decreasing in signal precision a_1, whereas the qualitative comparison of average price choices in T6 and T7 of Table 3.7 suggests the reverse. Although the MWW test indicate that these prices do not significantly differ from one another, our finding is not in line with Hypothesis 4(b).[51]

3.5 Conclusion

This paper analyzes a theoretical model and an experiment to examine voluntary disclosure of demand information and product-market strategies in duopoly.

The model extends some existing theoretical models dealing with simultaneous disclosure choices by duopolists by allowing firms to be asymmetric. We identify conditions for a Cournot duopoly under which firms choose the usual selective disclosure strategy, with disclosure of low demand and concealment of high demand. In addition, we give conditions under which one firm in an asymmetric Cournot duopoly chooses the reverse information-disclosure strategy in equilibrium. Further, we show that Bertrand competitors disclose high-demand information and conceal low demand.

[49] One-sided MWW test: p-value=0.0586.
[50] One-sided MWW test: p-value=0.0872.
[51] Two-sided MWW test: p-value=0.9168.

Our experiment considers information-disclosure and product-market choices, and the interaction between these choices too. The experiment's treatments consider unilateral disclosure, and bilateral disclosure in symmetric settings as well as asymmetric settings. Thereby, we replicate a result of Ackert et al. (2000), and we extend it by considering bilateral disclosure in addition to unilateral disclosure, Bertrand competition besides Cournot competition, and product differentiation.

A key finding is that subjects in the laboratory experiment often selectively disclose their information. This finding is robust to changes in the information structure, mode of competition, and the degree of product differentiation. On the one hand, the subjects' disclosure behavior suggests that the subjects understand that disclosed information informs their competitor about the competitor's demand. Their behavior suggests that they often try to manage expectations of their competitor about the size of the market demand to obtain a favorable product market choice of their competitor. On the other hand, the subjects in our experiment did not seem to grasp that their disclosed information also gives a signal to their competitor about their product-market conduct. In a different context, also Ackert et al. (2000) observe that subjects in the laboratory tend to ignore the signaling role of their information. They make this observation in a model with unilateral disclosure of independently distributed costs, whereas our model considers bilateral disclosure of a common demand intercept.

Moreover, our theoretical analysis tends to provide good qualitative predictions for behavior in a duopolistic product market with demand uncertainty. The product-market choices for subjects in our experiment tend to adjust to the subject's information, and they weakly adjust to the precision of information.

Our findings can be used as a starting point for understanding the impact of disclosure regulation on information transmission and product market competition. These theoretical and experimental findings can help to evaluate the effects of economic policy towards information exchange, such as competition policy or accounting rules.

3.A References

Ackert, L., Church, B., and Sankar, M., (2000). Voluntary Disclosure under Imperfect Competition: Experimental Evidence. *International Journal of Industrial Organization*, 18:81-105.

Benndorf, V., Kübler, D., and Normann, H-T. (2015). Privacy Concerns, Voluntary Disclosure of Information, and Unraveling: An Experiment. *European Economic Review*, 75:43-59.

Cai, H. and Wang, J. (2006). Overcommunication in Strategic Information Transmission Games. *Games and Economic Behavior*, 56:7-36.

Darrough, M.N. (1993). Disclosure Policy and Competition: Cournot vs. Bertrand. *The Accounting Review*, 68:534-561.

Dye, R.A. (1985). Disclosure of Nonproprietary Information. *Journal of Accounting Research*, 23:123-145.

Dye, R.A. (2001). An Evaluation of 'Essays on Disclosure' and the Disclosure Literature in Accounting. *Journal of Accounting and Economics*, 32:181-235.

Farrell, J. (1986). Voluntary Disclosure: Robustness of the Unraveling Result, and Comments on Its Importance. In Grieson, R.E., editor, *Antitrust and Regulation*, pages 91-103. Lexington, MA: Lexington Books.

Fischbacher, U. (2007). z-Tree: Zurich Toolbox for Ready–Made Economic Experiments. *Experimental Economics*, 10:171-180.

Gneezy, U. (2005). Deception: The Role of Consequences. *American Economic Review*, 95: 384-394.

Greiner, B. (2015). Subject Pool Recruitment Procedures: Organizing Experiments with ORSEE. *Journal of the Economic Science Association*, 1(1):114-125.

Gürerk, Ü., and Selten, R. (2012). The Effect of Payoff Tables on Experimental Oligopoly Behavior. *Experimental Economics*, 15:499-509.

Holt, C.A. (1985). An Experimental Test of the Consistent-Conjecture Hypothesis. *The American Economic Review*, 75:314-325.

Huck, S., Normann, H-T. and Oechssler, J. (1999). Learning in Cournot Oligopoly - An Experiment. *The Economic Journal*, 109: C80-C95.

Huck, S., Normann, H-T., and Oechssler, J. (2004). Two are few and four are many: Number Effects in Experimental Oligopolies. *Journal of Economic Behavior and Organization*, 53:435-466.

Hwang, H-S. (1993). Optimal Information Acquisition for Heterogenous Duopoly Firms. *Journal of Economic Theory*, 59:385-402.

Hwang, H-S. (1994). Heterogeneity and the Incentive to Share Information in Cournot Oligopoly Market. *International Economic Review*, 35:329-345.

Jansen, J. (2008). Information Acquisition and Strategic Disclosure in Oligopoly. *Journal of Economics and Management Strategy*, 17:113-148.

Jansen, J. and Pollak, A. (2015). Strategic Disclosure of Demand Information by Duopolists: Theory and Experiment. *Preprints of the Max Planck Institute for Research on Collective Goods 2015/09.*

Jin, G.Z., Luca, M., and Martin, D. (2015). Is No News (Perceived As) Bad News? An Experimental Investigation of Information Disclosure. *NBER Working Paper No. 21099.*

Jung, W-O., and Kwon, Y.K. (1988). Disclosure When the Market is Unsure of Information Endowment of Managers. *Journal of Accounting Research*, 26: 146-153.

King, R.R., and Wallin, D.E. (1991a). Market-Induced Information Disclosures: An Experimental Markets Investigation. *Contemporary Accounting Research*, 8:170-197.

King, R.R., and Wallin, D.E. (1991b). Voluntary Disclosures When Seller's Level of Information is Unknown. *Journal of Accounting Research*, 29:96-108.

Kühn, K-U. and Vives, X. (1995). *Information Exchanges among Firms and their Impact on Competition.* Luxembourg: Office for Official Publications of the European Communities.

Kühn, K-U. (2001). Fighting Collusion by Regulating Communication Between Firms. *Economic Policy*, 16: 167-204.

Milgrom, P.R. (1981). Good News and Bad News: Representation Theorems and Applications. *Bell Journal of Economics*, 12:380-391.

Milgrom, P.R. (2008). "What the Seller Won't Tell You: Persuasion and Disclosure in Markets. *Journal of Economic Perspectives*, 22:115-132.

Milgrom, P.R., and Roberts, J. (1986). Relying on the Information of Interested Parties. *RAND Journal of Economics*, 17:18-32.

Okuno-Fujiwara, M., Postlewaite, A., and Suzumura, K. (1990). Strategic Information Revelation. *Review of Economic Studies*, 57:25-47.

Pollak, A. (2012). Strategic Disclosure of Demand Information by Heterogeneous Duopolists: An Experimental Investigation. *Diploma thesis.*

Raith, M. (1996). A General Model of Information Sharing in Oligopoly. *Journal of Economic Theory*, 71:260-288.

Requate, T., and Waichman, I. (2011). A Profit Table or a Profit Calculator?: A Note on the Design of Cournot Oligopoly Experiments. *Experimental Economics*, 14:36-46.

Sankar, M.R. (1995). Disclosure of Predecision Information in a Duopoly. *Contemporary Accounting Research*, 11:829-859.

Selten, R. (1967). Die Strategiemethode zur Erforschung des eingeschränkt rationalen Verhaltens im Rahmen eines Oligopolexperimentes. In Sauermann, H., editor, *Beiträge zur Experimentellen Wirtschaftsforschung*, pages 136-168. Tübingen: J.C.B. Mohr (Paul Siebeck).

Siegel, S. and Castellan, N.J. (1988). *Nonparametric Statistics for the Behavioral Sciences - Second Edition.* New York: McGraw-Hill.

Verrecchia, R.E. (2001). Essays on Disclosure. *Journal of Accounting and Economics*, 32:97-180.

Vives, X. (1999). *Oligopoly Pricing: Old Ideas and New Tools.* Cambridge, MA: MIT Press.

3.B Mathematical appendix

Proofs of propositions

Proof of Proposition 1

The equilibrium output levels follow from solving the system of equations (3.9) and (3.8) for $\Theta_i \in \{\underline{\theta}, \overline{\theta}\}$ and $i, j = 1, 2$ with $i \neq j$.

Take $\theta, \widehat{\theta} \in \{\underline{\theta}, \overline{\theta}\}$ with $\theta \neq \widehat{\theta}$, and $i, j = 1, 2$ with $i \neq j$. Using (3.9) for firm j and the identity $Q_i(\theta; s_i) = 1 - Q_i(\widehat{\theta}; s_i)$, enables us to rewrite condition (3.8) for $\Theta_i = \theta$ as follows:

$$2x_i^*(\theta; s_i, s_j) = \theta - c_i - \delta x_j^*(\theta; s_j, s_i) + \delta \left[1 - A_j(\theta; s_j)\right] Q_i(\widehat{\theta}; s_i) \Delta_j(\theta; s_j, s_i) \quad (3.B.1)$$

where $\Delta_j(\theta; s_j, s_i) \equiv x_j^*(\theta; s_j, s_i) - x_j^*(\widehat{\theta}; s_j, s_i)$. After substituting an analogous condition of firm j for $x_j^*(\theta)$, we obtain the following:

$$\begin{aligned} x_i^*(\theta; s_i, s_j) = x_i^f(\theta) + \frac{\delta}{4 - \delta^2} \Big(& 2\left[1 - A_j(\theta; s_j)\right] Q_i(\widehat{\theta}; s_i) \Delta_j(\theta; s_j, s_i) \\ & - \delta \left[1 - A_i(\theta; s_i)\right] Q_j(\widehat{\theta}; s_j) \Delta_i(\theta; s_i, s_j) \Big) \end{aligned} \quad (3.B.2)$$

From (3.B.1) we derive the following expression for firm i's equilibrium output difference:

$$2\Delta_i(\theta; s_i, s_j) = \left(\theta - \widehat{\theta}\right) - \delta \left[A_j(\theta; s_j) Q_i(\widehat{\theta}; s_i) + A_j(\widehat{\theta}; s_j) Q_i(\theta; s_i)\right] \Delta_j(\theta; s_j, s_i)$$

Solving for firm i's equilibrium output difference, Δ_i, gives the following:

$$\Delta_i(\theta; s_i, s_j) = \quad (3.B.3)$$
$$\frac{\left(2 - \delta\left[A_j(\theta; s_j) Q_i(\widehat{\theta}; s_i) + A_j(\widehat{\theta}; s_j) Q_i(\theta; s_i)\right]\right)\left(\theta - \widehat{\theta}\right)}{4 - \delta^2 \left[A_j(\theta; s_j) Q_i(\widehat{\theta}; s_i) + A_j(\widehat{\theta}; s_j) Q_i(\theta; s_i)\right]\left[A_i(\theta; s_i) Q_j(\widehat{\theta}; s_j) + A_i(\widehat{\theta}; s_i) Q_j(\theta; s_j)\right]}$$

Equations (3.9), (3.B.2) and (3.B.3) define the equilibrium outputs of firm i if both firms do not disclose information. Now define $\mathcal{D}$ as in (3.10). By (3.B.2), (3.B.3), and (3.10), it is straightforward to show the following:

$$\frac{4-\delta^2}{\delta\left(\widehat{\theta}-\theta\right)}\mathcal{D}(s_i,s_j)\left[x_i^f(\theta)-x_i^*(\theta;s_i,s_j)\right]=$$

$$2\left[1-A_j(\theta;s_j)\right]Q_i(\widehat{\theta};s_i)\left[2-\delta A_i(\underline{\theta};s_i)Q_j(\overline{\theta};s_j)-\delta A_i(\overline{\theta};s_i)Q_j(\underline{\theta};s_j)\right]$$
$$-\,\delta\left[1-A_i(\theta;s_i)\right]Q_j(\widehat{\theta};s_j)\left[2-\delta A_j(\underline{\theta};s_j)Q_i(\overline{\theta};s_i)-\delta A_j(\overline{\theta};s_j)Q_i(\underline{\theta};s_i)\right]$$

By definitions (3.5) and (3.7), the components of the first term simplify as follows:

$$\begin{aligned}
\left[1-A_j(\theta;s_j)\right]Q_i(\widehat{\theta};s_i) &= \frac{1-a_j}{1-a_js_j(\theta)}\cdot\frac{q(\widehat{\theta})\left[1-a_is_i(\widehat{\theta})\right]}{E\{1-a_is_i(\theta)\}}\\
&= \frac{q(\widehat{\theta})\cdot(1-a_j)E\{1-a_js_j(\theta)\}\left[1-a_is_i(\underline{\theta})\right]\left[1-a_is_i(\overline{\theta})\right]}{\left[1-a_is_i(\theta)\right]\left[1-a_js_j(\theta)\right]E\{1-a_is_i(\theta)\}E\{1-a_js_j(\theta)\}}\\
&= \frac{q(\widehat{\theta})\cdot(1-a_j)E\{1-a_js_j(\theta)\}\left[1-a_is_i(\underline{\theta})\right]\left[1-a_is_i(\overline{\theta})\right]}{\prod_{h=1}^2\left[1-a_hs_h(\theta)\right]E\{1-a_hs_h(\theta)\}}
\end{aligned}$$

and (by using $Q_j(\underline{\theta};s_j)+Q_j(\overline{\theta};s_j)=1$)

$$\begin{aligned}
&A_i(\underline{\theta};s_i)Q_j(\overline{\theta};s_j)+A_i(\overline{\theta};s_i)Q_j(\underline{\theta};s_j)\\
&\quad=1-\left[1-A_i(\underline{\theta};s_i)\right]Q_j(\overline{\theta};s_j)-\left[1-A_i(\overline{\theta};s_i)\right]Q_j(\underline{\theta};s_j)\\
&\quad=1-\frac{1-a_i}{1-a_is_i(\underline{\theta})}\cdot\frac{q(\overline{\theta})\left[1-a_js_j(\overline{\theta})\right]}{E\{1-a_js_j(\theta)\}}-\frac{1-a_i}{1-a_is_i(\overline{\theta})}\cdot\frac{q(\underline{\theta})\left[1-a_js_j(\underline{\theta})\right]}{E\{1-a_js_j(\theta)\}}\\
&\quad=1-\frac{1-a_i}{E\{1-a_js_j(\theta)\}}\left(\frac{q(\overline{\theta})\left[1-a_js_j(\overline{\theta})\right]}{1-a_is_i(\underline{\theta})}+\frac{q(\underline{\theta})\left[1-a_js_j(\underline{\theta})\right]}{1-a_is_i(\overline{\theta})}\right)\\
&\quad=1-\frac{(1-a_i)E\left\{\left[1-a_is_i(\theta)\right]\left[1-a_js_j(\theta)\right]\right\}}{E\{1-a_js_j(\theta)\}\left[1-a_is_i(\underline{\theta})\right]\left[1-a_is_i(\overline{\theta})\right]}
\end{aligned}$$

The second term simplifies in a similar way. Hence, the equilibrium output $x_i^*(\theta;s_i,s_j)$ reduces to (3.11) where (3.12) defines ψ_i. This completes the proof.

Proof of Proposition 2

First, consider equilibrium strategies such that $\psi_j(s_j, s_i) = 0$. That is, suppose that firm j chooses $\left[s_j(\underline{\theta}), s_j(\overline{\theta})\right]$ in equilibrium, and the firm has beliefs consistent with the competitor's strategy $\left[s_i(\underline{\theta}), s_i(\overline{\theta})\right]$, such that firm j is indifferent between disclosure and concealment of its information. Using (3.12), the equation $\psi_j(s_j, s_i) = 0$ gives:

$$1 - a_j s_j(\overline{\theta}) = \frac{\delta a_i(1-a_j)q(\underline{\theta})\left[1 - a_i s_i(\underline{\theta})\right]\left[1 - a_j s_j(\underline{\theta})\right]\left[1 - s_i(\overline{\theta})\right]}{N} \tag{3.B.4}$$

where

$$N \equiv 2(1-a_i)E\{1 - a_i s_i(\theta)\}\left[1 - a_j s_j(\underline{\theta})\right] - \delta a_i(1-a_j)q(\overline{\theta})\left[1 - a_i s_i(\overline{\theta})\right]\left[1 - s_i(\underline{\theta})\right] \tag{3.B.5}$$

Inequality $1 - a_j s_j(\overline{\theta}) > 0$ implies that $N > 0$. Substitution of (3.B.4) in (3.12) gives:

$$\psi_i(s_i, s_j) = q(\underline{\theta})\left[1 - a_i s_i(\underline{\theta})\right]\left[1 - a_j s_j(\underline{\theta})\right](1-a_j)\frac{1}{N}\left[\delta(1-a_i)B + C\right]$$

where

$$B \equiv N + q(\overline{\theta})\delta a_i(1-a_j)\left[1 - a_i s_i(\overline{\theta})\right]\left[1 - s_i(\overline{\theta})\right] \tag{3.B.6}$$

and

$$\begin{aligned} C \;\equiv\;& 2\left[1 - a_i s_i(\overline{\theta})\right]\left(N + q(\overline{\theta})\delta a_i(1-a_j)\left[1 - a_i s_i(\underline{\theta})\right]\left[1 - s_i(\overline{\theta})\right]\right) \\ & -\delta^2(1-a_i)a_i\left[1 - a_j s_j(\underline{\theta})\right]\left[1 - s_i(\overline{\theta})\right]E\left\{1 - a_i s_i(\theta)\right\} \end{aligned} \tag{3.B.7}$$

It is straightforward to show that $\delta(1-a_i)B + C > 0$ for any s_i and s_j (see next section for details). This implies that if $\psi_j(s_j, s_i) = 0$, then $\psi_i(s_i, s_j) > 0$.

Second, consider equilibrium strategies such that $\psi_j(s_j, s_i) < 0$. That is, $[s_j(\underline{\theta}), s_j(\overline{\theta})] = (0, 1)$ in equilibrium and beliefs are consistent with this strategy and some strategy $\left[s_i(\underline{\theta}), s_i(\overline{\theta})\right]$. Using (3.12), the inequality $\psi_j(0, 1, s_i(\underline{\theta}), s_i(\overline{\theta})) < 0$ gives $a_j < a_j^H$ with:

$$a_j^H \equiv a_i \frac{q(\underline{\theta})\left[1 - a_i s_i(\underline{\theta})\right]\left[1 - s_i(\overline{\theta})\right] + q(\overline{\theta})\left[1 - a_i s_i(\overline{\theta})\right]\left[1 - s_i(\underline{\theta})\right]}{q(\overline{\theta})\left[1 - a_i s_i(\overline{\theta})\right]\left[1 - a_i s_i(\underline{\theta})\right]} \tag{3.B.8}$$

Suppose that $\psi_i(s_i(\underline{\theta}), s_i(\overline{\theta}), 0, 1) \leq 0$. By (3.12), this inequality gives $a_j \geq a_j^L$ with:

$$a_j^L \equiv \frac{2\left[1 - a_i s_i(\underline{\theta})\right]}{q(\overline{\theta})\left[2\left(1 - a_i s_i(\underline{\theta})\right) + \delta(1 - a_i)\right]} \tag{3.B.9}$$

Under these conditions, the existence of an equilibrium requires that $a_j^L \leq a_j^H$. By (3.B.8), (3.B.9) and $q(\underline{\theta}) = 1 - q(\overline{\theta})$, this inequality is equivalent to $\mathcal{A}(q(\overline{\theta})) \geq 0$, where:

$$\begin{aligned}
\mathcal{A}(q(\overline{\theta})) \quad \equiv \quad & \left(\left[1 - q(\overline{\theta})\right]\left[1 - a_i s_i(\underline{\theta})\right]\left[1 - s_i(\overline{\theta})\right] + q(\overline{\theta})\left[1 - a_i s_i(\overline{\theta})\right]\left[1 - s_i(\underline{\theta})\right]\right) \\
& \cdot a_i\left[2\left(1 - a_i s_i(\underline{\theta})\right) + \delta(1 - a_i)\right] - 2\left[1 - a_i s_i(\underline{\theta})\right]^2\left[1 - a_i s_i(\overline{\theta})\right]
\end{aligned}$$

Notice that $\mathcal{A}$ is linear in $q(\overline{\theta})$. Evaluating $\mathcal{A}$ for $q(\overline{\theta}) \to 1$ gives the following:

$$\begin{aligned}
\mathcal{A}(1) \quad &= \quad \left[1 - a_i s_i(\overline{\theta})\right] a_i\left[1 - s_i(\underline{\theta})\right]\left[2\left(1 - a_i s_i(\underline{\theta})\right) + \delta(1 - a_i)\right] \\
& \quad\quad -2\left[1 - a_i s_i(\underline{\theta})\right]^2\left[1 - a_i s_i(\overline{\theta})\right] \\
&= \quad \left[1 - a_i s_i(\overline{\theta})\right](1 - a_i)\left(\delta a_i\left[1 - s_i(\underline{\theta})\right] - 2\left[1 - a_i s_i(\underline{\theta})\right]\right) \\
&= \quad -\left[1 - a_i s_i(\overline{\theta})\right](1 - a_i)\left(2(1 - a_i) + (2 - \delta)a_i\left[1 - s_i(\underline{\theta})\right]\right) \\
&< \quad 0
\end{aligned}$$

Clearly, a_j^L in (3.B.9) is decreasing in $q(\overline{\theta})$, and the extreme value for $q(\overline{\theta})$ at which $a_j^L = 1$ equals $\underline{q} \equiv \frac{2[1 - a_i s_i(\underline{\theta})]}{2[1 - a_i s_i(\underline{\theta})] + \delta(1 - a_i)}$. Taking $q(\overline{\theta}) \to \underline{q}$ gives the following:

$$\begin{aligned}
\mathcal{A}(\underline{q}) \quad &= \quad \delta(1 - a_i)\left[1 - a_i s_i(\underline{\theta})\right] a_i\left[1 - s_i(\overline{\theta})\right] \\
& \quad\quad +2\left[1 - a_i s_i(\underline{\theta})\right]\left[1 - a_i s_i(\overline{\theta})\right] a_i\left[1 - s_i(\underline{\theta})\right] - 2\left[1 - a_i s_i(\underline{\theta})\right]^2\left[1 - a_i s_i(\overline{\theta})\right] \\
&= \quad -\left[1 - a_i s_i(\underline{\theta})\right]\left(2\left[1 - a_i s_i(\overline{\theta})\right](1 - a_i) - \delta(1 - a_i)a_i\left[1 - s_i(\overline{\theta})\right]\right) \\
&= \quad -\left[1 - a_i s_i(\underline{\theta})\right](1 - a_i)\left(2(1 - a_i) + (2 - \delta)\, a_i\left[1 - s_i(\overline{\theta})\right]\right) \\
&< \quad 0
\end{aligned}$$

Then, linearity of $\mathcal{A}$ in $q(\overline{\theta})$ implies that $\mathcal{A} < 0$ for all $\underline{q} \leq q(\overline{\theta}) < 1$. However, this implies that $a_j^L > a_j^H$, and therefore $\psi_i(s_i(\underline{\theta}), s_i(\overline{\theta}), 0, 1) \leq 0$ is not possible. In other words, if $\psi_j(0, 1, s_i(\underline{\theta}), s_i(\overline{\theta})) < 0$ in equilibrium, then $\psi_i(s_i(\underline{\theta}), s_i(\overline{\theta}), 0, 1) > 0$.

In conclusion, in any equilibrium there is always a firm i with $\psi_i(s_i, s_j) > 0$. Then it follows from Proposition 1 that $x_i^*(\underline{\theta}; s_i, s_j) < x_i^f(\underline{\theta})$ and $x_i^*(\overline{\theta}; s_i, s_j) > x_i^f(\overline{\theta})$, which implies that the optimal disclosure strategy for firm i is $\left[s_i(\underline{\theta}), s_i(\overline{\theta})\right] = (1, 0)$.

Derivations for proposition 2

Here we show that $\delta(1-a_i)B+C>0$, where B and C are defined in (3.B.6) and (3.B.7), respectively. We rewrite (3.B.6) as:

$$\begin{aligned}
B &= 2(1-a_i)E\{1-a_is_i(\theta)\}\left[1-a_js_j(\underline{\theta})\right] \\
&\quad +\delta q(\overline{\theta})\left[1-a_is_i(\overline{\theta})\right]a_i(1-a_j)\left[s_i(\underline{\theta})-s_i(\overline{\theta})\right]
\end{aligned}$$

and we rewrite (3.B.7) as follows:

$$\begin{aligned}
C &= 4\left[1-a_is_i(\overline{\theta})\right](1-a_i)E\{1-a_is_i(\theta)\}\left[1-a_js_j(\underline{\theta})\right] \\
&\quad -\delta^2a_i\left[1-s_i(\overline{\theta})\right](1-a_i)E\left\{1-a_is_i(\theta)\right\}\left[1-a_js_j(\underline{\theta})\right] \\
&\quad -2q(\overline{\theta})\left[1-a_is_i(\overline{\theta})\right]\delta a_i(1-a_j)\left[1-a_is_i(\overline{\theta})\right]\left[1-s_i(\underline{\theta})\right] \\
&\quad +2q(\overline{\theta})\left[1-a_is_i(\overline{\theta})\right]\delta a_i(1-a_j)\left[1-a_is_i(\underline{\theta})\right]\left[1-s_i(\overline{\theta})\right] \\
&= \left(4\left[1-a_is_i(\overline{\theta})\right]-\delta^2a_i\left[1-s_i(\overline{\theta})\right]\right)(1-a_i)E\{1-a_is_i(\theta)\}\left[1-a_js_j(\underline{\theta})\right] \\
&\quad +2\delta q(\overline{\theta})\left[1-a_is_i(\overline{\theta})\right]a_i(1-a_j)(1-a_i)\left[s_i(\underline{\theta})-s_i(\overline{\theta})\right] \\
&= (1-a_i)\cdot\left[\left(4-\delta^2\right)\left[1-a_is_i(\overline{\theta})\right]+\delta^2(1-a_i)\right]E\{1-a_is_i(\theta)\}\left[1-a_js_j(\underline{\theta})\right] \\
&\quad +(1-a_i)\cdot 2\delta q(\overline{\theta})\left[1-a_is_i(\overline{\theta})\right]a_i(1-a_j)\left[s_i(\underline{\theta})-s_i(\overline{\theta})\right]
\end{aligned}$$

Hence,

$$\begin{aligned}
\delta(1-a_i)B+C &= (1-a_i)(2+\delta)\cdot\left[(2-\delta)\left[1-a_is_i(\overline{\theta})\right]+\delta(1-a_i)\right] \\
&\quad \cdot E\{1-a_is_i(\theta)\}\left[1-a_js_j(\underline{\theta})\right] \\
&\quad +(1-a_i)(2+\delta)\cdot\delta q(\overline{\theta})\left[1-a_is_i(\overline{\theta})\right]a_i(1-a_j)\left[s_i(\underline{\theta})-s_i(\overline{\theta})\right] \\
&\geq (1-a_i)(2+\delta)\cdot 2(1-a_i)E\{1-a_is_i(\theta)\}\left[1-a_js_j(\underline{\theta})\right] \\
&\quad +(1-a_i)(2+\delta)\cdot\delta q(\overline{\theta})\left[1-a_is_i(\overline{\theta})\right]a_i(1-a_j)\left[s_i(\underline{\theta})-s_i(\overline{\theta})\right] \\
&> (1-a_i)(2+\delta)\cdot\delta q(\overline{\theta})\left[1-a_is_i(\overline{\theta})\right]a_i(1-a_j)\left[1-s_i(\underline{\theta})\right] \\
&\quad +(1-a_i)(2+\delta)\cdot\delta q(\overline{\theta})\left[1-a_is_i(\overline{\theta})\right]a_i(1-a_j)\left[s_i(\underline{\theta})-s_i(\overline{\theta})\right] \\
&= (1-a_i)(2+\delta)\cdot\delta q(\overline{\theta})\left[1-a_is_i(\overline{\theta})\right]a_i(1-a_j)\left[1-s_i(\overline{\theta})\right]\geq 0
\end{aligned}$$

where the first inequality follows from $1-a_is_i(\overline{\theta})\geq 1-a_i$, the second inequality follows from (3.B.5) and $N>0$, and the last inequality follows per definition.

Proof of proposition 3

Due to Proposition 2, we assume that firm j chooses disclosure strategy $\left[s_j^*(\underline{\theta}), s_j^*(\overline{\theta})\right]$ $= [1, 0]$, and firms have beliefs consistent with $\left[s_j^*(\underline{\theta}), s_j^*(\overline{\theta})\right]$ without loss of generality. Hence, we adopt this assumption throughout the proof. Then, for some strategy $S = \left[s_i(\underline{\theta}), s_i(\overline{\theta})\right]$, the function ψ_i from (3.12) reduces as follows:

$$\begin{aligned}\psi_i(S, [1, 0]) &= \delta(1 - a_i)(1 - a_j)\left(q(\underline{\theta})\left[1 - a_i s_i(\underline{\theta})\right](1 - a_j) + q(\overline{\theta})\left[1 - a_i s_i(\overline{\theta})\right]\right) \\ &\quad +2(1 - a_j)\left[1 - a_i s_i(\underline{\theta})\right]\left[1 - a_i s_i(\overline{\theta})\right]\left[q(\underline{\theta})(1 - a_j) + q(\overline{\theta})\right] \\ &\quad -\delta(1 - a_i)(1 - a_j)\left(q(\underline{\theta})\left[1 - a_i s_i(\underline{\theta})\right] + q(\overline{\theta})\left[1 - a_i s_i(\overline{\theta})\right]\right) \\ &= (1 - a_j)\left[1 - a_i s_i(\underline{\theta})\right] \\ &\quad \cdot \left(2\left[1 - a_i s_i(\overline{\theta})\right]\left[1 - q(\underline{\theta})a_j\right] - \delta(1 - a_i)q(\underline{\theta})a_j\right). \qquad (3.B.10)\end{aligned}$$

(a) Also assume that firms have beliefs consistent with $\left[s_i(\underline{\theta}), s_i(\overline{\theta})\right] = [1, 0]$. Then Proposition 1 implies that $x_i^*(\underline{\theta}; [1, 0], [1, 0]) \leq x_i^f(\underline{\theta})$ and $x_i^*(\overline{\theta}; [1, 0], [1, 0]) \geq x_i^f(\overline{\theta})$ if and only if $\psi_i([1, 0], [1, 0]) \geq 0$. It follows from (3.B.10) that $\psi_i(1, 0, 1, 0) \geq 0$ if and only if $2\left[1 - q(\underline{\theta})a_j\right] \geq \delta q(\underline{\theta})(1 - a_i)a_j$, which can be rewritten as $2 \geq q(\underline{\theta})a_j\left[2 + \delta(1 - a_i)\right]$.

(b) Now suppose that firms have beliefs consistent with $\left[s_i(\underline{\theta}), s_i(\overline{\theta})\right] = [0, 1]$. Then it follows from Proposition 1 that it is optimal for firm i to conceal $\Theta_i = \underline{\theta}$ and disclose $\Theta_i = \overline{\theta}$ if and only if $\psi_i([0, 1], [1, 0]) \leq 0$. By (3.B.10), the inequality $\psi_i([0, 1], [1, 0]) \leq 0$ holds if and only if $(2 + \delta)q(\underline{\theta})a_j \geq 2$.

(c) Here we assume that firms have beliefs consistent with some $\left[s_i^*(\underline{\theta}), s_i^*(\overline{\theta})\right]$. Then firm i is indifferent between disclosure and concealment if and only if $\psi_i([s_i^*(\underline{\theta}), s_i^*(\overline{\theta})],$ $[1, 0]) = 0$. Hence, (3.B.10) implies that the equation $\psi_i([s_i^*(\underline{\theta}), s_i^*(\overline{\theta})], [1, 0]) = 0$ is equivalent to $0 \leq s_i^*(\underline{\theta}) \leq 1$ and:

$$s_i^*(\overline{\theta}) = \frac{1}{a_i}\left(1 - \frac{\delta(1 - a_i)q(\underline{\theta})a_j}{2\left[1 - q(\underline{\theta})a_j\right]}\right)$$

Feasibility requires that $s_i^*(\overline{\theta}) \geq 0$, which the reduces to $q(\underline{\theta})a_j\left[2 + \delta(1 - a_i)\right] \leq 2$, and $s_i^*(\overline{\theta}) \leq 1$, which reduces to $q(\underline{\theta})a_j(2 + \delta) \geq 2$.

(d) Finally, firm i can neither strictly prefer to disclose all demand information, nor can the firm strictly prefer to conceal all information. This observation is due to the fact that (3.12) can only have a single sign. This completes the proof.

Proof of proposition 4

First, after disclosure of θ, profit maximization by firm i gives the best reply function $p_i = \frac{1}{2}\left[(1-\delta)\theta + c_i + \delta p_j\right]$ for $i, j = 1, 2$ with $i \neq j$. Solving the system of equations yields the equilibrium price (3.16). Second, if no firm disclosed information, and the firms have beliefs consistent with the disclosure strategies (s_j, s_i), then firm i's first-order condition is:

$$2p_i^*(\Theta_i){=}(1{-}\delta)E_j\{\theta|\Theta_i; s_j\}{+}c_i{+}\delta E_j\left\{A_j(\theta; s_j)p_j^*(\theta) + [1 - A_j(\theta; s_j)]\, p_j^*(\varnothing)\middle|\, \Theta_i; s_j\right\} \tag{3.B.11}$$

for $i, j = 1, 2$ with $i \neq j$, and $\Theta_i \in \{\underline{\theta}, \overline{\theta}, \varnothing\}$ where $E_j\{\theta|\theta; s_j\} = \theta$. This condition implies that $p_j^*(\varnothing; s_j, s_i) = E_i\left\{p_j^*(\theta; s_j, s_i)\middle|\, \varnothing; s_i\right\}$. Using this equation and the identity $Q_i(\theta; s_i) = 1 - Q_i(\widehat{\theta}; s_i)$, enables me to rewrite condition (3.B.11) for $\Theta_i = \theta$ as follows (for $\theta, \widehat{\theta} \in \{\underline{\theta}, \overline{\theta}\}$ with $\theta \neq \widehat{\theta}$, and $i, j = 1, 2$ with $i \neq j$):

$$2p_i^*(\theta; s_i, s_j) = (1-\delta)\theta + c_i + \delta p_j^*(\theta; s_j, s_i) - \delta\left[1 - A_j(\theta; s_j)\right] Q_i(\widehat{\theta}; s_i)\Delta_j^b(\theta; s_j, s_i) \tag{3.B.12}$$

where $\Delta_j^b(\theta; s_j, s_i) \equiv p_j^*(\theta; s_j, s_i) - p_j^*(\widehat{\theta}; s_j, s_i)$. After substituting an analogous condition of firm j for $p_j^*(\theta)$, I obtain the following:

$$\begin{aligned} p_i^*(\theta; s_i, s_j){=}p_i^f(\theta) - \frac{\delta}{4-\delta^2}\Big(&2\left[1 - A_j(\theta; s_j)\right] Q_i(\widehat{\theta}; s_i)\Delta_j^b(\theta; s_j, s_i) \\ &+ \delta\left[1 - A_i(\theta; s_i)\right] Q_j(\widehat{\theta}; s_j)\Delta_i^b(\theta; s_i, s_j)\Big) \end{aligned} \tag{3.B.13}$$

From (3.B.12) I derive the following expression for firm i's price difference in equilibrium:

$$2\Delta_i^b(\theta; s_i, s_j) = (1{-}\delta)\left(\theta - \widehat{\theta}\right){+}\delta\left[A_j(\theta; s_j)Q_i(\widehat{\theta}; s_i) + A_j(\widehat{\theta}; s_j)Q_i(\theta; s_i)\right]\Delta_j^b(\theta; s_j, s_i)$$

for $\theta, \widehat{\theta} \in \{\underline{\theta}, \overline{\theta}\}$ with $\theta \neq \widehat{\theta}$, and $i, j = 1, 2$ with $i \neq j$. Solving for firm i's price difference, Δ_i^b, gives the following:

$$\Delta_i^b(\theta; s_i, s_j) = \frac{(1-\delta)\left(2 + \delta\left[A_j(\theta; s_j)Q_i(\widehat{\theta}; s_i) + A_j(\widehat{\theta}; s_j)Q_i(\theta; s_i)\right]\right)\left(\theta - \widehat{\theta}\right)}{\mathcal{D}(s_i, s_j)} \tag{3.B.14}$$

with $\mathcal{D}(s_i, s_j)$ as defined in (3.10), and for $\theta, \widehat{\theta} \in \{\underline{\theta}, \overline{\theta}\}$ with $\theta \neq \widehat{\theta}$, and $i, j = 1, 2$ with $i \neq j$. Equations (3.B.13) and (3.B.14) define the equilibrium outputs of informed firm i if both firms do not disclose information.

By (3.B.13), (3.B.14), it is straightforward to show that the following holds for any $\theta, \widehat{\theta} \in \{\underline{\theta}, \overline{\theta}\}$ with $\theta \neq \widehat{\theta}$, and $i, j = 1, 2$ with $i \neq j$:

$$
\begin{aligned}
&\frac{(4-\delta^2)\,\mathcal{D}(s_i,s_j)}{\delta(1-\delta)\left(\theta-\widehat{\theta}\right)}\left[p_i^*(\theta;s_i,s_j)-p_i^f(\theta)\right] = \\
&\qquad -2\left[1-A_j(\theta;s_j)\right]Q_i(\widehat{\theta};s_i)\left(2+\delta\left[A_i(\theta;s_i)Q_j(\widehat{\theta};s_j)+A_i(\widehat{\theta};s_i)Q_j(\theta;s_j)\right]\right) \\
&\qquad -\delta\left[1-A_i(\theta;s_i)\right]Q_j(\widehat{\theta};s_j)\left(2+\delta\left[A_j(\theta;s_j)Q_i(\widehat{\theta};s_i)+A_j(\widehat{\theta};s_j)Q_i(\theta;s_i)\right]\right)
\end{aligned}
$$

As in the proof of Proposition 1, the components of the first term can be simplified by observing the following:

$$
\left[1-A_j(\theta;s_j)\right]Q_i(\widehat{\theta};s_i) = \frac{q(\widehat{\theta})\cdot(1-a_j)E\{1-a_js_j(\theta)\}\left[1-a_is_i(\underline{\theta})\right]\left[1-a_is_i(\overline{\theta})\right]}{\prod_{h=1}^{2}\left[1-a_hs_h(\theta)\right]E\{1-a_hs_h(\theta)\}}
$$

$$
A_i(\theta;s_i)Q_j(\widehat{\theta};s_j)+A_i(\widehat{\theta};s_i)Q_j(\theta;s_j) = 1-\frac{(1-a_i)E\left\{\left[1-a_is_i(\theta)\right]\left[1-a_js_j(\theta)\right]\right\}}{E\{1-a_js_j(\theta)\}\left[1-a_is_i(\underline{\theta})\right]\left[1-a_is_i(\overline{\theta})\right]}
$$

The second term simplifies in a similar way. Hence, the equilibrium price of firm i reduces to (3.17), where:

$$
\begin{aligned}
\psi_i^b(s_i,s_j) \;\equiv\;& 2\left[1-a_is_i(\underline{\theta})\right]\left[1-a_is_i(\overline{\theta})\right](1-a_j)E\{1-a_js_j(\theta)\} \\
&+\delta(1-a_i)E\{1-a_is_i(\theta)\}\left[1-a_js_j(\underline{\theta})\right]\left[1-a_js_j(\overline{\theta})\right] \\
&-\delta(1-a_i)E\left\{\left[1-a_is_i(\theta)\right]\left[1-a_js_j(\theta)\right]\right\}(1-a_j). \qquad (3.B.15)
\end{aligned}
$$

Clearly, the first term of (3.B.15) is positive. The sum of the second and third terms of (3.B.15) is non-negative, since:

$$
\begin{aligned}
&E\{1-a_is_i(\theta)\}\left[1-a_js_j(\underline{\theta})\right]\left[1-a_js_j(\overline{\theta})\right]-E\left\{\left[1-a_is_i(\theta)\right]\left[1-a_js_j(\theta)\right]\right\}(1-a_j) \\
&\quad= q(\underline{\theta})\left[1-a_is_i(\underline{\theta})\right]\left[1-a_js_j(\underline{\theta})\right]\left(\left[1-a_js_j(\overline{\theta})\right]-(1-a_j)\right) \\
&\qquad+q(\overline{\theta})\left[1-a_is_i(\overline{\theta})\right]\left[1-a_js_j(\overline{\theta})\right]\left(\left[1-a_js_j(\underline{\theta})\right]-(1-a_j)\right) \\
&\quad= q(\underline{\theta})\left[1-a_is_i(\underline{\theta})\right]\left[1-a_js_j(\underline{\theta})\right]a_j\left[1-s_j(\overline{\theta})\right] \\
&\qquad+q(\overline{\theta})\left[1-a_is_i(\overline{\theta})\right]\left[1-a_js_j(\overline{\theta})\right]a_j\left[1-s_j(\underline{\theta})\right] \\
&\quad\geq 0.
\end{aligned}
$$

Hence, $\psi_i^b(s_i,s_j) > 0$ for any (s_i,s_j).

Finally, it is easy to derive the equilibrium profits of firm i with $\Theta_i = \theta$ by using the first-order conditions. In particular, the equilibrium profit is $\pi_i^f(\theta) \equiv \frac{1}{1-\delta^2}\left(p_i^f(\theta)-c_i\right)^2$ after disclosure, and it is $\pi_i^*(\theta;s_i,s_j) \equiv \frac{1}{1-\delta^2}\left(p_i^*(\theta;s_i,s_j)-c_i\right)^2$

after no disclosure. Hence, firm i's profit from disclosure is $\pi_i^f(\theta)$, while the firm's expected profit from concealment of θ is $a_j s_j(\theta)\pi_i^f(\theta) + [1 - a_j s_j(\theta)]\, \pi_i^*(\theta; s_i, s_j)$. Consequently, the firm prefers disclosure if and only if $p_i^f(\theta) > p_i^*(\theta; s_i, s_j)$. From (3.17) it follows that $p_i^*(\underline{\theta}; s_i, s_j) > p_i^f(\underline{\theta})$ and $p_i^*(\overline{\theta}; s_i, s_j) < p_i^f(\overline{\theta})$ for any (s_i, s_j), which implies that $\left[s_i(\underline{\theta}), s_i(\overline{\theta})\right] = (0, 1)$ is the dominant disclosure strategy for firm i (for $i = 1, 2$). This completes the proof.

Derivations for hypotheses

Hypotheses 1 and 2 follow immediately from the propositions. Below we provide the analytical derivations that underpin Hypotheses 3 and 4, respectively.

Derivations for hypothesis 3

(a) First, we show that if $q(\underline{\theta}) = \frac{1}{2}$, then $x_i^*(\varnothing; [1,0], [1,0]) < x_i^f(\overline{\theta})$. If $q(\underline{\theta}) = \frac{1}{2}$, then we can rewrite the uninformed firm's equilibrium output as follows:

$$\begin{aligned}
x_i^*(\varnothing; [1,0], [1,0]) &= E_j \left\{ x_i^*(\theta; [1,0], [1,0]) | \, \varnothing; [1,0] \right\} \\
&= q_j(\underline{\theta}; 1, 0) x_i^f(\underline{\theta}) + q_j(\overline{\theta}; 1, 0) x_i^f(\overline{\theta}) \\
&\quad - \left(\frac{q_j(\underline{\theta}; 1, 0)}{(1 - a_i)(1 - a_j)} - q_j(\overline{\theta}; 1, 0) \right) \frac{\frac{\delta}{4 - \delta^2} \frac{1}{2} \left(\overline{\theta} - \underline{\theta} \right) \psi_i([1,0],[1,0])}{\mathcal{D}([1,0],[1,0]) \left(1 - \frac{1}{2} a_i\right) \left(1 - \frac{1}{2} a_j\right)} \\
&= E_j \left\{ x_i^f(\theta) \middle| \, \varnothing; [1,0] \right\} - \frac{\frac{a_i}{1 - a_i} \frac{\delta}{4 - \delta^2} \frac{1}{4} \left(\overline{\theta} - \underline{\theta} \right) \psi_i([1,0],[1,0])}{\mathcal{D}([1,0],[1,0]) \left(1 - \frac{1}{2} a_i\right) \left(1 - \frac{1}{2} a_j\right)^2} \\
&< E_j \left\{ x_i^f(\theta) \middle| \, \varnothing; [1,0] \right\} < x_i^f(\overline{\theta}).
\end{aligned}$$

Second, we show that if $q(\underline{\theta}) = \frac{1}{2}$, then $x_i^f(\underline{\theta}) < x_i^*(\varnothing; [1,0], [1,0])$. As we show above, we can rewrite $x_i^*(\varnothing; [1,0], [1,0])$ as follows if $q(\underline{\theta}) = \frac{1}{2}$:

$$\begin{aligned}
x_i^*(\varnothing; [1,0], [1,0]) &= E_j \left\{ x_i^f(\theta) \middle| \, \varnothing; [1,0] \right\} - \frac{\frac{a_i}{1 - a_i} \frac{\delta}{4 - \delta^2} \frac{1}{4} \left(\overline{\theta} - \underline{\theta} \right) \psi_i([1,0],[1,0])}{\mathcal{D}([1,0],[1,0]) \left(1 - \frac{1}{2} a_i\right) \left(1 - \frac{1}{2} a_j\right)^2} \\
&= x_i^f(\underline{\theta}) + q_j(\overline{\theta}; 1, 0) \left[x_i^f(\overline{\theta}) - x_i^f(\underline{\theta}) \right] \\
&\quad - \frac{\frac{a_i}{1 - a_i} \frac{\delta}{(2 - \delta)(2 + \delta)} \frac{1}{4} \left(\overline{\theta} - \underline{\theta} \right) \psi_i([1,0],[1,0])}{\mathcal{D}([1,0],[1,0]) \left(1 - \frac{1}{2} a_i\right) \left(1 - \frac{1}{2} a_j\right)^2} \\
&= x_i^f(\underline{\theta}) + \frac{\frac{1}{2} \left(\overline{\theta} - \underline{\theta} \right)}{\left(1 - \frac{1}{2} a_j\right)(2 + \delta)} \left(1 - \frac{\frac{a_i}{1 - a_i} \frac{\delta}{2 - \delta} \frac{1}{2} \psi_i([1,0],[1,0])}{\mathcal{D}([1,0],[1,0]) \left(1 - \frac{1}{2} a_i\right) \left(1 - \frac{1}{2} a_j\right)} \right)
\end{aligned}$$

which exceeds $x_i^f(\underline{\theta})$, since

$$\frac{a_i}{1-a_i}\delta\frac{1}{2}\psi_i([1,0],[1,0]) - (2-\delta)\mathcal{D}([1,0],[1,0])\left(1-\frac{1}{2}a_i\right)\left(1-\frac{1}{2}a_j\right) < 0.$$

The latter follows from a basic analysis of the inequality's left-hand-side. We can rewrite it as follows:

$$\begin{aligned} LHS &= \frac{1}{2}\delta a_i(1-a_j)\left[2\left(1-\frac{1}{2}a_j\right)+\frac{1}{2}\delta\left[1+(1-a_i)(1-a_j)\right]-\delta\left(1-\frac{1}{2}a_i\right)\right] \\ &\quad -(2-\delta)\left[4\left(1-\frac{1}{2}a_i\right)\left(1-\frac{1}{2}a_j\right)-\frac{1}{4}\delta^2 a_i a_j(1-a_i)(1-a_j)\right] \end{aligned}$$

This expression is convex in a_i, and it is negative, since it is negative for the extreme values of a_i. In particular, if we evaluate the expression for $a_i = 0$, then it reduces to $-(2-\delta)4\left(1-\frac{1}{2}a_j\right) < 0$. Moreover, if we evaluate the expression for $a_i = 1$, then we obtain: $2\left(1-\frac{1}{2}a_j\right)\left[\frac{1}{2}\delta(1-a_j)-(2-\delta)\right] \leq -\left(1-\frac{1}{2}a_j\right)(1+a_j) < 0$.

(b) Second, we show that $x_i^f(\underline{\theta}) < x_i^*(\varnothing;[0,1],[1,0]) < x_i^f(\overline{\theta})$ holds for firm i if the conditions of Corollary 1(b) are satisfied. Under these conditions, $\psi_i^b([0,1],[1,0]) < 0$, which implies that $x_i^f(\underline{\theta}) < x_i^*(\underline{\theta};[0,1],[1,0])$ and $x_i^*(\overline{\theta};[0,1],[1,0]) < x_i^f(\overline{\theta})$. Furthermore, equation (3.B.3) in the proof of Proposition 1 gives $\Delta_i(\overline{\theta};[0,1],[1,0]) > 0$, which implies that $x_i^*(\underline{\theta};[0,1],[1,0]) < x_i^*(\overline{\theta};[0,1],[1,0])$. Hence, the following inequality emerges:

$$x_i^f(\underline{\theta}) < x_i^*(\underline{\theta};[0,1],[1,0]) < x_i^*(\overline{\theta};[0,1],[1,0]) < x_i^f(\overline{\theta}).$$

Due to (3.9), the output $x_i^*(\varnothing;[0,1],[1,0])$ is a convex combination of $x_i^*(\underline{\theta};[0,1],[1,0])$ and $x_i^*(\overline{\theta};[0,1],[1,0])$, which immediately gives (3.19).

(c) Finally, we show that $p_i^f(\underline{\theta}) < p_i^*(\varnothing;[0,1],[0,1]) < p_i^f(\overline{\theta})$ under Bertrand competition. Expression (3.17) implies the following inequality:

$$p_i^f(\underline{\theta}) < p_i^*(\underline{\theta};[0,1],[0,1]) < p_i^*(\overline{\theta};[0,1],[0,1]) < p_i^f(\overline{\theta}),$$

where the second inequality follows from the observation that $\Delta_i^b(\overline{\theta};s_i,s_j)$ in (3.B.14) is positive. The price of an uninformed firm, $p_i^*(\varnothing;[0,1],[0,1])$, equals the conditionally expected value of the informed firm's prices, and thereby it is a convex combination of $p_i^*(\underline{\theta};[0,1],[0,1])$ and $p_i^*(\overline{\theta};[0,1],[0,1])$. This immediately gives (3.20).

Derivations for hypothesis 4

(a) If demand is uniformly distributed ($q(\underline{\theta}) = \frac{1}{2}$), then firms disclose only information about low demand in the unique equilibrium, i.e., $[s_i(\underline{\theta}), s_i(\overline{\theta})] = [1,0]$ for $i = 1,2$. Hence, a firm's equilibrium outputs (3.11) simplify as follows (for $i,j = 1,2$ and $i \neq j$):

$$x_i^*(\underline{\theta};[1,0],[1,0]) = x_i^f(\underline{\theta}) - \frac{\frac{\delta(\overline{\theta}-\underline{\theta})}{2(4-\delta^2)}\left[2-a_j-\frac{1}{2}\delta a_j(1-a_i)\right]}{(2-a_i)(2-a_j)-\frac{1}{4}\delta^2 a_i a_j(1-a_i)(1-a_j)} \tag{3.B.16}$$

$$x_i^*(\overline{\theta};[1,0],[1,0]) = x_i^f(\overline{\theta}) + \frac{\frac{\delta(\overline{\theta}-\underline{\theta})}{2(4-\delta^2)}(1-a_i)(1-a_j)\left[2-a_j-\frac{1}{2}\delta a_j(1-a_i)\right]}{(2-a_i)(2-a_j)-\frac{1}{4}\delta^2 a_i a_j(1-a_i)(1-a_j)} \tag{3.B.17}$$

Partial differentiation of (3.B.16) with respect to a_i gives the following:

$$\frac{\partial x_i^*(\underline{\theta};[1,0],[1,0])}{\partial a_i} = \frac{-\frac{\delta(\overline{\theta}-\underline{\theta})}{2(4-\delta^2)}\mathcal{K}_1}{\left[(2-a_i)(2-a_j)-\frac{1}{4}\delta^2 a_i a_j(1-a_i)(1-a_j)\right]^2}$$

where

$$\begin{aligned}
\mathcal{K}_1 \equiv\; & \frac{1}{2}\delta^2 a_j\left[(2-a_i)(2-a_j)-\frac{1}{4}\delta^2 a_i a_j(1-a_i)(1-a_j)\right] \\
& +\left[2-a_j-\frac{1}{2}\delta a_j(1-a_i)\right]\left[2-a_j+\frac{1}{4}\delta^2 a_j(1-2a_i)(1-a_j)\right] \\
>\; & 0.
\end{aligned}$$

Hence, $\partial x_i^*(\underline{\theta};[1,0],[1,0])/\partial a_i < 0$.

Similarly, partial differentiation of (3.B.17) with respect to a_i gives the following:

$$\frac{\partial x_i^*(\overline{\theta};[1,0],[1,0])}{\partial a_i} = \frac{-\frac{\delta(\overline{\theta}-\underline{\theta})}{2(4-\delta^2)}(1-a_j)\cdot\mathcal{K}_2}{\left[(2-a_i)(2-a_j)-\frac{1}{4}\delta^2 a_i a_j(1-a_i)(1-a_j)\right]^2}$$

where

$$\begin{aligned}
\mathcal{K}_2 \equiv\; & \left[2-a_j-\delta a_j(1-a_i)\right]\left[(2-a_i)(2-a_j)-\frac{1}{4}\delta^2 a_i a_j(1-a_i)(1-a_j)\right] \\
& -(1-a_i)\left[2-a_j-\frac{1}{2}\delta a_j(1-a_i)\right]\left[2-a_j+\frac{1}{4}\delta^2 a_j(1-2a_i)(1-a_j)\right] \\
=\; & \left[2-a_j-\delta a_j(1-a_i)\right](2-a_j) \\
& -(1-a_i)^2\frac{1}{2}\delta a_j\left(2-a_j+\left[2-a_j-\frac{1}{2}\delta a_j\right]\frac{1}{2}\delta(1-a_j)\right).
\end{aligned}$$

It is straightforward to show that $\mathcal{K}_2$ is decreasing in a_j. This implies the following:

$$\mathcal{K}_2 \geq 1 - \delta(1-a_i) - \frac{1}{2}\delta\left(1-a_i\right)^2 \geq a_i - \frac{1}{2}\left(1-a_i\right)^2.$$

The right-hand-side of this inequality is positive if $a_i \geq 0.3$. Hence,

$$\partial x_i^*(\overline{\theta};[1,0],[1,0])/\partial a_i < 0$$

for all $a_i \geq 0.3$.

Finally, if $q(\underline{\theta}) = \frac{1}{2}$, then equations (3.9), (3.B.16) and (3.B.17) give:

$$\begin{aligned}
x_i^*(\varnothing;[1,0],[1,0]) &= E_j\left\{x_i^*(\theta;[1,0],[1,0])\,|\,\varnothing;[1,0]\right\} \\
&= \frac{1-a_j}{2-a_j}x_i^*(\underline{\theta};[1,0],[1,0]) + \frac{1}{2-a_j}x_i^*(\overline{\theta};[1,0],[1,0]) \\
&= \frac{1-a_j}{2-a_j}x_i^f(\underline{\theta}) + \frac{1}{2-a_j}x_i^f(\overline{\theta}) \\
&\quad - \frac{\frac{\delta(\overline{\theta}-\underline{\theta})}{2(4-\delta^2)}\left[2-a_j-\frac{1}{2}\delta a_j(1-a_i)\right]\left(\frac{1-a_j}{2-a_j}-\frac{(1-a_i)(1-a_j)}{2-a_j}\right)}{\left(2-a_i\right)\left(2-a_j\right)-\frac{1}{4}\delta^2 a_i a_j(1-a_i)(1-a_j)} \\
&= E_j\left\{x_i^f(\theta)\,\middle|\,\varnothing;[1,0]\right\} - \frac{\frac{\delta(\overline{\theta}-\underline{\theta})}{2(4-\delta^2)}\left[2-a_j-\frac{1}{2}\delta a_j(1-a_i)\right]\cdot\frac{1-a_j}{2-a_j}a_i}{\left(2-a_i\right)\left(2-a_j\right)-\frac{1}{4}\delta^2 a_i a_j(1-a_i)(1-a_j)}
\end{aligned}$$

Partial differentiation of this expression with respect to a_i gives the following:

$$\begin{aligned}
\frac{\partial x_i^*(\varnothing;[1,0],[1,0])}{\partial a_i} &= \frac{-\frac{\delta(\overline{\theta}-\underline{\theta})}{2(4-\delta^2)}\mathcal{K}_1\cdot\frac{1-a_j}{2-a_j}a_i}{\left[\left(2-a_i\right)\left(2-a_j\right)-\frac{1}{4}\delta^2 a_i a_j(1-a_i)(1-a_j)\right]^2} \\
&\quad - \frac{\frac{\delta(\overline{\theta}-\underline{\theta})}{2(4-\delta^2)}\left[2-a_j-\frac{1}{2}\delta a_j(1-a_i)\right]\cdot\frac{1-a_j}{2-a_j}}{\left(2-a_i\right)\left(2-a_j\right)-\frac{1}{4}\delta^2 a_i a_j(1-a_i)(1-a_j)},
\end{aligned}$$

which is non-positive, since both terms are non-positive.

(b) Under Bertrand competition, the firms choose the disclosure strategies $[s_i(\underline{\theta}), s_i(\overline{\theta})] = [0, 1]$ for $i = 1, 2$ in the unique equilibrium. This simplifies the equilibrium prices as follows:

$$p_i^*(\underline{\theta}; [0,1], [0,1]) = p_i^f(\underline{\theta}) + \delta \frac{1-\delta}{2-\delta} q(\overline{\theta})(\overline{\theta} - \underline{\theta}) \cdot \frac{(1-a_i)(1-a_j)\left[2\left(1-q(\overline{\theta})a_j\right) + \delta q(\overline{\theta})a_j(1-a_i)\right]}{4\left[1-q(\overline{\theta})a_i\right]\left[1-q(\overline{\theta})a_j\right] - \delta^2 q(\overline{\theta})^2 a_i a_j (1-a_i)(1-a_j)} \tag{3.B.18}$$

$$p_i^*(\overline{\theta}; [0,1], [0,1]) = p_i^f(\overline{\theta}) - \delta \frac{1-\delta}{2-\delta} q(\underline{\theta})(\overline{\theta} - \underline{\theta}) \cdot \frac{2\left(1-q(\overline{\theta})a_j\right) + \delta q(\overline{\theta})a_j(1-a_i)}{4\left[1-q(\overline{\theta})a_i\right]\left[1-q(\overline{\theta})a_j\right] - \delta^2 q(\overline{\theta})^2 a_i a_j (1-a_i)(1-a_j)} \tag{3.B.19}$$

Partial differentiation of (3.B.18) with respect to probability a_i gives the following:

$$\frac{\partial p_i^*(\underline{\theta}; [0,1], [0,1])}{\partial a_i} = \frac{-\delta \frac{1-\delta}{2-\delta} q(\overline{\theta})(\overline{\theta} - \underline{\theta})(1-a_j) \cdot \mathcal{K}_3}{\left(4\left[1-q(\overline{\theta})a_i\right]\left[1-q(\overline{\theta})a_j\right] - \delta^2 q(\overline{\theta})^2 a_i a_j (1-a_i)(1-a_j)\right)^2}$$

where

$$\begin{aligned}
\mathcal{K}_3 \equiv\ & \left(\left[2\left(1-q(\overline{\theta})a_j\right) + \delta q(\overline{\theta})a_j(1-a_i)\right] + \delta q(\overline{\theta})a_j(1-a_i)\right) \\
& \cdot \left(4\left[1-q(\overline{\theta})a_i\right]\left[1-q(\overline{\theta})a_j\right] - \delta^2 q(\overline{\theta})^2 a_i a_j (1-a_i)(1-a_j)\right) \\
& -(1-a_i)\left[2\left(1-q(\overline{\theta})a_j\right) + \delta q(\overline{\theta})a_j(1-a_i)\right] \\
& \cdot \left(4q(\overline{\theta})a_i\left[1-q(\overline{\theta})a_j\right] + \delta^2 q(\overline{\theta})^2 a_j (1-a_i)(1-a_j) - \delta^2 q(\overline{\theta})^2 a_i a_j (1-a_j)\right) \\
=\ & \left[2\left(1-q(\overline{\theta})a_j\right) + \delta q(\overline{\theta})a_j(1-a_i)\right] \\
& \cdot \left(4\left[1-q(\overline{\theta})\right]\left[1-q(\overline{\theta})a_j\right] - \delta^2 q(\overline{\theta})^2 a_j (1-a_i)^2(1-a_j)\right) \\
& +\delta q(\overline{\theta})a_j(1-a_i)\left(4\left[1-q(\overline{\theta})a_i\right]\left[1-q(\overline{\theta})a_j\right] - \delta^2 q(\overline{\theta})^2 a_i a_j (1-a_i)(1-a_j)\right) \\
=\ & \left[2\left(1-q(\overline{\theta})a_j\right) + \delta q(\overline{\theta})a_j(1-a_i)\right] 4\left[1-q(\overline{\theta})\right]\left[1-q(\overline{\theta})a_j\right] \\
& +\delta q(\overline{\theta})a_j(1-a_i)\left(2\left[1-q(\overline{\theta})a_i\right]\left[1-q(\overline{\theta})a_j\right] - \delta^2 q(\overline{\theta})^2 a_j (1-a_i)(1-a_j)\right) \\
& +2\delta q(\overline{\theta})a_j(1-a_i)\left[1-q(\overline{\theta})a_j\right]\left(1-q(\overline{\theta})\left[a_i + (1-a_i)\delta(1-a_j)\right]\right) > 0.
\end{aligned}$$

This implies that $\partial p_i^*(\underline{\theta}; [0,1], [0,1])/\partial a_i < 0$.

Using (3.7), (3.B.18) and (3.B.19), we can rewrite the equilibrium price of an uninformed firm as follows:

$$\begin{aligned}
p_i^*(\varnothing;[0,1],[0,1]) &= Q_j(\underline{\theta};[0,1])p_i^*(\underline{\theta};[0,1],[0,1]) + Q_j(\overline{\theta};[0,1])p_i^*(\overline{\theta};[0,1],[0,1]) \\
&= Q_j(\underline{\theta};[0,1])p_i^f(\underline{\theta}) + Q_j(\overline{\theta};[0,1])p_i^f(\overline{\theta}) \\
&\quad -\delta\frac{1-\delta}{2-\delta}q(\underline{\theta})q(\overline{\theta})\frac{1-a_j}{1-p(\overline{\theta})a_j}(\overline{\theta}-\underline{\theta}) \\
&\quad \cdot\frac{a_i\left[2\left(1-q(\overline{\theta})a_j\right)+\delta q(\overline{\theta})a_j(1-a_i)\right]}{4\left[1-q(\overline{\theta})a_i\right]\left[1-q(\overline{\theta})a_j\right]-\delta^2 q(\overline{\theta})^2 a_i a_j(1-a_i)(1-a_j)}
\end{aligned}$$

Partial differentiation of this expression with respect to probability a_i gives:

$$\frac{\partial p_i^*(\varnothing;[0,1],[0,1])}{\partial a_i} = \frac{-\delta\frac{1-\delta}{2-\delta}q(\underline{\theta})q(\overline{\theta})(\overline{\theta}-\underline{\theta})\frac{1-a_j}{1-p(\overline{\theta})a_j}\cdot\mathcal{K}_4}{\left(4\left[1-q(\overline{\theta})a_i\right]\left[1-q(\overline{\theta})a_j\right]-\delta^2 q(\overline{\theta})^2 a_i a_j(1-a_i)(1-a_j)\right)^2}$$

where

$$\begin{aligned}
\mathcal{K}_4 &\equiv \left[2\left(1-q(\overline{\theta})a_j\right)+\delta q(\overline{\theta})a_j(1-a_i)-\delta q(\overline{\theta})a_i a_j\right] \\
&\quad \cdot\left(4\left[1-q(\overline{\theta})a_i\right]\left[1-q(\overline{\theta})a_j\right]-\delta^2 q(\overline{\theta})^2 a_i a_j(1-a_i)(1-a_j)\right) \\
&\quad +a_i\left[2\left(1-q(\overline{\theta})a_j\right)+\delta q(\overline{\theta})a_j(1-a_i)\right] \\
&\quad \cdot\left(4q(\overline{\theta})\left[1-q(\overline{\theta})a_j\right]+\delta^2 q(\overline{\theta})^2 a_j(1-a_i)(1-a_j)-\delta^2 q(\overline{\theta})^2 a_i a_j(1-a_j)\right) \\
&= \left[2\left(1-q(\overline{\theta})a_j\right)+\delta q(\overline{\theta})a_j(1-a_i)\right]\left(4\left[1-q(\overline{\theta})a_j\right]-\delta^2 q(\overline{\theta})^2 a_i^2 a_j(1-a_j)\right) \\
&\quad -\delta q(\overline{\theta})a_i a_j\left(4\left[1-q(\overline{\theta})a_i\right]\left[1-q(\overline{\theta})a_j\right]-\delta^2 q(\overline{\theta})^2 a_i a_j(1-a_i)(1-a_j)\right) \\
&= 2\left[1-q(\overline{\theta})a_j\right]\left(4\left[1-q(\overline{\theta})a_j\right]-\delta^2 q(\overline{\theta})^2 a_i^2 a_j(1-a_j)\right) \\
&\quad +\delta q(\overline{\theta})4a_j\left[1-q(\overline{\theta})a_j\right]\left(1-a_i\left[2-q(\overline{\theta})a_i\right]\right) \\
&\geq 2\left[1-q(\overline{\theta})a_j\right]\left(4\left[1-q(\overline{\theta})a_j\right]-\delta^2 q(\overline{\theta})^2 a_j(1-a_j)\right) \\
&\quad -\delta q(\overline{\theta})4a_j\left[1-q(\overline{\theta})\right]\left[1-q(\overline{\theta})a_j\right] \\
&\geq 2\left[1-q(\overline{\theta})a_j\right]\left(4\left[1-q(\overline{\theta})a_j\right]-2q(\overline{\theta})a_j\left[1-q(\overline{\theta})\right]-q(\overline{\theta})^2 a_j(1-a_j)\right) \\
&\geq 2\left[1-q(\overline{\theta})a_j\right]^2\left(4-q(\overline{\theta})\left[2+a_j\right]\right)>0.
\end{aligned}$$

Hence, $\partial p_i^*(\varnothing;[0,1],[0,1])/\partial a_i < 0$.

3.C Table of test results & Stability of disclosure behavior

Table 3.9: p-values for comparing outputs with high-demand information in Part II

	Firm 1	Firm 2
	$x_1^*(\overline{\theta};\cdot) > x_1^f(\overline{\theta})$	$x_2^*(\overline{\theta};\cdot) > x_2^f(\overline{\theta})$
T1	—	0.1124
T2	0.0215	0.0215
T3	0.0215	0.0398
T4	0.0473	0.3429
T5	—	0.2501

Note: In T2 we do not distinguish between firms as they are ex ante identical. All p-values refer to one-sided Wilcoxon tests.

Table 3.10: p-values for comparing product market choices with complete information and no information in Part II

	Firm 1		Firm 2	
	$x_1^f(\underline{\theta}) < x_1^*(\varnothing;\cdot)$	$x_1^*(\varnothing;\cdot) < x_1^f(\overline{\theta})$	$x_2^f(\underline{\theta}) < x_2^*(\varnothing;\cdot)$	$x_2^*(\varnothing;\cdot) < x_2^f(\overline{\theta})$
T1	0.0215	0.0398	0.0215	0.0398
T2	0.0398	0.1124	0.0398	0.1124
T3	0.0215	0.0690	0.0215	0.0215
T4	0.0215	0.0215	0.0215	0.0215
T5	0.0215	0.0215	0.0215	0.0398
	$p_1^f(\underline{\theta}) < p_1^*(\varnothing;\cdot)$	$p_1^*(\varnothing;\cdot) < p_1^f(\overline{\theta})$	$p_2^f(\underline{\theta}) < p_2^*(\varnothing;\cdot)$	$p_2^*(\varnothing;\cdot) < p_2^f(\overline{\theta})$
T6	0.0398	0.0215	0.0398	0.0215
T7	0.0215	0.0215	0.0215	0.0215

Note: In T2 and T7 we do not distinguish between firms as they are ex ante identical. All p-values refer to one-sided Wilcoxon tests.

Table 3.11: p-values for comparing firm 1's outputs across T1-T3 in Part II

	Incomplete Information	
	$\Theta_1 = \varnothing$	$\Theta_1 = \overline{\theta}$
$x_1(\cdot;\text{T1}) > x_1(\cdot;\text{T3})$	0.1736	—
$x_1(\cdot;\text{T3}) > x_1(\cdot;\text{T2})$	0.3007	0.0872
$x_1(\cdot;\text{T1}) > x_1(\cdot;\text{T2})$	0.0586	—

Note: The p-values correspond to one-sided MWW tests.

Stability of disclosure behavior

Here we summarize our analysis on changes in subjects' disclosure behavior over time. Table 3.12 (Table 3.13) gives the average disclosure frequencies of subjects with the role of firm 1 (firm 2) in the first five instances where these subjects received a particular informative signal as well as the frequencies in the last five instances where they observed this signal. Although the disclosure frequencies appear to increase in time, the two-sided p-values in Table 3.14 indicate that the changes are not statistically significant in most cases.

Table 3.12: Disclosure frequencies of Firm 1 at start and end of Part II (in %)

	Low demand ($\Theta_1 = \underline{\theta}$)		High demand ($\Theta_1 = \overline{\theta}$)	
	first 5 instances	last 5 instances	first 5 instances	last 5 instances
T1	—	—	—	—
T2	80.0 (21.7)	90.0 (9.7)	47.3 (23.7)	62.6 (23.9)
T3	83.5 (12.1)	86.3 (13.0)	46.6 (21.3)	55.1 (23.9)
T4	92.0 (17.9)	96.0 (8.9)	—	—
T5	—	—	—	—
T6	—	—	—	—
T7	36.0 (13.2)	44.7 (19.8)	78.7 (21.0)	90.0 (22.4)

Note: Standard deviations are reported in parentheses.
In T2 and T7 we do not distinguish between firms as they are ex ante identical.

Table 3.13: Disclosure frequencies of Firm 2 at start and end of Part II (in %)

	Low demand ($\Theta_2 = \underline{\theta}$)		High demand ($\Theta_2 = \overline{\theta}$)	
	first 5 instances	last 5 instances	first 5 instances	last 5 instances
T1	92.0 (8.7)	100 (0.0)	32.0 (16.6)	52.0 (15.2)
T2	80.0 (21.7)	90.0 (9.7)	47.3 (23.7)	62.6 (23.9)
T3	80.0 (17.0)	88.0 (15.9)	28.0 (19.7)	37.3 (38.2)
T4	77.3 (18.6)	86.7 (18.3)	30.3 (18.4)	31.9 (20.0)
T5	74.7 (11.0)	85.3 (17.2)	10.7 (10.1)	17.3 (18.6)
T6	35.7 (21.8)	41.3 (32.1)	81.3 (11.9)	100 (0.0)
T7	36.0 (13.2)	44.7 (19.8)	78.7 (21.0)	90.0 (22.4)

Note: Standard deviations are reported in parentheses.
In T2 and T7 we do not distinguish between firms as they are ex ante identical.

Table 3.14: p-values for comparing disclosure frequencies at start of Part II with those at end of Part II

	Firm 1		Firm 2	
	$\Theta_1 = \underline{\theta}$	$\Theta_1 = \overline{\theta}$	$\Theta_2 = \underline{\theta}$	$\Theta_2 = \overline{\theta}$
T1	—	—	0.0897	0.0394
T2	0.1736	0.0431	0.1736	0.0431
T3	0.4120	0.0394	0.3961	0.4142
T4	0.3173	—	0.0522	0.3173
T5	—	—	0.2763	0.4982
T6	—	—	0.5716	0.0422
T7	0.3452	0.0431	0.3452	0.0431

Note: All p-values refer to two-sided Wilcoxon tests.
In T2 and T7 we do not distinguish between firms as they are ex ante identical.

3.D English Instructions (translated)

The following subsections contain the translated instructions for the homogeneous goods Cournot treatments (T1-T4), differentiated goods Cournot treatment (T5) and the differentiated goods Bertrand treatments (T6-T7). The original German instructions are available upon request.

Curley brackets indicate treatment variations. Naturally, neither the treatment names, nor the parameter values of the other treatments were part of the original instructions.

Homogeneous goods Cournot treatments (T1-T4)

Instructions – General Information

Welcome to the experiment!

In this experiment, you can earn money. How much you will earn depends on your decisions as well as on the decisions taken by other participants. Regardless of your decisions during the experiment, you will receive an additional 2.50 Euro for your presence.

The experiment consists of three parts. Before each part, you receive precise instructions. All decisions taken during the course of this experiment are payout relevant. During the experiment, the currency ECU (Experimental Currency Units) is used. At the end of the experiment, all amounts in ECU are converted into Euro and paid to you in cash. The exchange rate is 1 Euro for {T1-T3: 28,000; T4: 23,000} ECU. Amounts are rounded up to full 10 Cent in your favor.

All decisions which you make during the experiment are anonymous. Your payout at the end of the experiment is confidential.

Please do not communicate any more with the other participants from now on. In case you have any questions, now or during the experiment, please raise your hand. Then we will come to you and answer your question. Please ensure additionally that your mobile phone is switched off. Material (books, lecture notes, etc.), which does not concern the experiment, may not be used during the experiment. Non-compliance with these rules can lead to exclusion from the experiment and all payouts.

The following instructions refer to the first part. After the end of the first part, you receive further instructions.

Instructions Part I

Part I of the experiment consists of 20 rounds which proceed in identical manner:

In this part of the experiment, you interact as producer with another participant, your competitor. Your competitor is randomly matched to you. Each round this random matching is done anew. We ensure that you never have the same competitor in two consecutive rounds.

You and your competitor produce identical goods for a common market. Each produced good is sold at market price.

The market price is computed from the market demand minus the quantity produced by you and your competitor:

$\Rightarrow$*Market Price = Market Demand – Your Quantity – Competitor's Quantity*

However, the market price cannot be smaller than zero. If the produced quantity exceeds the market demand, then the market price equals zero.

Each round the market demand is determined by chance. The market demand is low with a probability of {T1-T3: 50%; T4: 90%} and amounts to 240. With a probability of {T1-T3: 50%; T4: 10%} it is high and amounts to 300. The positive market price is thus given by:

$\Rightarrow$ if market demand is high:
Market Price = 300 – Your Quantity – Competitor's Quantity

$\Rightarrow$ if market demand is low:
Market Price = 240 – Your Quantity – Competitor's Quantity

At the beginning of each round, you learn after a few seconds whether the market demand is high or low. The competitor also learns whether the market demand is high or low. Afterwards, you choose your quantity (if applicable, including decimal places). The competitor chooses his quantity simultaneously. While making these choices, neither you nor your competitor can see what quantity the other chooses.

The market price is determined after you and your competitor have chosen the production quantities. Your profit is determined by your quantity, which is sold at market price. Neither you nor your competitor have to bear production costs.

$\Rightarrow$ *Profit = Market Price* $\times$ *Your Quantity*

At the end of each round, you will be informed about your profit for that round, the market price, and the chosen quantities.

At the end of the experiment, the profits over all rounds will be converted into EURO and paid out to you.

Quiz Part I

Please mark the correct answers

1. **The market demand is high and equals 300. You produce 140 goods and your competitor produces 120 goods:**

   (a) How high is the market price?

      i. 0
      ii. 20
      iii. 40
      iv. 160
      v. 180
      vi. None of the above

   (b) How high is your profit?

      i. 2,800
      ii. 5,600
      iii. 22,400
      iv. 25,200
      v. None of the above

2. **The market demand is low and equals 240. You produce 140 goods and your competitor produces 25 goods:**

   (a) How high is the market price?

      i. -20
      ii. 0
      iii. 60
      iv. 100
      v. 120
      vi. None of the above

(b) How high is your profit?

   i. -2,800
   ii. 0
   iii. 8,400
   iv. 14,000
   v. 16,800
   vi. None of the above

3. **Who is your competitor?**

   (a) A random participant of this experiment is assigned to me over all rounds.

   (b) In each round, a random participant is assigned to me. It is possible that the same participant is assigned to me in consecutive rounds.

   (c) In each round, a random participant is assigned to me. It is excluded that the same participant is assigned to me in consecutive rounds.

   (d) None of the above

4. **Which round(s) are paid out at the end of the experiment?**

   (a) All rounds

   (b) A randomly picked round

   (c) Only the last round

   (d) None of the above

5. **Do you and/or your competitor know the market demand at the moment of quantity decisions?**

   (a) Nobody knows the market demand, because it is random.

   (b) Only I know the market demand.

   (c) Only my competitor knows the market demand.

   (d) My competitor and I know the market demand.

   (e) None of the above

Instructions Part II

This part of the experiment is an extension of the first part. From now on, you do not always know the market demand. If you do know the market demand, you can choose to announce it to the competitor. The same applies for your competitor. The matching of competitors is done as in Part I.

Part II of the experiment consists of 50 rounds with identical proceeding:

As in the first part, the market demand is high with a probability of {T1-T3: 50%; T4: 10%}, and low with a probability of {T1-T3: 50%; T4: 90%}. How high it is in the current round is not automatically apparent to you. **However, you and your competitor run a market analysis each round.** Whether it is successful is randomly determined in each round anew:

Independent of the current market demand, and the market analysis of the competitor, Your market analysis is successful or unsuccessful with a certain probability. In addition, you know the probability of success for the market analysis of your competitor, but you do not know his result. The same holds for your competitor.

The probabilities of success, depending on your role, are:

	Own market analysis		**Competitor's market analysis**	
	Successful	Not successful	Successful	Not successful
Role A	{T1:0%} {T2:90%} {T3-T4:30%}	{T1:100%} {T2:10%} {T3-T4:70%}	90%	10%
Role B	90%	10%	{T1:0%} {T2:90%} {T3-T4:30%}	{T1:100%} {T2:10%} {T3-T4:70%}

In case of a successful market analysis, you learn how high the market demand is. If you learned the level of the market demand, then it is correct in any case. In case the market analysis is not successful, you will not learn the market demand.

After the market analysis is conducted, you can costlessly inform your competitor about the market demand, provided that you learned it. Your competitor can also choose to inform you about the result of his market analysis. All information sent is always truthful. Sending false information is not possible.

- If you **know** whether the market demand is high, respectively low:
  - You can **"inform"** your competitor. Your competitor then knows for certain that the market demand is high, respectively low. In addition, he knows that you learned the market demand.
  - You can **"not inform"** your competitor. In this case, the competitor only knows the market demand, if his own market analysis was successful. The competitor does not know whether you learned the market demand.
- If you **do not know** whether market demand is high, respectively low:
  - You can solely **"not inform"** your competitor. In this case, the competitor only knows the market demand, if his own market analysis was successful. In addition, the competitor does not know whether you learned the market demand.

Only after you and your competitor have decided to "inform" / "not (to) inform" the other, information will be transferred.

In case you received information from the competitor and/or your own market analysis was successful, then you know the market demand. If you neither received information from the competitor nor was your own market analysis successful, then you do not know the market demand.

The further course of this part is identical to the first part. You and your competitor choose your quantities and are informed about the result for that round.

At the end of the experiment, the profits over all rounds are converted into EURO and paid out to you.

Quiz Part II

Please mark the correct answers

The market analysis has shown that the market demand is “high”:

a. The market demand is probably high. However, market demand could be low, if the market analysis was wrong. This depends on chance.

b. The market demand is definitely high. My competitor also knows this, if his market analysis was successful.

c. The market demand is definitely low. My competitor also knows this, if his market analysis was successful.

d. The market demand is definitely high. In any case, this is also known to my competitor.

e. None of the above

My market analysis was not successful:

a. I do not know the market demand. My competitor definitely does not know the market demand.

b. I do not know the market demand. My competitor definitely knows the market demand.

c. When deciding on quantity, I only know the market demand if my competitor’s market analysis was successful and he sent me information.

d. I know the market demand.

e. None of the above

Your competitor has announced that the market demand is “low”:

a. The market demand is definitely low, as it is not possible to send false information.

b. The market demand could be high, if my competitor chose to send false information on purpose.

c. None of the above

Instructions Part III

This part is an extension of the experiment from Part II. Now, a department takes over the task to "inform"/ "not (to) inform" the competitor. You instruct the department in which cases the information should be transferred. The quantity decision is still taken by yourself. The same applies for your competitor. The probabilities for the market demand, your market analysis, and the market analysis of the competitor remain as in Part II. The matching of competitors is still determined randomly.

Part III of the experiment consists of one round with the following proceeding:

At the beginning of the round, you do not know the result of your market analysis. **However, you give binding instructions to your internal department about the instances in which it must inform the competitor about the market demand,** in case the market analysis is successful.

You have 4 options:

1. **Never inform**
   The competitor only knows the market demand, if his market analysis was successful. he does not know, whether you learned the market demand.

2. **Only inform if market demand is low**
   Case 1: Market analysis is successful and market demand is low
   Your competitor knows for certain, that the market demand is low. In addition, the competitor knows that you learned how high the market demand is.
   Case 2: Market analysis is not successful and/or the market demand is high
   The competitor only knows the market demand, if his own market analysis was successful. He does not know whether you learned the market demand.

3. **Only inform if market demand is high**
   Case 1: Market analysis is successful and market demand is high
   The competitor knows for certain, that the market demand is high. In addition, he knows that you learned how high the market demand is.
   Case 2: Market analysis is not successful and/or the market demand is low
   The competitor only knows the market demand, if his own market analysis was successful. he does not know whether you learned how high the market demand is.

4. **Always inform**
   Case 1: Market analysis is successful
   The competitor knows for certain, that the market demand is high/low. In addition, he knows that you learned the market demand.
   Case 2: Market analysis is not successful
   The competitor only knows the market demand, if his own market analysis was successful. he does not know whether you learned how high the market demand is.

Hereafter, you are informed, as before, whether your market analysis was successful and whether you received information from the competitor.

As in Part II, the decision about the production quantity follows. Subsequently, you are informed about the outcome of this round, as usual.

At the end of the experiment, the profits over all rounds are converted into EURO and paid out to you.

Differentiated goods Cournot treatment (T5)

Instructions – General Information

Welcome to the experiment!

In this experiment, you can earn money. How much you will earn depends on your decisions as well as on the decisions taken by other participants. Regardless of your decisions during the experiment, you will receive an additional 2.50 Euro for your presence.

The experiment consists of three parts. Before each part, you receive precise instructions. All decisions taken during the course of this experiment are payout relevant. During the experiment, the currency ECU (Experimental Currency Units) is used. At the end of the experiment, all amounts in ECU are converted into Euro and paid to you in cash. The exchange rate is 1 Euro for 40,000 ECU. Amounts are rounded up to full 10 Cent in your favor.

All decisions which you make during the experiment are anonymous. Your payout at the end of the experiment is confidential.

Please do not communicate any more with the other participants from now on. In case you have any questions, now or during the experiment, please raise your hand. Then we will come to you and answer your question. Please ensure additionally that your mobile phone is switched off. Material (books, lecture notes, etc.), which does not concern the experiment, may not be used during the experiment. Non-compliance with these rules can lead to exclusion from the experiment and all payouts.

The following instructions refer to the first part. After the end of the first part, you receive further instructions.

Instructions Part I

Part I of the experiment consists of 20 rounds which proceed in identical manner:

In this part of the experiment, you interact as producer with another participant, your competitor. Your competitor is randomly matched to you. Each round this random matching is done anew. We ensure that you never have the same competitor in two consecutive rounds.

You and your competitor produce different goods. The prices for these goods depend on your own production quantity, the competitor's production quantity, and the general market demand. Each produced good is sold at market price.

Your price is computed from the general market demand minus the own production quantity and half of the competitor's production quantity:

$$\Rightarrow \textit{Your Price} = \textit{General Market Demand} \\ - \textit{Your Quantity} \\ - 0.5 \times \textit{Competitor's Quantity}$$

$$\Rightarrow \textit{Competitor's Price} = \textit{General Market Demand} \\ - \textit{Competitor's Quantity} \\ - 0.5 \times \textit{Your Quantity}$$

However, the market prices cannot be smaller than zero. If the above calculation would give a negative market price, then the market price equals zero.

Each round the general market demand is determined by chance. The general market demand is low with a probability of 50% and amounts to 240. With a probability of 50% it is high and amounts to 300. The positive prices are thus given by:

⇒ if general market demand is high:
Your Price = 300 – Your Quantity – 0.5 × Competitor's Quantity
Competitor's Price = 300 – Competitor's Quantity – 0.5 × Your Quantity

⇒ if general market demand is low:
Your Price = 240 – Your Quantity – 0.5 × Competitor's Quantity
Competitor's Price = 240 – Competitor's Quantity – 0.5 × Your Quantity

At the beginning of each round, you learn after a few seconds whether the general market demand is high or low. The competitor also learns whether the general market demand is high or low. Afterwards, you choose your quantity (if applicable, including decimal places). The competitor chooses his quantity simultaneously. While making these choices, neither you nor your competitor can see what quantity the other chooses.

The market prices are determined after you and your competitor have chosen the production quantities. Your profit is determined by your quantity, which is sold at your price. Neither you nor your competitor have to bear production costs.

$$\Rightarrow \textit{Your Profit} = \textit{Your Price} \times \textit{Your Quantity}$$

At the end of each round, you will be informed about your profit for that round, your price, and the chosen quantities.

At the end of the experiment, the profits over all rounds will be converted into EURO and paid out to you.

Quiz Part I

Please mark the correct answers

1. **The general market demand is high and equals 300. You produce 140 goods and your competitor produces 120 goods:**

   (a) How high is your market price?

   i. 0
   ii. 20
   iii. 40
   iv. 160
   v. 170
   vi. None of the above

   (b) How high is the market price of your competitor?

   i. 0
   ii. 20
   iii. 40
   iv. 80
   v. 110
   vi. 170
   vii. None of the above

   (c) How high is your profit?

   i. 2,800
   ii. 11,200
   iii. 14,000
   iv. 23,800
   v. None of the above

2. **Who is your competitor?**
   (a) A random participant is assigned to me for all rounds.
   (b) In each round, a random participant is assigned to me. It is possible that the same participant is assigned to me in consecutive rounds.
   (c) In each round, a random participant is assigned to me. It is excluded that the same participant is assigned to me in consecutive rounds.
   (d) None of the above

3. **The general market demand is low and equals 240. You produce 140 goods and your competitor produces 240 goods:**
   (a) How high is your market price?
      i. -20
      ii. 0
      iii. 50
      iv. 100
      v. 120
      vi. None of the above
   (b) How high is the market price of the competitor?
      i. -20
      ii. 0
      iii. 50
      iv. 100
      v. 120
      vi. None of the above
   (c) How high is your profit?
      i. -8,400
      ii. -2,800
      iii. 0
      iv. 7,000
      v. 14,000
      vi. 16,800
      vii. None of the above

4. **Which round(s) are paid out at the end of the experiment?**
    (a) All rounds
    (b) A randomly picked round
    (c) Only the last round
    (d) None of the above
5. **Do you and/or your competitor know the market demand at the moment of quantity decisions?**
    (a) Nobody knows the market demand, because it is random.
    (b) Only I know the market demand.
    (c) Only my competitor knows the market demand.
    (d) My competitor and I know the market demand.
    (e) None of the above

Instructions Part II

This part of the experiment is an extension of the first part. From now on, you do not always know the general market demand. If you do know the general market demand, you can choose to announce it to the competitor. The same applies for your competitor. The matching of competitors is done as in Part I.

Part II of the experiment consists of 50 rounds with identical proceeding:

As in the first part, the general market demand is high with a probability of 50%, and low with a probability of 50%. How high it is in the current round is not automatically apparent to you. **However, you and your competitor run a market analysis each round.** Whether it is successful is randomly determined in each round anew:

Independent of the current general market demand, and the market analysis of the competitor, Your market analysis is successful or unsuccessful with a certain probability. In addition, you know the probability of success for the market analysis of your competitor, but you do not know his result. The same holds for your competitor.

The probabilities of success, depending on your role, are:

	Own market analysis		**Competitor's market analysis**	
	Successful	Not successful	Successful	Not successful
Role A	0%	100%	90%	10%
Role B	90%	10%	0%	100%

In case of a successful market analysis, you learn how high the general market demand is. If you learned the level of the market demand, then it is correct in any case. In case the market analysis is not successful, you will not learn the market demand.

After the market analysis is conducted, you can costlessly inform your competitor about the general market demand, provided that you learned it. Your competitor can also choose to inform you about the result of his market analysis. All information sent is always truthful. Sending false information is not possible.

- If you **know** whether the general market demand is high, respectively low:
  - You can **"inform"** your competitor. Your competitor then knows for certain that the general market demand is high, respectively low. In addition, he knows that you learned the general market demand.

  - You can **“not inform”** your competitor. In this case, the competitor only knows the general market demand, if his own market analysis was successful. The competitor does not know whether you learned the general market demand.

- If you **do not know** whether the general market demand is high, respectively low:

  - You can solely **“not inform”** your competitor. In this case, the competitor only knows the general market demand, if his own market analysis was successful. In addition, the competitor does not know whether you learned the general market demand.

Only after you and your competitor have decided to “inform” / “not (to) inform” the other, information will be transferred.

In case you received information from the competitor and/or your own market analysis was successful, then you know the general market demand. If you neither received information from the competitor nor was your own market analysis successful, then you do not know the general market demand.

The further course of this part is identical to the first part. You and your competitor choose your quantities and are informed about the result for that round.

At the end of the experiment, the profits over all rounds are converted into EURO and paid out to you.

Quiz Part II

Please mark the correct answers

The market analysis has shown that the general market demand is "high":

a. The general market demand is probably high. However, market demand could be low, if the market analysis was wrong. This depends on chance.

b. The general market demand is definitely high. My competitor also knows this, if his market analysis was successful.

c. The general market demand is definitely low. My competitor also knows this, if his market analysis was successful.

d. The general market demand is definitely high. In any case, this is also known to my competitor.

e. None of the above

My market analysis was not successful:

a. I do not know the general market demand. My competitor definitely does not know the general market demand.

b. I do not know the general market demand. My competitor definitely knows the general market demand.

c. When deciding on quantity, I only know the general market demand if my competitor's market analysis was successful and he sent me information.

d. I know the general market demand.

e. None of the above

Your competitor has announced that the general market demand is "low":

a. The general market demand is definitely low, as it is not possible to send false information.

b. The general market demand could be high, if my competitor chose to send false information on purpose.

c. None of the above

Instructions Part III

This part is an extension of the experiment from Part II. Now, a department takes over the task to "inform"/ "not (to) inform" the competitor. You instruct the department in which cases the information should be transferred. The quantity decision is still taken by yourself. The same applies for your competitor. The probabilities for the general market demand, your market analysis, and the market analysis of the competitor remain as in Part II. The matching of competitors is still determined randomly.

Part III of the experiment consists of one round with the following proceeding:

At the beginning of the round, you do not know the result of your market analysis. **However, you give binding instructions to your internal department about the instances in which it must inform the competitor about the general market demand,** in case the market analysis is successful.

You have 4 options:

1. **Never inform**
   The competitor only knows the general market demand, if his market analysis was successful. he does not know, whether you learned the general market demand.

2. **Only inform if market demand is low**
   Case 1: Market analysis is successful and general market demand is low
   Your competitor knows for certain, that general market demand is low. In addition, the competitor knows that you learned how high the general market demand is.
   Case 2: Market analysis is not successful and/or general market demand is high
   The competitor only knows the general market demand, if his own market analysis was successful. He does not know whether you learned the general market demand.

3. **Only inform if market demand is high**
   Case 1: Market analysis is successful and general market demand is high
   The competitor knows for certain, that the general market demand is high. In addition, he knows that you learned how high the general market demand is.
   Case 2: Market analysis is not successful and/or general market demand is low
   The competitor only knows the general market demand, if his own market analysis was successful. he does not know whether you learned how high the general market demand is.

4. **Always inform**
   Case 1: Market analysis is successful
   The competitor knows for certain, that the general market demand is high/low. In addition, he knows that you learned the general market demand.
   Case 2: Market analysis is not successful
   The competitor only knows the general market demand, if his own market analysis was successful. he does not know whether you learned how high the general market demand is.

Hereafter, you are informed, as before, whether your market analysis was successful and whether you received information from the competitor.

As in Part II, the decision about the production quantity follows. Subsequently, you are informed about the outcome of this round, as usual.

At the end of the experiment, the profits over all rounds are converted into EURO and paid out to you.

Differentiated goods Bertrand treatments (T6-T7)

Instructions – General Information

Welcome to the experiment!

In this experiment, you can earn money. How much you will earn depends on your decisions as well as on the decisions taken by other participants. Regardless of your decisions during the experiment, you will receive an additional 2.50 Euro for your presence.

The experiment consists of three parts. Before each part, you receive precise instructions. All decisions taken during the course of this experiment are payout relevant. During the experiment, the currency ECU (Experimental Currency Units) is used. At the end of the experiment, all amounts in ECU are converted into Euro and paid to you in cash. The exchange rate is 1 Euro for 56,000 ECU. Amounts are rounded up to full 10 Cent in your favor.

All decisions which you make during the experiment are anonymous. Your payout at the end of the experiment is confidential.

Please do not communicate any more with the other participants from now on. In case you have any questions, now or during the experiment, please raise your hand. Then we will come to you and answer your question. Please ensure additionally that your mobile phone is switched off. Material (books, lecture notes, etc.), which does not concern the experiment, may not be used during the experiment. Non-compliance with these rules can lead to exclusion from the experiment and all payouts.

The following instructions refer to the first part. After the end of the first part, you receive further instructions.

Instructions Part I

Part I of the experiment consists of 20 rounds which proceed in identical manner:

In this part of the experiment, you interact as producer with another participant, your competitor. Your competitor is randomly matched to you. Each round this random matching is done anew. We ensure that you never have the same competitor in two consecutive rounds.

You and your competitor produce different goods. The salable quantities for these goods depend on your price, the competitor's price, and the general market demand. You and your competitor produce exactly your salable quantities.

The salable quantities are computed from the general market demand minus twice your own price plus the competitor's price:

$$\Rightarrow \textit{Your Quantity} = \textit{General Market Demand} - 2 \times \textit{Your Price} + \textit{Competitor's Price}$$

$$\Rightarrow \textit{Competitor's Quantity} = \textit{General Market Demand} - 2 \times \textit{Competitor's Price} + \textit{Your Price}$$

However, the quantities cannot be smaller than zero. If the above calculation would give a negative quantity, then this quantity equals zero.

Each round the general market demand is determined by chance. The general market demand is low with a probability of 50% and amounts to 240. With a probability of 50% general market demand is high and amounts to 300. The positive quantities are thus given by:

⇒ if general market demand is high:
Your Quantity = *300 – 2 × Your Price + Competitor's Price*
Competitor's Quantity = *300 – 2 × Competitor's Price + Your Price*

⇒ if general market demand is low:
Your Quantity = *240 – 2 × Your Price + Competitor's Price*
Competitor's Quantity = *240 – 2 × Competitor's Quantity + Your Price*

At the beginning of each round, you learn after a few seconds whether the general market demand is high or low. The competitor also learns whether the general market demand is high or low. Afterwards, you choose your price (if applicable, including decimal places). The competitor chooses his price simultaneously. While making these choices, neither you nor your competitor can see what price the other chooses.

The salable quantities are determined after you and your competitor have chosen the prices. Your profit is determined by your quantity, which is sold at your price. Neither you nor your competitor have to bear production costs.

$$\Rightarrow \textit{Your Profit} = \textit{Your Price} \times \textit{Your Quantity}$$

At the end of each round, you will be informed about your profit for that round, your chosen price, and your quantity.

At the end of the experiment, the profits over all rounds will be converted into EURO and paid out to you.

Quiz Part I

Please mark the correct answers

1. **The general market demand is high and equals 300. You choose a price of 200 ECU/unit and your competitor a price of 150 ECU/unit:**

   (a) How high is your salable quantity?

      i. -50
      ii. 0
      iii. 50
      iv. 100
      v. 150
      vi. 200
      vii. None of the above

   (b) How high is the salable quantity of the competitor?

      i. -50
      ii. 0
      iii. 50
      iv. 100
      v. 150
      vi. 200
      vii. None of the above

   (c) How high is your profit?

      i. -10,000
      ii. 0
      iii. 10,000
      iv. 20,000
      v. 30,000
      vi. 40,000
      vii. None of the above

2. **Who is your competitor?**
   (a) A random participant of this experiment is assigned to me over all rounds.
   (b) In each round, a random participant is assigned to me. It is possible that the same participant is assigned to me in consecutive rounds.
   (c) In each round, a random participant is assigned to me. It is excluded that the same participant is assigned to me in consecutive rounds.
   (d) None of the above
3. **The general market demand is low and equals 240. You choose a price of 200 ECU/unit and your competitor a price of 150 ECU/unit:**
   (a) How high is your salable quantity?
      i. -210
      ii. -10
      iii. 0
      iv. 10
      v. 120
      vi. 140
      vii. None of the above
   (b) How high is the salable quantity of the competitor?
      i. -210
      ii. -10
      iii. 0
      iv. 10
      v. 120
      vi. 140
      vii. None of the above

(c) How high is your profit?

   i. -42,000
   ii. -2,000
   iii. 0
   iv. 2,000
   v. 24,000
   vi. 28,000
   vii. None of the above

4. **Which round(s) are paid out at the end of the experiment?**

   (a) All rounds

   (b) A randomly picked round

   (c) Only the last round

   (d) None of the above

5. **Do you and/or your competitor know the market demand at the moment of price decisions?**

   (a) Nobody knows the market demand, because it is random.

   (b) Only I know the market demand.

   (c) Only my competitor knows the market demand.

   (d) My competitor and I know the market demand.

   (e) None of the above

Instructions Part II

This part of the experiment is an extension of the first part. From now on, you do not always know the general market demand. If you do know the general market demand, you can choose to announce it to the competitor. The same applies for your competitor. The matching of competitors is done as in Part I.

Part II of the experiment consists of 50 rounds with identical proceeding:

As in the first part, the general market demand is high with a probability of 50%, and low with a probability of 50%. How high it is in the current round is not automatically apparent to you. **However, you and your competitor run a market analysis each round.** Whether it is successful is randomly determined in each round anew:

Independent of the current general market demand, and the market analysis of the competitor, Your market analysis is successful or unsuccessful with a certain probability. In addition, you know the probability of success for the market analysis of your competitor, but you do not know his result. The same holds for your competitor.

The probabilities of success, depending on your role, are:

	Own market analysis		**Competitor's market analysis**	
	Successful	Not successful	Successful	Not successful
Role A	{T6:0%} {T7:90%}	{T6:100%} {T7:10%}	90%	10%
Role B	90%	10%	{T6:0%} {T7:90%}	{T6:100%} {T7:10%}

In case of a successful market analysis, you learn how high the general market demand is. If you learned the level of the market demand, then it is correct in any case. In case the market analysis is not successful, you will not learn the market demand.

After the market analysis is conducted, you can costlessly inform your competitor about the general market demand, provided that you learned it. Your competitor can also choose to inform you about the result of his market analysis. All information sent is always truthful. Sending false information is not possible.

- If you **know** whether the general market demand is high, respectively low:
  - You can **"inform"** your competitor. Your competitor then knows for certain that the general market demand is high, respectively low. In addition, he knows that you learned the general market demand.
  - You can **"not inform"** your competitor. In this case, the competitor only knows the general market demand, if his own market analysis was successful. The competitor does not know whether you learned the general market demand.
- If you **do not know** whether the general market demand is high, respectively low:
  - You can solely **"not inform"** your competitor. In this case, the competitor only knows the general market demand, if his own market analysis was successful. In addition, the competitor does not know whether you learned the general market demand.

Only after you and your competitor have decided to "inform" / "not (to) inform" the other, information will be transferred.

In case you received information from the competitor and/or your own market analysis was successful, then you know the general market demand. If you neither received information from the competitor nor was your own market analysis successful, then you do not know the general market demand.

The further course of this part is identical to the first part. You and your competitor choose your prices and are informed about the result for that round.

At the end of the experiment, the profits over all rounds are converted into EURO and paid out to you.

Quiz Part II

Please mark the correct answers

The market analysis has shown that the general market demand is “high”:

a. The general market demand is probably high. However, market demand could be low, if the market analysis was wrong. This depends on chance.

b. The general market demand is definitely high. My competitor also knows this, if his market analysis was successful.

c. The general market demand is definitely low. My competitor also knows this, if his market analysis was successful.

d. The general market demand is definitely high. In any case, this is also known to my competitor.

e. None of the above

My market analysis was not successful:

a. I do not know the general market demand. My competitor definitely does not know the general market demand.

b. I do not know the general market demand. My competitor definitely knows the general market demand.

c. When deciding on quantity, I only know the general market demand if my competitor’s market analysis was successful and he sent me information.

d. I know the general market demand.

e. None of the above

Your competitor has announced that the general market demand is “low”:

a. The general market demand is definitely low, as it is not possible to send false information.

b. The general market demand could be high, if my competitor chose to send false information on purpose.

c. None of the above

Instructions Part III

This part is an extension of the experiment from Part II. Now, a department takes over the task to "inform"/ "not (to) inform" the competitor. You instruct the department in which cases the information should be transferred. The quantity decision is still taken by yourself. The same applies for your competitor. The probabilities for the general market demand, your market analysis, and the market analysis of the competitor remain as in Part II. The matching of competitors is still determined randomly.

Part III of the experiment consists of <u>one round</u> *with the following proceeding:*

At the beginning of the round, you do not know the result of your market analysis. **However, you give binding instructions to your internal department about the instances in which it must inform the competitor about the general market demand,** in case the market analysis is successful.

You have 4 options:

1. **Never inform**
   The competitor only knows the general market demand, if his market analysis was successful. he does not know, whether you learned the general market demand.

2. **Only inform if market demand is low**
   <u>Case 1: Market analysis is successful and general market demand is low</u>
   Your competitor knows for certain, that general market demand is low. In addition, the competitor knows that you learned how high the general market demand is.
   <u>Case 2: Market analysis is not successful and/or general market demand is high</u>
   The competitor only knows the general market demand, if his own market analysis was successful. He does not know whether you learned the general market demand.

3. **Only inform if market demand is high**
   Case 1: Market analysis is successful and general market demand is high
   The competitor knows for certain, that the general market demand is high. In addition, he knows that you learned how high the general market demand is.
   Case 2: Market analysis is not successful and/or general market demand is low
   The competitor only knows the general market demand, if his own market analysis was successful. he does not know whether you learned how high the general market demand is.

4. **Always inform**
   Case 1: Market analysis is successful
   The competitor knows for certain, that the general market demand is high/low. In addition, he knows that you learned the general market demand.
   Case 2: Market analysis is not successful
   The competitor only knows the general market demand, if his own market analysis was successful. he does not know whether you learned how high the general market demand is.

Hereafter, you are informed, as before, whether your market analysis was successful and whether you received information from the competitor.

As in Part II, the decision about the price follows. Subsequently, you are informed about the outcome of this round, as usual.

At the end of the experiment, the profits over all rounds are converted into EURO and paid out to you.

3.E German Instructions (original)

In this the section, the original German Instructions are presented for the homogeneous goods Cournot treatments. The original instructions for the differentiated goods Cournot treatments as well as the differentiated Bertrand treatments are written in a similar style.

Homogeneous goods Cournot treatments (T1-T4)

Instruktionen – Allgemeiner Teil

Herzlich Willkommen zum Experiment!

In diesem Experiment können Sie Geld verdienen. Wie viel Sie verdienen werden, hängt von Ihren Entscheidungen bzw. den Entscheidungen anderer Experimentteilnehmer ab. Unabhängig von den Entscheidungen während des Experimentes erhalten Sie zusätzlich 2,50 Euro für Ihr Erscheinen.

Das Experiment besteht aus drei Teilen. Vor allen Teilen erhalten Sie jeweils genaue Instruktionen. Alle Entscheidungen, die Sie im Verlauf des Experimentes treffen, sind auszahlungsrelevant. Während des Experimentes wird die Währung ECU (Experimental Currency Units) verwendet. Am Ende des Experimentes werden alle ECU-Beträge in Euro umgerechnet und Ihnen ausgezahlt. Der Umrechnungskurs beträgt 1 Euro für {T1=T2=T3=28.000; T4=23.000} ECU. Bei der Umrechnung wird auf volle 10 Cent zu Ihren Gunsten aufgerundet.

Alle Entscheidungen, die Sie während des Experimentes treffen, sind anonym. Ihre Auszahlung am Ende des Experimentes wird vertraulich behandelt.

Bitte kommunizieren Sie ab sofort nicht mehr mit den anderen Teilnehmern. Falls Sie jetzt oder während des Experimentes eine Frage haben, heben Sie bitte die Hand. Wir werden dann zu Ihnen kommen und Ihre Frage beantworten. Während des Experimentes bitten wir Sie außerdem Ihr Mobiltelefon auszuschalten. Unterlagen (Bücher, Vorlesungsskripte, etc.), die nichts mit dem Experiment zu tun haben, dürfen während des Experimentes nicht verwendet werden. Bei Verstößen gegen diese Regeln können wir Sie vom Experiment und allen Auszahlungen ausschließen.

Die folgenden Instruktionen beziehen sich auf den ersten Teil. Nach Ende des ersten Teils erhalten Sie weitere Instruktionen.

Instruktionen Teil I

Teil I des Experimentes besteht aus 20 Runden mit identischem Ablauf:

In diesem Teil des Experimentes agieren Sie als Produzent mit einem anderen Experimentteilnehmer, Ihrem Wettbewerber. Ihr Wettbewerber ist Ihnen zufällig zugeordnet. Die zufällige Zuordnung erfolgt jede Runde neu. Dabei stellen wir sicher, dass Sie in zwei aufeinanderfolgenden Runden niemals denselben Wettbewerber haben.

Sie und Ihr Wettbewerber produzieren identische Güter für einen gemeinsamen Markt. Jedes produzierte Gut wird zum Marktpreis verkauft.

Der Marktpreis berechnet sich aus der Marktnachfrage abzüglich der Produktionsmenge von Ihnen und Ihrem Wettbewerber:

$$\Rightarrow \qquad \textit{Marktpreis} = \textit{Marktnachfrage} - \textit{Ihre Produktionsmenge} \\ - \textit{Produktionsmenge des Wettbewerbers}$$

Der Marktpreis kann jedoch nicht kleiner als null sein. Falls mehr Güter als die Marktnachfrage produziert wurden, ist der Marktpreis genau 0.

Die Marktnachfrage wird in jeder Runde durch Zufall neu bestimmt. Mit einer Wahrscheinlichkeit von {T1=T2=T3=50%,T4=90%} ist die Marktnachfrage niedrig und beträgt 240. Mit einer Wahrscheinlichkeit von {T1=T2=T3=50%,T4=10%} ist sie hoch und beträgt 300. Der positive Marktpreis berechnet sich somit

⇒ bei hoher Marktnachfrage durch:
Marktpreis = 300 – Ihre Produktionsmenge – Produktionsmenge des Wettbewerbers

⇒ bei niedriger Marktnachfrage durch:
Marktpreis = 240 – Ihre Produktionsmenge – Produktionsmenge des Wettbewerbers

Zu Beginn jeder Runde erfahren Sie nach wenigen Sekunden, ob die Marktnachfrage hoch oder niedrig ist. Der Wettbewerber erfährt ebenfalls, ob die Marktnachfrage hoch oder niedrig ist. Hiernach wählen Sie Ihre Produktionsmenge (ggf. mit Nachkommastellen). Der Wettbewerber wählt simultan seine Produktionsmenge. Weder für Sie noch für Ihren Wettbewerber ist dabei die Menge des jeweils Anderen ersichtlich.

Der Marktpreis wird ermittelt, nachdem Sie und Ihr Wettbewerber die Produktionsmengen gewählt haben. Ihr Gewinn wird durch die Anzahl Ihrer produzierten Güter bestimmt, die jeweils zum Marktpreis verkauft werden. Es fallen weder für Sie noch für Ihren Wettbewerber Produktionskosten an.

$$\Rightarrow \textit{Gewinn} = \textit{Marktpreis} \times \textit{Ihre Produktionsmenge}$$

Ihr Rundengewinn sowie der Marktpreis und die gewählten Produktionsmengen werden Ihnen am Ende jeder Runde mitgeteilt.

Am Ende des Experimentes werden alle Rundengewinne in EURO umgerechnet und Ihnen ausbezahlt.

Quiz Teil I

Bitte markieren Sie die richtigen Antworten

1. **Die Marktnachfrage ist hoch und beträgt 300. Sie produzieren 140 Güter und Ihr Wettbewerber 120 Güter:**

   (a) Wie hoch ist der Marktpreis?

      i. 0
      ii. 20
      iii. 40
      iv. 160
      v. 180
      vi. Keines der genannten

   (b) Wie hoch ist Ihr Gewinn?

      i. 2800
      ii. 5600
      iii. 22400
      iv. 25200
      v. Keines der genannten

2. **Die Marktnachfrage ist niedrig und beträgt 240. Sie produzieren 140 Güter und Ihr Wettbewerber 25 Güter:**

   (a) Wie hoch ist der Marktpreis?

      i. -20
      ii. 0
      iii. 60
      iv. 100
      v. 120
      vi. Keines der genannten

(b) Wie hoch ist Ihr Gewinn?

    i. -2800
    ii. 0
    iii. 8400
    iv. 14000
    v. 16800
    vi. Keines der genannten

3. **Wer ist Ihr Wettbewerber?**

    (a) Ein zufälliger Teilnehmer dieses Experimentes ist mir über alle Runden fest zugeordnet.

    (b) In jeder Runde wird mir ein zufälliger Teilnehmer zugeordnet. Dabei ist es möglich, dass mir mehrmals hintereinander derselbe Teilnehmer zugeordnet wird.

    (c) In jeder Runde wird mir ein zufälliger Teilnehmer zugeordnet. Dabei ist es ausgeschlossen, dass mir mehrmals hintereinander derselbe Teilnehmer zugeordnet wird.

    (d) Keines der genannten

4. **Welche Runde(n) werden am Ende des Experimentes ausbezahlt?**

    (a) Alle Runden

    (b) Eine zufällige Runde

    (c) Nur die letzte Runde

    (d) Keines der genannten

5. **Kennen Sie und/oder Ihr Wettbewerber die Marktnachfrage zum Zeitpunkt der Produktionsentscheidung?**

    (a) Niemand kennt die Marktnachfrage, da sie vom Zufall abhängig ist.

    (b) Nur ich kenne die Marktnachfrage.

    (c) Nur mein Wettbewerber kennt die Marktnachfrage.

    (d) Ich und mein Wettbewerber kennen die Marktnachfrage.

    (e) Keines der genannten

Instruktionen Teil II

Dieser Teil des Experimentes ist eine Erweiterung des ersten Teils. Die Marktnachfrage ist Ihnen nun nicht immer bekannt. Wenn Sie die Marktnachfrage kennen, haben Sie die Wahl diese dem Wettbewerber mitzuteilen. Gleiches gilt für Ihren Wettbewerber. Die Zuordnung von Wettbewerbern erfolgt wie in Teil I.

Teil II des Experimentes besteht aus 50 Runden mit identischem Ablauf:

Die Marktnachfrage ist wie im ersten Teil mit einer Wahrscheinlichkeit von {T1=T2=T3=50%, T4=10%} hoch und einer Wahrscheinlichkeit von {T1=T2=T3=50%, T4=90%} niedrig. Wie hoch Sie in der jeweils aktuellen Runde ist, ist Ihnen nicht automatisch ersichtlich. **Sie und Ihr Wettbewerber betreiben jedoch in jeder Runde eine Marktanalyse.** Ob diese erfolgreich ist, wird in jeder Runde durch Zufall neu bestimmt:

Unabhängig von der aktuellen Marktnachfrage und der Marktanalyse des Wettbewerbers ist Ihre Marktanalyse mit einer bestimmten Wahrscheinlichkeit erfolgreich oder nicht erfolgreich. Sie kennen darüber hinaus die Erfolgswahrscheinlichkeit der Marktanalyse Ihres Wettbewerbers, nicht jedoch sein Ergebnis. Gleiches gilt für Ihren Wettbewerber.

Die Erfolgswahrscheinlichkeiten, in Abhängigkeit Ihrer Rolle, betragen:

	Eigene Marktanalyse		**Marktanalyse Wettbewerber**	
	Erfolgreich	Nicht erfolgreich	Erfolgreich	Nicht erfolgreich
Rolle A	{T1:0%} {T2:90%} {T3-T4:30%}	{T1:100%} {T2:10%} {T3-T4:70%}	90%	10%
Rolle B	90%	10%	{T1:0%} {T2:90%} {T3-T4:30%}	{T1:100%} {T2:10%} {T3-T4:70%}

Bei erfolgreicher Marktanalyse erfahren Sie die Höhe der Marktnachfrage. Falls Sie die Höhe der Marktnachfrage erfahren haben, ist diese in jedem Fall korrekt. Ist die Marktanalyse nicht erfolgreich, erfahren Sie die Marktnachfrage nicht.

Nach erfolgter Marktanalyse können Sie Ihren Wettbewerber ohne Entstehung von Kosten über die Marktnachfrage informieren, sofern Ihnen diese bekannt ist. Ihr Wettbewerber hat ebenfalls die Wahl, Sie über das Ergebnis seiner Marktanalyse zu informieren. Alle gesendeten Informationen entsprechen immer der Wahrheit. Eine Übermittlung von falschen Informationen ist nicht möglich.

- Falls Sie **wissen**, dass die Marknachfrage hoch bzw. niedrig ist:
  - Sie können den Wettbewerber **„informieren“**. Der Wettbewerber weiß dann mit Sicherheit, dass die Marktnachfrage hoch bzw. niedrig ist. Ebenfalls weiß er, dass Sie die Marktnachfrage erfahren haben.
  - Sie können den Wettbewerber **„nicht informieren“**. In diesem Fall kennt der Wettbewerber die Marktnachfrage nur, wenn seine eigene Marktanalyse erfolgreich war. Der Wettbewerber weiß nicht, ob Sie die Marktnachfrage erfahren haben.
- Falls sie **nicht wissen**, ob die Marktnachfrage hoch bzw. niedrig ist:
  - Sie können den Wettbewerber lediglich **„nicht informieren“**. In diesem Fall kennt der Wettbewerber die Marktnachfrage nur wenn seine eigene Marktanalyse erfolgreich war. Ebenfalls weiß der Wettbewerber nicht, ob Sie die Marktnachfrage erfahren haben.

Erst nachdem Sie und Ihr Wettbewerber entschieden haben den jeweils Anderen zu „informieren“ / „nicht (zu) informieren“, werden die Informationen übermittelt.

Falls Sie eine Information des Wettbewerbers erhalten haben und/oder Ihre eigene Marktanalyse erfolgreich war, ist Ihnen die Marktnachfrage bekannt. Wenn Sie weder eine Information des Wettbewerbers erhalten haben, noch die eigene Marktanalyse erfolgreich war, kennen Sie die Marktnachfrage nicht.

Der weitere Verlauf dieses Teiles ist wie im ersten Teil. Sie und Ihr Wettbewerber wählen Ihre Produktionsmengen und bekommen das Rundenergebnis mitgeteilt.

Am Ende des Experimentes werden alle Rundengewinne in EURO umgerechnet und Ihnen ausbezahlt.

Quiz Teil II

Bitte markieren Sie die richtigen Antworten

Die Marktanalyse hat ergeben, dass die Marktnachfrage „hoch“ ist:

a. Die Marktnachfrage ist wahrscheinlich hoch. Sie könnte jedoch niedrig sein, falls sich die Marktanalyse geirrt hat. Dies hängt vom Zufall ab.

b. Die Marktnachfrage ist mit absoluter Sicherheit hoch. Der Wettwerber weiß dies auch, falls seine Marktanalyse erfolgreich war.

c. Die Marktnachfrage ist mit absoluter Sicherheit niedrig. Der Wettwerber weiß dies auch, falls seine Marktanalyse erfolgreich war.

d. Die Marktnachfrage ist mit absoluter Sicherheit hoch. Dies ist in jedem Fall auch meinem Wettbewerber bekannt.

e. Keines der genannten

Meine Marktanalyse war nicht erfolgreich:

a. Ich kenne die Marktnachfrage nicht. Mein Wettbewerber kennt die Marktnachfrage definitiv nicht.

b. Ich kenne die Marktnachfrage nicht. Mein Wettbewerber kennt die Marktnachfrage definitiv.

c. Ich kenne die Marktnachfrage zum Zeitpunkt der Produktionsentscheidung nur, falls die Marktanalyse des Wettbewerbers erfolgreich war und er mir Informationen übermittelt hat.

d. Ich kenne die Marktnachfrage.

e. Keines der genannten

Ihr Wettbewerber hat mitgeteilt, dass die Marktnachfrage „niedrig“ ist:

a. Die Marktnachfrage ist mit absoluter Sicherheit niedrig, da keine falschen Informationen übermittelt werden können.

b. Die Marktnachfrage könnte hoch sein, falls der Wettbewerber bewusst eine falsche Information gesendet hat.

c. Keines der genannten

Instruktionen Teil III

Dieser Teil ist eine Erweiterung des Experimentes aus Teil II. Eine Abteilung übernimmt nun die Aufgabe den Wettbewerber zu „informieren"/„nicht (zu) informieren". Sie erteilen der Fachabteilung die Anweisung in welchen Fällen die Informationen übermittelt werden sollen. Die Entscheidung über die Produktionsmenge treffen Sie weiterhin selbst. Gleiches gilt für Ihren Wettbewerber. Die Wahrscheinlichkeiten für die Marktnachfrage, Ihre Marktanalyse und die Marktanalyse des Wettbewerbers bleiben wie in Teil II. Die Zuordnung Ihres Wettbewerbers wird weiterhin durch den Zufall bestimmt.

Teil III des Experimentes besteht aus einer Runde mit folgendem Ablauf:

Zu Beginn der Runde kennen Sie das Ergebnis Ihrer Marktanalyse nicht. **Sie geben jedoch Ihrer Fachabteilung verbindliche Anweisungen in welchen Fällen diese den Wettbewerber über die Marktnachfrage informieren soll**, falls die Marktanalyse erfolgreich ist.

Sie haben hierbei 4 Optionen:

1. **Niemals informieren**
   Der Wettbewerber kennt die Marktnachfrage nur, wenn seine eigene Marktanalyse erfolgreich war. Er weiß nicht, ob Sie die Höhe der Marktnachfrage erfahren haben.

2. **Nur bei niedriger Nachfrage informieren**
   Fall 1: Marktanalyse ist erfolgreich und Marktnachfrage ist niedrig
   Der Wettbewerber weiß mit Sicherheit, dass die Marktnachfrage niedrig ist. Ebenfalls weiß der Wettbewerber, dass Sie die Höhe der Marktnachfrage erfahren haben.
   Fall 2: Marktanalyse ist nicht erfolgreich und/oder die Marktnachfrage ist hoch
   Der Wettbewerber kennt die Marktnachfrage nur, wenn seine eigene Marktanalyse erfolgreich war. Er weiß nicht, ob Sie die Höhe der Marktnachfrage erfahren haben.

3. **Nur bei hoher Nachfrage informieren**
   Fall 1: Marktanalyse ist erfolgreich und Marktnachfrage ist hoch
   Der Wettbewerber weiß mit Sicherheit, dass die Marktnachfrage hoch ist. Ebenfalls weiß er, dass Sie die Höhe der Marktnachfrage erfahren haben.
   Fall 2: Marktanalyse ist nicht erfolgreich und/oder die Marktnachfrage ist niedrig
   Der Wettbewerber kennt die Marktnachfrage nur, wenn seine eigene Marktanalyse erfolgreich war. Er weiß nicht, ob Sie die Höhe der Marktnachfrage erfahren haben.

4. **Immer informieren**
   Fall 1: Marktanalyse ist erfolgreich
   Der Wettbewerber weiß mit Sicherheit, dass die Marktnachfrage hoch/niedrig ist. Ebenfalls weiß er, dass Sie die Höhe der Marktnachfrage erfahren haben.
   Fall 2: Marktanalyse ist nicht erfolgreich
   Der Wettbewerber kennt die Marktnachfrage nur, wenn seine eigene Marktanalyse erfolgreich war. Er weiß nicht, ob Sie die Höhe der Marktnachfrage erfahren haben.

Hieran anschließend wird Ihnen, wie bisher, mitgeteilt, ob ihre Marktanalyse erfolgreich war und ob Sie eine Information vom Wettbewerber erhalten haben.

Es folgt wie in Teil II die Entscheidung über die Produktionsmenge. Danach wird das Rundenergebnis in gewohnter Form mitgeteilt.

Am Ende des Experimentes werden alle Rundengewinne in EURO umgerechnet und Ihnen ausbezahlt.

Chapter 4

Robust Mechanism Design and Social Preferences*

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Abstract

We study two classic challenges in mechanism design – bilateral trade à la Myerson and Satterthwaite (1983) and redistributive income taxation à la Mirrlees (1971) and Piketty (1993) – to show that some standard mechanism design solutions systematically fail with social preferences. We thus introduce the notion of a social-preference-robust mechanism which works not only for selfish but also for social preferences of different nature and intensity, and characterize the optimal mechanism in this class. With the help of a series of laboratory experiments we find that behavior can indeed be better controlled with social-preference-robust mechanisms.

Keywords: Robust Mechanism Design, Social Preferences, Bilateral Trade, Income Taxation, Laboratory Experiment

JEL Codes: C92, D02, D03, D82, H2

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4.1 Introduction

Inspired by Wilson (1987), Bergemann and Morris (2005) have provided a formalization of mechanisms that are robust in the sense that they do not rely on a common prior distribution of material payoffs. We add another dimension in which we seek robustness. A mechanism that works well under selfish preferences might fail under social preferences. Indeed, behavioral economics has shown that many agents behave socially. One challenge is, though, that social preferences can differ with respect to their nature and intensity, leading to different kinds of social preference models, including altruism, inequity-aversion, and intentionality (Cooper and Kagel (2013)). Because we want a mechanism to work not only for selfish preferences but also for a large set of social preferences, we introduce the notion of social-preference-robust mechanism: a mechanism must not depend on specific assumptions about the nature and intensity of selfish and social preferences.

In this paper, we show theoretically that optimal mechanisms that are derived under the assumption of selfish preferences may not generate the intended behavior if individuals have social preferences. Second, and most importantly, we introduce the notion of a social-preference-robust mechanism and derive mechanisms that are optimal in this class. Finally, we use laboratory experiments to demonstrate that social preferences are a non-negligible factor in our context, and to compare the performance of the optimal mechanisms under selfish preferences and the optimal social-preference-robust mechanisms.

For the applications studied in this paper, the notion of robustness due to Bergemann and Morris is equivalent to the requirement that a mechanism has a dominant strategy equilibrium. Depending on the application, this may significantly restrict the set of implementable outcomes.[1] Thus, there may be the concern that adding another robustness-requirement will restrict the set of admissible mechanisms even further and is therefore problematic. In our view, comparing mechanisms that, according to theory, sacrifice performance for a more robust solution concept to mechanisms that, according to theory, sacrifice robustness in return for performance, is ultimately an empirical question. Our laboratory experiments are first steps in this direction.

[1]For instance, Hagerty and Rogerson (1987) study the bilateral trade-problem due to Myerson and Satterthwaite (1983) and show that, with incentive and participation constraints that are robust in the Bergemann and Morris (2005)-sense, the set of admissible mechanisms is heavily restricted. For other applications, there is no restriction at all. For instance, for a problem of redistributive income taxation, Bierbrauer (2011) shows that there is an optimal mechanism with a dominant strategy equilibrium.

Throughout, we use two classic applications of mechanism design theory, a version of the bilateral-trade problem due to Myerson and Satterthwaite (1983) and versions of the optimal income tax problem due to Mirrlees (1971) and Piketty (1993) to illustrate our theoretical analysis.

The bilateral trade problem. The bilateral-trade problem provides us with a simple, and stylized setup that facilitates a clear exposition of our approach. Moreover, it admits interpretations that are of interest in public economics, environmental economics, or contract theory. The basics are as follows: A buyer either has a high or low valuation of a good produced by a seller. The seller either has a high or a low cost of producing the good. An economic outcome specifies, for each possible combination of the buyer's valuation and the seller's cost, the quantity to be exchanged, the price paid by the buyer and the revenue received by the seller. Both the buyer and the seller have private information. Thus, an allocation mechanism has to ensure that the buyer does not understate his valuation so as to get a desired quantity at a lower price. Analogously, the seller has to be incentivized so that she does not exaggerate her cost in order to receive a larger compensation.

The essence of the bilateral trade problem is that there are two parties and that each party has private information on its benefits (or costs) from a transaction with the other party. The labels "buyer" and "seller" need not to be taken literally. This environment can be reinterpreted as a problem of public-goods provision in which one party (the buyer) benefits from larger provision levels whereas the other party (the seller) bears a cost. By how much the first party benefits and the second party loses is private information. It can also be reinterpreted as a problem to control externalities. One party (the seller) can invest so as to avoid emissions which harm the other party (the buyer). The cost of the investment to one party and the benefit of reduced emissions to the other party are private information. In a principal-agent-framework, we may think of one party (the buyer) as benefiting from effort that is exerted by the other party (the seller). The size of the benefit and the disutility of effort are, respectively, private information of the principal and the agent.

Our analysis proceeds as follows: We first characterize an optimal direct mechanism for the bilateral trade problem under the standard assumption of selfish preferences, i.e. both, the buyer and the seller, are assumed to maximize their own payoff, respectively, and this is common knowledge. We solve for the mechanism that maximizes the seller's expected profits subject to incentive constraints, participation constraints, and a resource constraint. We work with *ex post* incentive and participation constraints, i.e. we insist that after the outcome of the mechanism and the other party's private information have become known, no party regrets to have participated and to have revealed its own information.

As has been shown by Bergemann and Morris (2005), ex post constraints imply that a mechanism is robust in the sense that its outcome does not depend on the individual's probabilistic beliefs about the other party's private information. Moreover, we use the arguments in Bergemann and Morris (2005) for our experimental testing strategy. In their characterization of robust mechanisms *complete information environments* play a key role. In such an environment, the buyer knows the seller's cost and the seller knows the buyer's valuation, and, moreover, this is commonly known among them. The mechanism designer, however, lacks this information and therefore still has to provide incentives for a revelation of privately held information. Bergemann and Morris provide conditions so that the requirement of robustness is equivalent to the requirement that a mechanism generates the intended outcome in every complete information environment, which in turn is equivalent to the requirement that incentive and participation constraints hold in an *ex post* sense.[2]

In our laboratory approach, we investigate the performance of an optimally designed robust mechanism in all complete information environments. This approach is useful because it allows us to isolate the role of social preferences in a highly controlled setting, which eliminates complications that are related to decision-making under uncertainty. For instance, it is well-known that, even in one-person decision tasks, people often do not maximize expected utility (see Camerer (1995)), and that moreover, in social contexts, social and risk preferences may interact in non-trivial ways (see, e.g., Bolton and Ockenfels (2010), and the references therein). The complete information environments in our study avoid such complicating factors.[3]

For the bilateral trade problem, the mechanism which maximizes the seller's expected profits under selfish preferences has the following properties: (i) The trading surplus is allocated in an asymmetric way, i.e. the seller gets a larger fraction than the buyer; (ii) Whenever the buyer's valuation is low, his participation constraint binds, so that he does not realize any gains from trade; (iii) Whenever the buyer's

[2]Throughout we focus on social choice functions, as opposed to social choice correspondences. Consequently, by Corollary 1 in Bergemann and Morris (2005), *ex post* implementability is both necessary and sufficient for robust implementability. Moreover, if agents are selfish, then our environment gives rise to private values so that incentive compatibility in an *ex post* sense is equivalent to the requirement that truth-telling is a dominant strategy under a direct mechanism for the given social choice function.

[3]Thus, for our experimental testing strategy, we take for granted the equivalence between implementability in all complete information environments and implementability in all incomplete information environments. We explicitly investigate the former and draw conclusions for the latter. We also take for granted the validity of the revelation principle. That is, we only check whether individuals behave truthfully under a direct mechanism for a given social choice function. We discuss the advantages and limits of this approach in our concluding section.

valuation is high, his incentive constraint binds, so that he is indifferent between revealing his valuation and understating it. Experimentally, we find that under this mechanism, a non-negligible fraction of high valuation buyers understates their valuation. In all other situations, deviations — if they occur at all — are significantly less frequent.

We argue that this pattern is consistent with models of social preferences such as Fehr and Schmidt (1999), and Falk and Fischbacher (2006), among others. The basic idea is the following. A buyer with a high valuation can understate his valuation at a very small personal cost since the relevant incentive constraint binds. The benefit of this strategy is that this reduces the seller's payoff and therefore brings the seller's payoff closer to his own, thereby reducing inequality. In fact, as we will demonstrate later, many social preference models would predict this behavior.

We then introduce a class of direct mechanisms that "work" if the possibility of social preferences is acknowledged. Specifically, we introduce the notion of a direct mechanism that is externality-free. Under such a mechanism, the buyer's equilibrium payoff does not depend on the seller's type and vice versa; i.e. if, say, the buyer reveals his valuation, his payoff no longer depends on whether the seller communicates a high or a low cost to the mechanism designer. Hence, the seller cannot influence the buyer's payoff.

Almost all widely-used models of social preferences satisfy a property of selfishness in the absence of externalities, i.e. if a player considers a choice between two actions a and b, and moreover, if the monetary payoffs of everybody else are unaffected by this choice, then the player will choose a over b if her own payoff under a is higher than her own payoff under b. Now, suppose that a direct mechanism is *ex post* incentive-compatible and externality-free. Then truth-telling will be an equilibrium for any social preference model in which individuals are selfish in the absence of externalities.

We impose externality-freeness as an additional constraint on our problem of robust mechanism design. We then characterize the optimal robust and externality-free mechanism and investigate its performance in an experiment. We find that there are no longer deviations from truth-telling. We interpret this finding as providing evidence for the relevance of social preferences in mechanism design: If there are externalities a significant fraction of individuals deviates from truth-telling. If those externalities are shut down, individuals behave truthfully.

Externality-freeness is an additional constraint. While it makes sure that individuals behave in a predictable way it reduces expected profits relative to the theoretical benchmark of a model with selfish preferences. This raises the question whether the seller makes more money if she uses an externality-free mechanism. We answer this both theoretically and empirically: The externality-free mechanism makes more money if the number of participants whose behavior is motivated by social preferences exceeds a threshold. In our laboratory context, this number was below the threshold, so that the "conventional" mechanism made more money than the externality-free mechanism.

Based on these observations, we finally engineer a mechanism that satisfies the property of externality-freeness only locally. Specifically, we impose externality-freeness for those action-profiles where deviations from selfish behavior were frequently observed in our experiment data. We show theoretically that local externality-freeness is a constraint that can be satisfied without having to sacrifice performance: If all agents are selfish then there is an optimal mechanism that is locally externality-free. In our experiment data, however, an optimal mechanism that is locally externality-free performs significantly better than an optimal mechanism that is not externality-free. Hence, if one knows precisely which deviations from selfish behavior are tempting, one can design a mechanism that performs strictly better than both the optimal mechanism for selfish agents and the optimal globally externality-free mechanism.

Income Taxation. The bilateral trade setup is one in which externalities are at the center of the allocation problem: More consumption for the buyer can be realized only with higher costs for the seller, and additional revenue for the seller can only be realized if the buyer pays more. Hence, it seems natural that the buyer's behavior will affect the seller's payoff and vice versa. A requirement of externality-freeness which shuts down this interdependence may therefore appear demanding. In settings different from the bilateral trade problem, externality-freeness may arise naturally. For example, price-taking behavior in markets with a large number of participants gives rise to externality-freeness. If a single individual changes her demand, this leaves prices unaffected and so remain the options available to all other agents. Market behavior is therefore unaffected by social preferences, see Dufwenberg et al. (2011). Another setting in which externality-freeness may appear natural is the design of tax systems. Here, externality-freeness requires that income taxes paid by one individual depend only on this individual's income, and not on the income earned by other individuals. Thus, when formalizing the modern approach to optimal income taxation, Mirrlees (1971) and his followers have looked exclusively at externality-free allocations.

However, as has been shown by Piketty (1993), for an economy with finitely many individuals and a commonly known cross-section distribution of types, an optimal Mirrleesian income tax system can be outperformed by one that is *not* externality-free. Specifically, Piketty shows that first-best utilitarian redistribution from high-skilled individuals to low-skilled individuals can be reached, while this is impossible with a Mirrleesian approach. A crucial feature of Piketty's approach is that types are assumed to be correlated in a particular way. For instance, if there are two individuals and it is commonly known that one of them is high-skilled and one is low-skilled, then the individuals' types are perfectly negatively correlated: If person 1 is of high ability, then person 2 is of low ability and vice versa. Piketty's construction of a mechanism that reaches the first-best utilitarian outcome heavily exploits this feature of the environment. If individual types are the realizations of independent random variables, then the optimal mechanism is externality-free, see Bierbrauer (2011).

Piketty's observations challenge the appeal of the Mirrleesian approach to tax policy in the same way as the seminal analysis of Atkinson and Stiglitz (1976) has challenged Ramsey models of taxation: Atkinson and Stiglitz argued that the Ramsey approach lacks a satisfactory theoretical foundation as it is based on an optimization in a set of policies that can be shown to be suboptimal. Piketty's analysis also resembles the possibility results by Crémer and McLean (1985, 1988) in auction theory. There are also some important differences though. Piketty uses the solution concept of a dominant strategy equilibrium which implies that his approach is robust in the sense of Bergemann and Morris (2005). The approach of Crémer and McLean is based on the solution concept of a Bayes-Nash equilibrium and strongly depends on specific properties of a common prior. It is therefore not robust in the sense of Bergemann and Morris (2005). Crémer and McLean have shown that, with correlated values and selfish agents, there exist Bayes-Nash equilibria that achieve first-best outcomes. These findings have then been generalized to other types of allocation problems, see e.g., Kosenok and Severinov (2008). Importantly, the mechanisms that achieve first-best outcomes in the presence of correlated types give rise to payoff interdependencies or externalities among the players. Therefore, they raise the question whether social preferences might interfere with the possibility to achieve first-best outcomes. Piketty's treatment of the income tax problem is an example that allows us to get at this more general question in a particular context.

We run an experiment and show that Piketty's mechanism indeed provokes deviations from the intended behavior, and again, we argue that these deviations can be explained by models of social preferences. We then compare Piketty's mechanism to an optimal Mirrleesian mechanism. The latter is externality-free and we find that it successfully controls behavior; there are no longer significant deviations from truth-telling. We also find that the level of welfare that is generated by the Mirrleesian mechanism is significantly larger than the level of welfare generated by Piketty's mechanism. This last observation makes an interesting difference to our findings for the bilateral trade problem. With the income tax problem, imposing externality-freeness is also good for the performance of the mechanism. The difference is not due to different social preferences, but reflects the fact that the externality-free mechanism is preferable only if the number of socially motivated agents exceeds a threshold. For the simple illustrative models that we use in the experiment, this threshold is much larger for the bilateral trade problem (and too large for what we observe in the laboratory).

Outline. The next section discusses related literature. In Section 4.3 we elaborate on why models of social preferences are consistent with the observation that individuals deviate from truth-telling under a mechanism that would be optimal if all individuals were selfish, and with the observation that they do not deviate under a mechanism that is externality-free. It also contains a detailed description of the bilateral trade problem that we study. In addition, Section 4.4 describes our laboratory findings for the bilateral trade problem, and in Section 4.5, we clarify the conditions under which an optimal externality-free mechanism outperforms an optimal mechanism for selfish agents and relate them to our experiment data. Section 4.6 contains our analysis of the income tax problem. The last section concludes.

4.2 Related literature

There is a rich literature on models of social preferences. Within this literature there are different subcategories, such as, for instance, the distinction between outcomes-based and intention-based models of social preferences. Well-known models of outcomes-based social preferences are Fehr and Schmidt (1999) and Bolton and Ockenfels (2000). Models of intention-based social preferences include Rabin (1993) and Falk and Fischbacher (2006). There is a large literature on mechanism design with interdependent valuations, see e.g. the survey in Jehiel and Moldovanu (2006). In principle, models of outcomes-based social preferences can be viewed as specific models with interdependent valuations. By contrast, models with intention-based social preferences cannot be viewed as models with interdependent valuations. In these models, preferences are menu-dependent, see Sobel (2005) for a discussion.

Such a menu dependence does not arise in the literature on mechanism design with interdependent valuations. We introduce social preferences into a model of robust mechanism design. This complements the analysis of Bergemann and Morris (2005) who were seeking robustness with respect to the specification of the individuals' probabilistic beliefs.

Our work builds on earlier contributions by Bierbrauer and Netzer (2016) and Bartling and Netzer (2016), see also Netzer and Volk (2014) for an extension of some of the analysis in Bierbrauer and Netzer (2016). These papers share the broad motivation to incorporate social preferences into mechanism design. There are, however, important differences. Bierbrauer and Netzer (2016) and Netzer and Volk (2014) focus on a specific model of social preference, the intention-based model of Rabin (1993), so that there is no concern for social-preference robustness. Bartling and Netzer (2016) discuss a broader class of social-preferences and study a race between an auction format that is social-preference-robust but requires Bayesian sophistication and an auction format that is Bergemann-Morris-robust but not social preference-robust. In this paper, we formalize social-preference-robustness and, moreover, make sure that we do not sacrifice robustness with respect to specification of probabilistic beliefs along the way. We can then have a race between mechanisms that are social-preference-robust and mechanisms that are optimal if agents are selfish – subject to the constraint that all of these mechanisms are Bergemann-Morris-robust. An advantage of this approach is that we can be more confident to identify the role of social preferences, as opposed to the limits to Bayesian sophistication.

For the purpose of illustration, we focus on two classic applications of mechanism design, the bilateral trade problem and the problem of redistributive income taxation. Myerson and Satterthwaite (1983) establish an impossibility result for efficient trade in a setting with two privately informed parties.[4] Our focus is different. We look at a second-best mechanism for this problem and ask how its performance is affected by social preferences. The classical reference for redistributive income taxation is Mirrlees (1971). We relate the Mirrleesian treatment to an alternative one that has been proposed by Piketty (1993).[5]

There is a large experimental economics literature testing mechanisms. Most laboratory studies deal with mechanisms to overcome free-riding in public goods environments (Chen (2008)), auction design (e.g., Ariely et al. (2005), Kagel et al.

[4]Related impossibility results hold for problems of public-goods provision, see Güth and Hellwig (1986) and Mailath and Postlewaite (1990).

[5]The mechanism design approach to the problem of optimal income taxation is also discussed in Hammond (1979), Stiglitz (1982), Dierker and Haller (1990), Guesnerie (1995), and Bierbrauer (2011).

(2010)), and the effectiveness of various matching markets (e.g., Kagel and Roth (2000), Chen and Sönmez (2006)). Roth (2012) provides a survey. Some studies take into account social preferences when engineering mechanisms. For instance, it has been shown that feedback about others' behavior or outcomes, which would be irrelevant if agents were selfish, can strongly affect social comparison processes and reciprocal interaction, and thus the effectiveness of mechanisms to promote efficiency and resolve conflicts (e.g., Chen et al. (2010), Bolton et al. (2013), Ockenfels et al. (2014); Bolton and Ockenfels (2012) provide a survey). Social preferences are also important in bilateral bargaining with complete information, most notably in ultimatum bargaining (Güth et al. (1982); Güth and Kocher (2013) provide a survey). In fact, this literature has been a starting point for various social preference models that we are considering in this paper — yet the observed patterns of behavior have generally not been related to the mechanism design literature. This is different with laboratory studies of bilateral trade with incomplete information, such as Radner and Schotter (1989), Valley et al. (2002) and Kittsteiner et al. (2012). One major finding in this literature is, for instance, that cheap talk communication among bargainers can significantly improve efficiency. These findings are generally not related to social preference models, though.

4.3 Mechanism design with and without social preferences

This section contains theoretical results which relate mechanism design theory to models of social preferences. Throughout, we use the bilateral trade problem to illustrate the conceptual questions that arise. We begin with the benchmark of optimal mechanism design under the assumption that individuals are purely selfish. We then show that many models of social preferences give rise to the prediction that such mechanisms will not generate truthful behavior. However, while maximizing expected payoffs is a well-defined goal, there are many ways to be socially motivated. In fact, one of the most robust insights from behavioral economics and psychology is the large variance of social behaviors across individuals (e.g., Camerer (2003)). As a result, there is now a plethora of social preference models, and almost all models permit individual heterogeneity by allowing different parameter values for different individuals (e.g., Cooper and Kagel (2013)). This poses a problem for mechanism design because optimal mechanisms depend on the nature of the agents' preferences. Our approach to deal with this problem is neither to just select one of those models, nor are we even attempting to identify the best model. We will also not assume that idiosyncratic social preferences are commonly known. All these approaches would violate the spirit of robust mechanism design. Rather, we restrict our attention to a property of social preferences which is shared by almost all widely-used social preference models and which is independent of the exact parameter values: individuals maximize their own payoffs, regardless of their social preferences, if there is no possibility to affect the payoffs of others. As we will show, this general property of social behavior is sufficient to construct "externality-free" mechanisms which generate truthful behavior, regardless of what is known about the specific type and parameters of the agents' social preferences.

There are two dimensions in this comparison of social choice functions that are externality-free with social choice functions that are implementable if individuals are selfish. First, we ask, whether, under a direct mechanism, individual behavior is as intended by the mechanism designer. Second, we use welfare measures to compare the performances of these social choice functions.

The second comparison is complicated by the need to provide an answer to the following question: What is the appropriate objective function for a mechanism design approach that seeks robustness with respect to the nature and intensity of social preferences? The conventional approach in welfare economics would be to postulate a social welfare objective that respects individual preferences and hence is a non-decreasing function of any one individual's utility. If, for instance, individuals have social preferences that exhibit inequity aversion as in the social preferences models of Fehr and Schmidt (1999) or Bolton and Ockenfels (2000) then the individuals' inequity aversion should be reflected in the social welfare function. If individuals have intention-based social preferences as in the models of Rabin (1993) or Falk and Fischbacher (2006) then the individuals' experiences of kindness in the interaction with others should show up in the social welfare function. Thus, the appropriate objective function depends itself on the nature and the intensity of the individuals' social preferences.

All social preference models allow that the individuals' preferences put some or all weight on own payoffs. Inequity aversion models additionally involve a disutility that is associated with unequal outcomes. As will become clear from our characterizations below, if we impose externality-freeness as an additional constraint, the resulting social choice functions will be more egalitarian than the ones that result from a conventional mechanism design approach under the assumption that individuals are selfish. Consequently, if individuals assign sufficient weight to the disutility of unequal outcomes then the externality-free social choice function generates more welfare than a social choice function that is incentive-compatible, but not externality-free. The more interesting question is therefore whether the externality-free social choice function outperforms the conventional social choice function even if the weight on the social preference term is small. We will focus on this case and ask whether the performance of an externality-free social choice function is higher under the extreme assumption that social preferences receive zero weight in the welfare objective.

Analogously, the utility function that is invoked by models of intention-based social preferences involves not only a concern for selfish payoff but also for the kindness or unkindness experienced in the interaction with others. If we impose externality-freeness, then – according to Rabin (1993) and Falk and Fischbacher (2006) – the kindness term takes a value of zero because individuals no longer have a chance of affecting each other's payoffs. By contrast, a truthful equilibrium of a direct mechanism for an incentive compatible social choice function generates an equilibrium kindness that is negative: If individuals behave selfishly this means that opportunities to make others better off remain unused so that kindness cannot become positive. Again, if kindness sensations receive sufficient weight in the individuals' utility functions, then the externality-free social choice function will generate more welfare. It is therefore more challenging to check whether the externality-free social choice function looks better even with a small weight on kindness sensations. If the externality-free social choice function generates more welfare even with a zero weight on kindness, we can conclude that the externality-free social choice function outperforms the conventional social function, whatever the weight on kindness sensations in the welfare objective.

4.3.1 The bilateral trade problem

There are two agents, referred to as the buyer and the seller. An economic outcome is a triple (q, p_s, p_b), where $q \in \mathbb{R}_+$ is the quantity that is traded, $p_b \in \mathbb{R}$ is a payment made by the buyer, and $p_s \in \mathbb{R}$ is a payment received by the seller. Monetary payoffs are $\pi_b = \theta_b q - p_b$, for the buyer and $\pi_s = -\theta_s k(q) + p_s$, for the seller where k is an increasing and convex cost function. The buyer's valuation θ_b either takes a high or a low value, $\theta_b \in \Theta_b = \{\underline{\theta}_b, \bar{\theta}_b\}$. Similarly, the seller's cost parameter θ_s can take a high or a low value so that $\theta_s \in \Theta_s = \{\underline{\theta}_s, \bar{\theta}_s\}$. A pair $(\theta_b, \theta_s) \in \Theta_b \times \Theta_s$ is referred to as a state of the economy. A social choice function or direct mechanism f : $\Theta_b \times \Theta_s \to \mathbb{R}_+ \times \mathbb{R} \times \mathbb{R}$ specifies an economic outcome for each state of the economy. Occasionally, we write $f = (q^f, p_b^f, p_s^f)$ to distinguish the different components of f.[6]

[6]Our setting differs from the one originally studied by Myerson and Satterthwaite (1983) in that we have a convex cost function for the seller and allow for quantities in $\mathbb{R}_+$. In the original paper,

With a requirement of ex post budget balance, the price paid by the buyer equals the price received by the seller in every state of the world, i.e. for all (θ_b, θ_s), $p_b^f(\theta_b, \theta_s) = p_s^f(\theta_b, \theta_s)$. Below, we also formalize a requirement of expected budget balance. This allows for states in which the payment of the buyer is not equal to the payment received by the seller, as long as they are equal when computing an average across states. (Possibly, the mechanism is executed frequently, so that the designer expects to break even if budget balance holds on average.) The flexibility provided by the requirement of expected budget balance is important for some of the results that follow. With a requirement of *ex post* budget balance there is less scope for adjusting the traded quantities and the corresponding payments to the privately held information of the buyer and the seller.[7]

We denote by

$$\pi_b(\theta_b, f(\theta_b', \theta_s')) := \theta_b q^f(\theta_b', \theta_s') - p_b^f(\theta_b', \theta_s')$$

the payoff that is realized by a buyer with type θ_b if he announces a type θ_b' and the seller announces a type θ_s' under direct mechanism f. The expression $\pi_s(\theta_s, f(\theta_b', \theta_s'))$ is defined analogously.

We assume that the buyer has private information on whether his valuation θ_b is high or low. Analogously, the seller privately observes whether θ_s takes a high or a low value. Hence, a direct mechanism induces a game of incomplete information. Our analysis in the following focuses on a very specific and artificial class of incomplete information environments, namely the ones in which the types are commonly known among the players but unknown to the mechanism designer. In total there are four such complete information environments, one for each state of the economy. "Complete information" refers to a situation in which the players' monetary payoffs are commonly known. Information may still be incomplete in other dimensions, e.g., regarding the weight of fairness considerations in the other player's utility function. It has been shown by Bergemann and Morris (2005) that

the seller's cost function is linear and quantities are in $[0, 1]$ so that constrained efficient social choice functions take values in $\{0, 1\}$, either there is trade or there is no trade. In our setting, constrained efficient social choice functions do not have this "all-or-nothing" property. Instead, quantities vary with the state of the economy. As will become clear, optimal social choice functions are then characterized by binding incentive and participation constraints that give rise to a familiar pattern with "downward distortions at the bottom" and "no distortions at the top". This facilitates the discussion of the relevance of social preferences for mechanism design.

[7]We do not wish to argue that the requirement of expected budget balance is, for practical purposes, more relevant than the requirement of *ex post* budget balance. This will depend on the application. The mechanisms that we study in this paper are primarily meant as diagnostic tools for the relevance of social preferences in mechanism design. In this respect, the requirement of expected budget balance proves useful.

the implementability of a social choice function in all such complete information environments is not only necessary but also sufficient for the robust implementability of a social choice function, i.e. for its implementability in all conceivable incomplete information environments. Thus, our focus on complete information environments is not only useful to cleanly isolate the effect of social preferences, but also justified by the robustness criterion.

Suppose that individuals are only interested in their own payoff. Then truth-telling is an equilibrium in all complete information environments if and only if the following *ex post* incentive compatibility constraints are satisfied: For all $(\theta_b, \theta_s) \in \Theta_b \times \Theta_s$,

$$\pi_b(\theta_b, f(\theta_b, \theta_s)) \geq \pi_b(\theta_b, f(\theta_b', \theta_s)) \quad \text{for all} \quad \theta_b' \in \Theta_b \;, \tag{4.1}$$

and

$$\pi_s(\theta_s, f(\theta_b, \theta_s)) \geq \pi_s(\theta_s, f(\theta_b, \theta_s')) \quad \text{for all} \quad \theta_s' \in \Theta_s \;. \tag{4.2}$$

Moreover, individuals prefer to play the mechanism over a status quo outcome with no trade if and only if the following *ex post* participation constraints are satisfied: For all $(\theta_b, \theta_s) \in \Theta_b \times \Theta_s$,

$$\pi_b(\theta_b, f(\theta_b, \theta_s)) \geq 0 \quad \text{and} \quad \pi_s(\theta_s, f(\theta_b, \theta_s)) \geq 0 \;. \tag{4.3}$$

In the body of the text, we limit attention to direct mechanisms and to truth-telling equilibria. For models with selfish individuals, or more generally, for models with outcome-based preferences – which possibly include a concern for an equitable distribution of payoffs – this is without loss of generality by the revelation principle. For models with intention-based social preferences, such as Rabin (1993) or Dufwenberg and Kirchsteiger (2004), the revelation principle does not generally hold, see Bierbrauer and Netzer (2016) for a proof. Still, it is a sufficient condition for the implementability of a social choice function that it can be implemented as the truth-telling equilibrium of a direct mechanism. We focus on this sufficient condition. It can also be viewed as a necessary condition for social preference robustness because there is a class of social preference models – namely those with outcomes-based preferences – that require the implementability as the truthful equilibrium of a direct mechanism.

Another property of interest to us is the externality-freeness of a social choice function f. This property holds if, for all $\theta_b \in \Theta_b$,

$$\pi_b(\theta_b, f(\theta_b, \underline{\theta}_s)) = \pi_b(\theta_b, f(\theta_b, \bar{\theta}_s)),$$

and if, for all $\theta_s \in \Theta_s$,

$$\pi_s(\theta_s, f(\underline{\theta}_b, \theta_s)) = \pi_s(\theta_s, f(\bar{\theta}_b, \theta_s)).$$

If these properties hold, then the buyer, say, cannot influence the seller's payoff, provided that the latter tells the truth. I.e. the buyer's report does not come with an externality on the seller. As we will argue later in more detail, many models of social preferences give rise to the prediction that externality-freeness in conjunction with *ex post* incentive compatibility is a sufficient condition for the implementability of a social choice function.

4.3.2 Optimal mechanism design under selfish preferences

A mechanism designer wishes to come up with a mechanism for bilateral trade. Design takes place at the *ex ante* stage, i.e. before the state of the economy is realized. The designer acts in the interest of one of the parties, here the seller. The designer does not know what information the buyer and the seller have about each other at the moment where trade takes place. Hence, he seeks robustness with respect to the information structure and employs *ex post* incentive and participation constraints. The designer assumes that individuals are selfish so that these constraints are sufficient to ensure that individuals are willing to play the corresponding direct mechanism and to reveal their types. Finally, he requires budget balance only in an average sense, see equation (4.4) below.

Formally, we assume that a social choice function f is chosen with the objective to maximize expected seller profits, $\sum_{\Theta_b \times \Theta_s} g(\theta_b, \theta_s)\pi_s(\theta, f(\theta_b, \theta_s))$, where g is a probability mass function that gives the mechanism designer's subjective beliefs on the likelihood of the different states of the economy. The incentive and participation constraints in (4.1), (4.2) and (4.3) have to be respected. In addition, the following resource constraint has to hold

$$\sum_{\Theta_b \times \Theta_s} g(\theta_b, \theta_s) p_b^f(\theta_b, \theta_s) \geq \sum_{\Theta_b \times \Theta_s} g(\theta_b, \theta_s) p_s^f(\theta_b, \theta_s) \; . \tag{4.4}$$

To solve this *full problem*, we first study a *relaxed problem* which leaves out the incentive and participation constraints for the seller. Proposition 1 characterizes its solution. This solution to the relaxed problem is also a solution to the full problem if it satisfies all constraints of the full problem, as is the case for Example 1 below.

Proposition 1. *A social choice function f solves the relaxed problem of robust mechanism design if and only if it has the following properties:*

(a) For any one $\theta_s \in \Theta_s$, the participation constraint of a low type buyer is binding:

$$\pi_b(\underline{\theta}_b, f(\underline{\theta}_b, \theta_s)) = 0 \ .$$

(b) For any one $\theta_s \in \Theta_s$, the incentive constraint of a high type buyer is binding:

$$\pi_b(\overline{\theta}_b, f(\overline{\theta}_b, \theta_s)) = \pi_b(\overline{\theta}_b, f(\underline{\theta}_b, \theta_s)) \ .$$

(c) The trading rule is such that, for any one $\theta_s \in \Theta_s$, there is a downward distortion at the bottom

$$q^f(\underline{\theta}_b, \theta_s) \quad \in \quad argmax_q \left(\underline{\theta}_b - \frac{g(\overline{\theta}_b, \theta_s)}{g(\underline{\theta}_b, \theta_s)}(\overline{\theta}_b - \underline{\theta}_b) \right) q - \theta_s k(q) \ ,$$

and no distortion at the top

$$q^f(\overline{\theta}_b, \theta_s) \quad \in \quad argmax_q \ \overline{\theta}_b q - \theta_s k(q) \ .$$

(d) The payment rule for the buyer is such that, for any one θ_s,

$$p_b^f(\underline{\theta}_b, \theta_s) = \underline{\theta}_b q^f(\underline{\theta}_b, \theta_s) \ ,$$

and

$$p_b^f(\overline{\theta}_b, \theta_s) = \overline{\theta}_b q^f(\overline{\theta}_b, \theta_s) - (\overline{\theta}_b - \underline{\theta}_b) q^f(\underline{\theta}_b, \theta_s) \ .$$

(e) The revenue for the seller is such that

$$\sum_{\Theta_b \times \Theta_s} g(\theta_b, \theta_s) p_b^f(\theta_b, \theta_s) = \sum_{\Theta_b \times \Theta_s} g(\theta_b, \theta_s) p_s^f(\theta_b, \theta_s) \ .$$

A formal proof of Proposition 1 is provided in Appendix 4.B. Here, we provide a sketch of the main argument: Since we leave out the seller's incentive constraint, we can treat the seller's cost parameter as a known quantity. Hence, we think of the relaxed problem as consisting of two separate profit-maximization problems, one for a high-cost seller and one for a low-cost seller, which are linked only via the resource constraint. In each of these problems, however, the buyer's incentive and participation constraints remain relevant. Therefore, we have two profit-maximization problems. The formal structure of any one of those problems is the same as the structure of a non-linear pricing problem with two buyer types. This problem is well-known so that standard arguments can be used to derive properties (a)-(e) above. A classical reference is Mussa and Rosen (1978), see Bolton and Dewatripont (2005) for a textbook treatment.

The solution to the relaxed problem leaves degrees of freedom for the specification of the payments to the seller. Consequently, any specification of the seller's revenues, so that the expected revenue is equal to the buyer's expected payment, is part of a solution to the relaxed problem. If there is one such specification that satisfies the seller's *ex post* incentive and participation constraints, then this solution to the relaxed problem is also a solution to the full problem. In the following we provide a specific example in which these payments are specified in such a way that they satisfy not only these constraints, but also give rise to *ex post* budget balance:[8] In every state (θ_b, θ_s), the price paid by the buyer equals the revenue obtained by the seller,

$$p_b^f(\theta_b, \theta_s) = p_s^f(\theta_b, \theta_s) \ . \tag{4.5}$$

Example 1: An optimal robust social choice function. Suppose that $\underline{\theta}_b = 1.00$, $\overline{\theta}_b = 1.30$, $\underline{\theta}_s = 0.20$, and $\overline{\theta}_s = 0.65$ and that the designer assigns equal probability mass to all possible combinations of buyer and seller types. Also assume that the seller has a quadratic cost function $k(q) = \frac{1}{2}q^2$. Finally, assume that the reservation utility levels of both the buyer and the seller are given by $\bar{\pi}_b = \bar{\pi}_s = 2.68$. For these parameters, an optimal robust social choice function f looks as follows: The traded quantities are given by

$$q^f(\underline{\theta}_b, \underline{\theta}_s) = 3.50, \ q^f(\underline{\theta}_b, \bar{\theta}_s) = 1.08, \ q^f(\bar{\theta}_b, \underline{\theta}_s) = 6.50 \quad \text{and} \quad q^f(\bar{\theta}_b, \bar{\theta}_s) = 2.00 \ .$$

The buyer's payments are

$$p_b^f(\underline{\theta}_b, \underline{\theta}_s) = 3.50, \ p_b^f(\underline{\theta}_b, \bar{\theta}_s) = 1.08, \ p_b^f(\bar{\theta}_b, \underline{\theta}_s) = 7.40 \quad \text{and} \quad p_b^f(\bar{\theta}_b, \bar{\theta}_s) = 2.28 \ .$$

Finally, the seller's revenues are

$$p_s^f(\underline{\theta}_b, \underline{\theta}_s) = 3.50, \ p_s^f(\underline{\theta}_b, \bar{\theta}_s) = 1.08, \ p_s^f(\bar{\theta}_b, \underline{\theta}_s) = 7.40 \quad \text{and} \quad p_s^f(\bar{\theta}_b, \bar{\theta}_s) = 2.28 \ .$$

[8] With bounded provision levels and linear costs, as in Myerson and Satterthwaite (1983), the optimal mechanism would not admit an implementation with *ex post* budget balance. This follows from Hagerty and Rogerson (1987). Thus, only with a convex cost function, there is an optimal mechanism for selfish agents that looks natural in the sense that, in every state, the buyer's payment is equal to the seller's revenue.

By construction, f is *ex post* incentive compatible and satisfies the *ex post* participation constraints. However, it is not externality-free.

These properties can be verified by looking at the games which are induced by this social choice function on the various complete information environments. For instance, the following matrix represents the normal form game that is induced by f in a complete information environment so that the buyer has a low valuation and the seller has a low cost.

More specifically, the payoffs in this and the following matrices result from affine transformations $\tilde{\pi}_b$ and $\tilde{\pi}^s$ of π_b and π^s, respectively, that are of no consequence for the validity of Proposition 1 (and of Propositions 3 and 5 below). We used these payoff matrices also for the laboratory experiments described in Section 4.4. The transformations were helpful in making sure that the participants earned 10 Euros on average.

Moreover, this and the following normal form games are generated by an approximation f^x of f which is such that, whenever an incentive constraint is binding under f, a deviation from truth-telling has a small cost of two cents under f^x. Our laboratory experiments used f^x rather than f. Thus, under f^x it is less tempting to deviate from truth-telling and we can be more confident that the deviations from truth-telling that we observe reflect social preferences, as opposed to an arbitrary selection from a set of best responses.

Table 1: The game induced by f for $(\theta_b, \theta_s) = (\underline{\theta}_b, \underline{\theta}_s)$.

$(\tilde{\pi}_b, \tilde{\pi}_s)$	$\underline{\theta}_s$	$\overline{\theta}_s$
$\underline{\theta}_b$	$(2.68, 5.52)$	$(2.68, 3.88)$
$\overline{\theta}_b$	$(1.56, 6.65)$	$(2.33, 5.03)$

The first entry in each cell is an affine transformation of the buyer's payoff

$$\tilde{\pi}_b(\underline{\theta}_b, f(\theta'_b, \theta'_s)) = \alpha\, \pi_b(\underline{\theta}_b, f(\theta'_b, \theta'_s)) + \beta = \alpha \left\{ \underline{\theta}_b q^f(\theta'_b, \theta'_s) - p_b^f(\theta'_b, \theta'_s) \right\} + \beta \,,$$

where (θ'_b, θ'_s) is the action profile chosen by the buyer and the seller. We chose $\alpha = 1.25$ and $\beta = 2.68$ to ensure that participants earned 10 Euros on average. The second entry in the cell is an affine transformation of the seller's payoff

$$\tilde{\pi}_s(\underline{\theta}_s, f(\theta'_b, \theta'_s)) = \alpha\, \pi_s(\underline{\theta}_s, f(\theta'_b, \theta'_s)) + \beta = \alpha \left\{ p_s^f(\theta'_b, \theta'_s) - \underline{\theta}_s k(q^f(\theta'_b, \theta'_s)) \right\} + \beta \,.$$

If both individuals truthfully reveal their types, the payoffs in the upper left corner are realized. Note that under truth-telling both payoffs are weakly larger than the reservation utility of 2.68 so that the relevant *ex post* participation constraints are satisfied. Also note that the seller does not benefit from an exaggeration of her cost, if the buyer communicates his low valuation truthfully. Likewise, the buyer does not benefit from an exaggeration of his willingness to pay, given that the seller communicates her low cost truthfully. Hence, the relevant *ex post* incentive constraints are satisfied. Finally, note that externality-freeness is violated: If the seller behaves truthfully, her payoff is higher if the buyer communicates a high willingness to pay.

For later reference, we also describe the normal form games that are induced in the remaining complete information environments.

Table 2: The game induced by f for $(\theta_b, \theta_s) = (\underline{\theta}_b, \overline{\theta}_s)$.

$(\tilde{\pi}_b, \tilde{\pi}_s)$	$\underline{\theta}_s$	$\overline{\theta}_s$
$\underline{\theta}_b$	$(2.68, 2.08)$	$(2.68, 3.56)$
$\overline{\theta}_b$	$(1.56, -5.23)$	$(2.33, 3.90)$

Table 3: The game induced by f for $(\theta_b, \theta_s) = (\overline{\theta}_b, \underline{\theta}_s)$.

$(\tilde{\pi}_b, \tilde{\pi}_s)$	$\underline{\theta}_s$	$\overline{\theta}_s$
$\underline{\theta}_b$	$(3.97, 5.52)$	$(3.06, 3.88)$
$\overline{\theta}_b$	$(3.99, 6.65)$	$(3.08, 5.03)$

Table 4: The game induced by f for $(\theta_b, \theta_s) = (\overline{\theta}_b, \overline{\theta}_s)$.

$(\tilde{\pi}_b, \tilde{\pi}_s)$	$\underline{\theta}_s$	$\overline{\theta}_s$
$\underline{\theta}_b$	$(3.97, 2.08)$	$(3.06, 3.56)$
$\overline{\theta}_b$	$(3.99, -5.23)$	$(3.08, 3.90)$

An inspection of Tables 1 through 4 reveals the following properties of f: (i) Under truth-telling the seller's payoff exceeds the buyer's payoff in all states of the economy, (ii) if the buyer's type is low (Tables 1 and 2), then his payoff under truth-telling is equal to $\beta = 2.68$, i.e. the participation constraint of a low type buyer binds, (iii) if the buyer's type is high (Tables 3 and 4), then the buyer's incentive constraint is binding in the sense that understating comes at a very small personal cost (the payoff drops from 3.99 to of 3.97).

4.3.3 An observation on models of social preferences

We now show that the social choice function in Proposition 1 is not robust in the following sense: It provokes deviations from truth-telling if individuals are motivated by social preferences. To formalize a possibility of social preferences, we assume that any one individual $i \in \{b, s\}$ has a utility function $U_i(\theta_i, r_i, r_i^b, r_i^{bb})$ which depends in a parametric way on the individual's true type θ_i and, in addition, on the following three arguments: the individual's own report r_i, the individual's (first order) belief about the other player's report, r_i^b, and the individuals' (second order) belief about the other player's first-order belief, r_i^{bb}. Different models of social preferences make different assumptions about these utility functions.

Intention-based social preferences. Second-order beliefs play a role in models with intention-based social preferences such as Rabin (1993), Dufwenberg and Kirchsteiger (2004) or Falk and Fischbacher (2006). In these models, the utility function takes the following form

$$U_i(\theta_i, r_i, r_i^b, r_i^{bb}) = \pi_i(\theta_i, f(r_i, r_i^b)) + y_i\, \kappa_i(r_i, r_i^b, r_i^{bb})\, \kappa_j(r_i^b, r_i^{bb})\ . \tag{4.6}$$

The interpretation is that the players' interaction gives rise to sensations of kindness or unkindness, as captured by $y_i\, \kappa_i(r_i, r_i^b, r_i^{bb})\, \kappa_j(r_i^b, r_i^{bb})$. In this expression, $y_i \geq 0$ is an exogenous parameter, interpreted as the weight that agent i places on kindness considerations. The term $\kappa_i(r_i, r_i^b, r_i^{bb})$ is a measure of how kindly i intends to treat the other agent j. While the models of Rabin (1993), Dufwenberg and Kirchsteiger (2004) and Falk and Fischbacher (2006) differ in some respects, they all make the following assumption: Given r_i^b and r_i^{bb}, for any two reports r_i' and r_i'', $\pi_j(\theta_j, f(r_i', r_i^b)) \geq \pi_j(\theta_j, f(r_i'', r_i^b))$ implies that $\kappa_i(r_i', r_i^b, r_i^{bb}) \geq \kappa_i(r_i'', r_i^b, r_i^{bb})$, i.e. the kindness intended by i is larger if her report yields a larger payoff for j. Second-order beliefs are relevant here if player i expresses kindness by increasing j's payoff relative to the payoff that, according to the beliefs of i, j expects to be realizing. The latter payoff depends on the beliefs of i about the beliefs of j about i's behavior.

Whether or not i's utility is increasing in κ_i depends on i's belief about the kindness that is intended by player j and which is denoted by κ_j. If $\kappa_j > 0$, then i believes that j is kind and her utility increases, ceteris paribus, if j's payoff goes up. By contrast, if $\kappa_j < 0$, then i believes that j is unkind and her utility goes up if j is made worse off. Rabin (1993), Dufwenberg and Kirchsteiger (2004) and Falk and Fischbacher (2006) all assume that the function κ_j is such that, for given second-order beliefs r_i^{bb}, $\kappa_j(r_i^{b'}, r_i^{bb}) \geq \kappa_i(r_i^{b''}, r_i^{bb})$ whenever $\pi_i(\theta_i, f(r_i^{b'}, r_i^{bb})) \geq \pi_i(\theta_i, f(r_i^{b''}, r_i^{bb}))$. Second-order beliefs play a role here because, in order to assess the kindness that is intended by j, i has to form a belief about j's belief about i's report.

Outcome-based social preferences. In models with outcome-based social preferences such as Fehr and Schmidt (1999), Bolton and Ockenfels (2000), or Charness and Rabin (2002) second order beliefs play no role and individuals are assumed to care about their own payoff and the distribution of payoffs among the players. For instance, with Fehr-Schmidt-preferences, the utility function of individual i reads as

$$\begin{aligned} U_i \;=\; \pi_i(\theta_i, f(r_i, r_i^b)) \; & -\alpha_i \max\{\pi_j(\theta_j, f(r_i, r_i^b)) - \pi_i(\theta_i, f(r_i, r_i^b)), 0\} \\ & -\beta_i \max\{\pi_i(\theta_i, f(r_i, r_i^b)) - \pi_j(\theta_j, f(r_i, r_i^b)), 0\} \;, \end{aligned} \tag{4.7}$$

where it is assumed that $\alpha_i \geq \beta_i$ and that $0 \leq \beta_i < 1$.

Implications for the social choice function in Proposition 1. Many models of social preferences give rise to the prediction that a social choice function that would be optimal if individual were selfish will trigger deviations from truth-telling. Specifically, for our bilateral trade problem, high valuation buyers will understate their valuation. Models of outcome-based and intention-based social preferences provide different explanations for this: With outcome-based social preferences, the buyer may wish to harm the seller so as to make their expected payoffs more equal. The reasoning for intention-based models, such as Rabin (1993), would have a different logic. For the game in Table 4, the buyer would argue as follows: My expected payoff would be higher if the seller deviated from truth-telling and communicated a low cost. Since the seller does not make use of this opportunity to increase my payoff, he is unkind. I therefore wish to reciprocally reduce his expected payoff.

Whatever the source of the desire to reduce the seller's payoff, a high valuation buyer can reduce the seller's payoff by understating his valuation. Since the relevant incentive constraint binds, such an understatement is costless for the buyer, i.e. he does not have to sacrifice own payoff if he wishes to reduce the seller's payoff.

The following observation states this more formally for the case of Fehr-Schmidt-preferences. In Appendix 4.C we present analogous results for other models of social preferences.

Observation 1. *Consider a complete information types space for state (θ_b, θ_s) and suppose that $\theta_b = \bar{\theta}_b$. Suppose that f is such that*

$$\pi_s(\theta_s, f(\overline{\theta}_b, \theta_s)) > \pi_s(\theta_s, f(\underline{\theta}_b, \theta_s)) > \pi_b(\overline{\theta}_b, f(\underline{\theta}_b, \theta_s)) = \pi_b(\overline{\theta}_b, f(\overline{\theta}_b, \theta_s)) \tag{4.8}$$

Suppose that the seller behaves truthfully. Also suppose that the buyer has Fehr-Schmidt-preferences as in (4.7) with $\alpha_b \neq 0$. Then the buyer's best response is to understate his valuation.

The social choice function in Example 1 fulfills Condition (4.8). Consider Tables 3 and 4. The buyer's incentive constraint binds. Moreover, if the buyer understates his valuation, this harms the seller. The harm is, however, limited in the sense that the seller's reduced payoff still exceeds the buyer's payoff. For such a situation the Fehr-Schmidt-model of social preferences predicts that the buyer will deviate from truth-telling, *for any* pair of parameters (α_b, β_b) so that $\alpha_b \neq 0$. Put differently, truth-telling is a best response for the buyer only if $\alpha_b = 0$, i.e. only if the buyer is selfish.

4.3.4 Social-preference-robust mechanisms

The models of social preferences mentioned so far differ in many respects. They are, however, all consistent with the following assumption of *selfishness in the absence of externalities.*

Assumption 1. *Given r_i^b and r_i^{bb}, if r_i' and r_i'' are such that $\pi_j(\theta_j, f(r_i', r_i^b)) = \pi_j(\theta_j, f(r_i'', r_i^b))$ and $\pi_i(\theta_i, f(r_i', r_i^b)) > \pi_i(\theta_i, f(r_i'', r_i^b))$, then $U_i(\theta_i, r_i', r_i^b, r_i^{bb}) \geq U_i(\theta_i, r_i'', r_i^b, r_i^{bb})$.*

Assumption 1 holds provided that individuals prefer to choose strategies that increase their own payoff, whenever they can do so without affecting others. This does not preclude a willingness to sacrifice own payoff so as to either increase or reduce the payoff of others. It is a ceteris paribus assumption: In the set of strategies that have the same implications for player j, player i weakly prefers the ones that yield a higher payoff for herself. Assumption 1 has the following implication: In situations where players do not have the possibility to affect the payoffs of others, social preferences will be behaviorally irrelevant, and the players act as if they were selfish payoff maximizers.

The following observation illustrates that the utility function underlying the Fehr and Schmidt (1999)-model of social preferences satisfies Assumption 1 for all possible parametrization of the model. Appendix 4.C confirms this observation for other models of social preferences.[9]

Observation 2. *Suppose the buyer and the seller have preferences as in (4.7) with parameters (α_b, β_b) and (α_s, β_s), respectively. The utility functions U_b and U_s satisfy*

[9]Assumption 1 is also satisfied in models of pure altruism, see Becker (1974). All parameterized versions that Bolton and Ockenfels (2000) propose for their model are consistent with Assumption 1, too, although we note that it is theoretically possible to construct preferences that are consistent with their general assumptions and may still violate Assumption 1. Such preferences would be the only possible exception that we encountered among prominent social preference models.

Assumption 1, for all (α_b, β_b) so that $\alpha_b \geq \beta_b$ and $0 \leq \beta_b < 1$ and for all (α_s, β_s) so that $\alpha_s \geq \beta_s$ and $0 \leq \beta_s < 1$.

We now define a mechanism that is robust in the following sense: For any individual i, given correct first- and second-order beliefs, a truthful report maximizes U_i, for all utility functions satisfying Assumption 1.

Definition 1. *A direct mechanism for social choice function f is said to be social-preference-robust if it satisfies the following property: On any complete information environment, given correct first- and second-order beliefs, truth-telling by any player $i \in \{b, s\}$ is a best response to truth-telling by player $j \neq i$, for all utility functions U_i satisfying Assumption 1.*

Social-preference-robustness of a mechanism is an attractive property. It is robust against widely varying beliefs both of the mechanism designer and the participants about what is the appropriate specification and intensity of social preferences across individuals. As long as preferences satisfy Assumption 1, we can be assured that individuals behave truthfully under such a mechanism.

The following Proposition justifies our interest in externality-free mechanisms. If we add externality-freeness to the requirement of incentive compatibility, we arrive at a social-preference-robust mechanism.

Proposition 2. *Suppose that f is* ex post *incentive-compatible and externality-free. Then f is social-preference-robust.*

Proof. Consider a complete information environment for types (θ_i, θ_j). Suppose that player i believes that player j acts truthfully so that $r_i^b = \theta_j$ and that he believes that player j believes that he acts truthfully so that $r_i^{bb} = \theta_i$. By *ex post* incentive compatibility, $\pi_i(\theta_i, f(r_i, r_i^b))$ is maximized by choosing $r_i = \theta_i$. By externality-freeness, $\pi_j(\theta_j, f(r_i', r_i^b)) = \pi_j(\theta_j, f(r_i'', r_i^b))$ for any pair $r_i', r_i'' \in \Theta_i$. Hence, by Assumption 1, $r_i = \theta_i$ solves $\max_{r_i \in \Theta_i} U_i(\theta_i, r_i, r_i^b, r_i^{bb})$. □

Proposition 2 asserts that incentive-compatibility and externality-freeness are sufficient conditions for social-preference-robustness. This raises the question of necessary conditions. Above we said that a condition is sufficient if it ensures implementability *for all* social preference models so that individuals are selfish in the absence of externalities. Hence, it is natural to say that a condition is necessary for social-preference-robustness if there *exists one* relevant social preference model so that incentive-compatibility and externality-freeness are necessary for implementability. Bierbrauer and Netzer (2016) show that, under an ancillary condition, incentive-compatibility and externality-freeness are indeed necessary for the implementability of a social choice function for a version of the intention-based model of Rabin (1993) that allows for private information both on material payoffs and on the reciprocity weights in the players' overall utility function. However, Bierbrauer and Netzer (2016) employ Bayesian incentive compatibility constraints, as opposed to ex post incentive compatibility constraints. As we show in Appendix 4.D, this difference is of no consequence for the validity of the conclusion that externality-freeness is a necessary condition.

It may appear counterintuitive that incentive compatibility remains a necessary condition even though individuals may be motivated by social preferences. Shouldn't it be possible to use these social preferences in such a way that efficient outcomes can be reached that are out of reach if all individuals are selfish. Our answer to this question is "No" because we ask for social-preference-robustness and hence always include the possibility that agents are selfish. As a consequence, we cannot relax any of the constraints from conventional mechanism design. Quite to the contrary, we add a constraint, externality-freeness to ensure social-preference-robustness. The set of implementable outcomes therefore tends to become smaller if compared to a benchmark where all individuals are assumed to be selfish.

4.3.5 Optimal robust and externality-free mechanism design

We now add the requirement of externality-freeness to the bilateral trade problem. To characterize the solution of this problem it is instructive to begin, again, with a relaxed problem in which only a subset of all constraints is taken into account. Specifically, the relevant constraints are: the resource constraint in (4.4), the participation constraints for a low valuation buyer,

$$\pi_b(\underline{\theta}_b, f(\underline{\theta}_b, \theta_s)) \geq 0, \quad \text{for all} \quad \theta_s \in \Theta_s \ ,$$

the incentive constraint for a high type buyer who faces a low cost seller,

$$\pi_b(\bar{\theta}_b, f(\bar{\theta}_b, \underline{\theta}_s)) \geq \ \pi_b(\bar{\theta}_b, f(\underline{\theta}_b, \underline{\theta}_s)) \ ,$$

and, finally, the externality-freeness condition for a high valuation buyer

$$\pi_b(\bar{\theta}_b, f(\bar{\theta}_b, \underline{\theta}_s)) = \pi_b(\bar{\theta}_b, f(\bar{\theta}_b, \bar{\theta}_s)) \ .$$

Proposition 3. *A social choice function f' solves the relaxed problem of robust and externality-free mechanism design if and only if it has the following properties:*

(a)' For any one $\theta_s \in \Theta_s$, the participation constraint of a low type buyer is binding:

$$\pi_b(\underline{\theta}_b, f'(\underline{\theta}_b, \theta_s)) = 0 \ .$$

(b)' For $\theta_s = \underline{\theta}_s$, the incentive constraint of a high type buyer is binding.

(c)' The trading rule is such that there is a downward distortion only for state $(\underline{\theta}_b, \underline{\theta}_s)$;

$$q^{f'}(\underline{\theta}_b, \underline{\theta}_s) \quad \in \quad \mathit{argmax}_q \left(\underline{\theta}_b - \frac{g^m(\overline{\theta}_b)}{g(\underline{\theta}_b, \underline{\theta}_s)}(\overline{\theta}_b - \underline{\theta}_b) \right) q - \theta_s k(q) \ ,$$

where $g^m(\overline{\theta}_b) := g(\overline{\theta}_b, \underline{\theta}_s) + g(\overline{\theta}_b, \overline{\theta}_s)$. Otherwise, there is no distortion.

(d)' The payment rule for the buyer is such that, for any one θ_s,

$$p_b^{f'}(\underline{\theta}_b, \theta_s) = \underline{\theta}_b q^{f'}(\underline{\theta}_b, \theta_s) \ .$$

In addition

$$p_b^{f'}(\overline{\theta}_b, \underline{\theta}_s) = \overline{\theta}_b q^{f'}(\overline{\theta}_b, \underline{\theta}_s) - (\overline{\theta}_b - \underline{\theta}_b) q^{f'}(\underline{\theta}_b, \underline{\theta}_s) \ ,$$

and

$$p_b^{f'}(\overline{\theta}_b, \overline{\theta}_s) = \overline{\theta}_b q^{f'}(\overline{\theta}_b, \overline{\theta}_s) - (\overline{\theta}_b - \underline{\theta}_b) q^{f'}(\underline{\theta}_b, \underline{\theta}_s) \ ,$$

(e)' The revenue for the seller is such that

$$\sum_{\Theta_b \times \Theta_s} g(\theta_b, \theta_s) p_b^{f'}(\theta_b, \theta_s) = \sum_{\Theta_b \times \Theta_s} g(\theta_b, \theta_s) p_s^{f'}(\theta_b, \theta_s) \ .$$

A formal proof of the Proposition is relegated to Appendix 4.B. It proceeds as follows: The first step is to show that all inequality constraints of the relaxed problem have to be binding. Otherwise, it would be possible to implement the given trading rule $q^{f'}$ with higher payments of the buyer. This establishes $(a)'$ and $(b)'$. Second, we solve explicitly for the payments of the buyer as a function of the trading rule $q^{f'}$ — this yields $(d)'$ — and substitute the resulting expressions into the objective function. This resulting unconstrained optimization problem has first order conditions which characterize the optimal trading rule, see the optimality conditions in $(c)'$.

After having obtained the solution to the relaxed problem, we need to make sure that it is also a solution to the full problem. For the buyer, it can be shown that the neglected participation, incentive and externality-freeness constraints are satisfied provided that the solution to the relaxed problem is such that the traded quantity increases in the buyer's valuation and decreases in the seller's cost. If there is a solution to the relaxed problem that satisfies the seller's incentive, participation and externality-freeness constraints, then this solution to the relaxed problem is also a solution to the full problem. The social choice function f' in Example 2 below has all these properties.

The substantive difference between the optimal robust mechanism in Proposition 1 and the optimal robust and externality-free mechanism in Proposition 3 is in the pattern of distortions. The optimal robust mechanism has downward distortions whenever the buyer has a low valuation. The optimal robust and externality-free mechanism has a downward distortion in only one state, namely the state in which the buyer's valuation is low and the seller's cost is low. This distortion, however, is more severe than the distortion that arises for this state with the optimal robust mechanism.

Example 2: An optimal robust and externality-free social choice function. Suppose the parameters of the model are as in Example 1. The social choice function f', specified in Proposition 3, solves the problem of optimal robust and externality-free mechanism design formally defined in the previous paragraph: The traded quantities are given by

$$q^{f'}(\underline{\theta}_b, \underline{\theta}_s) = 2.00,\ q^{f'}(\underline{\theta}_b, \bar{\theta}_s) = 1.54,\ q^{f'}(\bar{\theta}_b, \underline{\theta}_s) = 6.50 \quad \text{and} \quad q^{f'}(\bar{\theta}_b, \bar{\theta}_s) = 2.00\ .$$

The buyer's payments are

$$p_b^{f'}(\underline{\theta}_b, \underline{\theta}_s) = 2.00,\ p_b^{f'}(\underline{\theta}_b, \bar{\theta}_s) = 1.54,\ p_b^{f'}(\bar{\theta}_b, \underline{\theta}_s) = 7.85 \quad \text{and} \quad p_b^{f'}(\bar{\theta}_b, \bar{\theta}_s) = 2.00\ .$$

Finally, the seller's revenues are

$$p_s^{f'}(\underline{\theta}_b, \underline{\theta}_s) = 2.52,\ p_s^{f'}(\underline{\theta}_b, \bar{\theta}_s) = 1.99,\ p_s^{f'}(\bar{\theta}_b, \underline{\theta}_s) = 6.35 \quad \text{and} \quad p_s^{f'}(\bar{\theta}_b, \bar{\theta}_s) = 2.52\ .$$

To illustrate the property of externality-freeness, we consider, once more, the various complete information games which are associated with this social choice function.

Table 1': The game induced by f' for $(\theta_b, \theta_s) = (\underline{\theta}_b, \underline{\theta}_s)$.

$(\tilde{\pi}_b, \tilde{\pi}_s)$	$\underline{\theta}_s$	$\overline{\theta}_s$
$\underline{\theta}_b$	$(2.68, 5.33)$	$(2.68, 4.86)$
$\overline{\theta}_b$	$(0.97, 5.33)$	$(2.66, 5.31)$

Along the same lines as for Table 1, one may verify that the relevant *ex post* incentive and participation constraints are satisfied. In addition, externality-freeness holds: If the seller communicates her low cost truthfully, then she gets a payoff of 5.33 irrespectively of whether the buyer communicates a high or a low valuation. Also, if the buyer reveals his low valuation, he gets 2.68 irrespectively of whether the seller communicates a high or a low cost.

Again, we also describe the normal form games that are induced by f' in the remaining complete information environments.

Table 2': The game induced by f' for $(\theta_b, \theta_s) = (\underline{\theta}_b, \overline{\theta}_s)$.

$(\tilde{\pi}_b, \tilde{\pi}_s)$	$\underline{\theta}_s$	$\overline{\theta}_s$
$\underline{\theta}_b$	$(2.68, 4.19)$	$(2.68, 4.21)$
$\overline{\theta}_b$	$(0.97, -6.57)$	$(2.66, 4.21)$

Table 3': The game induced by f' for $(\theta_b, \theta_s) = (\overline{\theta}_b, \underline{\theta}_s)$.

$(\tilde{\pi}_b, \tilde{\pi}_s)$	$\underline{\theta}_s$	$\overline{\theta}_s$
$\underline{\theta}_b$	$(3.41, 5.33)$	$(3.24, 4.86)$
$\overline{\theta}_b$	$(3.43, 5.33)$	$(3.43, 5.31)$

Table 4': The game induced by f' for $(\theta_b, \theta_s) = (\overline{\theta}_b, \overline{\theta}_s)$.

$(\tilde{\pi}_b, \tilde{\pi}_s)$	$\underline{\theta}_s$	$\overline{\theta}_s$
$\underline{\theta}_b$	$(3.41, 4.19)$	$(3.24, 4.21)$
$\overline{\theta}_b$	$(3.43, -6.57)$	$(3.43, 4.21)$

On top of externality-freeness, the social choice function f' in Tables 1' to 4' has the following properties: (i) The seller's payoff under truth-telling is higher than the buyer's payoff under truth-telling, (ii) a low type buyer realizes his reservation utility (see Tables 1' and 2'), and (iii) the buyer's incentive constraint binds if the seller's cost is low, but not if the seller's cost is high (see Tables 3' and 4').

A comparison of the social choice functions f and f' shows that the imposition of externality-freeness has a moderating effect on inequality. The difference between the equilibrium payoffs of the seller and the buyer is reduced as we move from the game in Table 1 to the game in Table 1', from the game in Table 3 to the game in Table 3' and from the game in Table 4 to the game in Table 4'. The pattern is reversed for Tables 2 and 2'. On average, there is less inequality with the externality-free social choice function. Ceteris paribus, an inequality-averse mechanism designer would therefore prefer an externality-free social choice function. In Section 4.5 below, we clarify the conditions under which even a mechanism designer with no inequality aversion whatsoever would opt for externality-freeness.

Everything else being equal, a mechanism designer with an objective that reflects the participants' intention-based social preferences would also prefer the externality-free social choice function. The prominent intention-based models (see Appendix 4.C for details) give rise to an equilibrium kindness of zero if the social choice function is externality-free. By contrast, equilibrium kindness is negative under an incentive-compatible social choice function that is not externality-free. Section 4.5 shows that externality-freeness may be desirable even if kindness sensations receive no weight in the designer's objective function.

4.4 A laboratory experiment

We conducted a laboratory experiment with five treatments. The first treatment is based on the optimal mechanism f under selfish preferences in Example 1 (T1), and the second treatment is based on the optimal externality-free mechanism f' under social preferences in Example 2 (T2). The three additional treatment variations (T3-5) will be described in subsequent sections. All treatments were conducted employing exactly the same laboratory procedures which are described below.

We designed the experiments so that the connection to the theory, in particular to Propositions 1 and 3, is immediate. As a consequence, the experiments may appear as "unnatural" or "artificial" as the tools of mechanism design theory such as direct mechanisms or complete information type spaces. We also kept the framing as neutral as possible. Participants were confronted with generic normal form games that had no explicit reference to trade, externalities or redistributive taxation. Finally, we implemented generic examples of social choice functions. This led to payoffs that are aesthetically not as appealing as natural numbers, but gives us confidence that we did not lure participants into social comparisons.

Laboratory Procedures. The experiments were conducted in the *Cologne Laboratory for Economic Research* at the University of Cologne. They had been programmed with *z-Tree* developed by Fischbacher (2007), and participants were recruited with the online recruitment system *ORSEE* developed by Greiner (2015). In total, we recruited 632 subjects who participated in twenty sessions, four for each of the five treatments. Each subject was allowed to participate in one session and in one treatment only (between-subject design). We collected at least 63 independent observations for each treatment and player role. Subjects were students from all faculties of the University of Cologne, mostly female (380 subjects), with an average age of 24 years. A session lasted 45-60 minutes. Average payments to subjects, including the show-up fee, was 10.76 Euro.

Upon arrival, subjects were randomly assigned to computer-terminals and received identical written instructions, which informed them about all general rules and procedures of the experiment. All treatment- and role-specific information was given on the computer-screen (see Appendix 4.F for instructions and screenshot). We used neutral terms to describe the game; e.g., player-roles were labeled Participant A (B) and strategies were labeled Top (Left) and Bottom (Right) respectively. In the following we refer to the specific roles within the experiment as buyers and sellers, to make this section consistent with previous ones.

Subjects then went through a *learning stage*, with no interaction among subjects and no decision-dependent payments. In the learning stage, subjects had to choose actions for each player role in each complete information game and then to state the resulting payoffs for the corresponding self-selected strategy combination. Subjects had to give the right answer before proceeding to the decision stage. This way we assured that all subjects were able to correctly read the payoff tables, without suggesting specific actions which might create anchoring or experimenter demand effects.

Then subjects entered the *decision stage* and were informed about their role in their matching group. The matching into groups and roles was anonymous, random and held constant over the course of the experiment. Within the decision stage, subjects had to choose one action for each of the four complete information games of their specific treatment. The order of the four games was identical to the order in Table 5. Only after all subjects submitted their choices, feedback was given to each subject on all choices and resulting outcomes in their group. Finally, one of the four games was randomly determined for being paid in addition to a 2.50 Euro show-up fee.

Results. Table 5 summarizes the decisions made in the experiment. Sellers report their true valuation in almost all cases. Buyers with a low type also make truthful reports in both treatments. This is different for high type buyers in T1, though. Here, 13% (17%) of the buyers understate their true valuation when facing a seller with a low (high) valuation.

Table 5: Choice Data T1 and T2

		Buyer		*Seller*	
	Game induced by	$\underline{\theta}_b$	$\overline{\theta}_b$	$\underline{\theta}_s$	$\overline{\theta}_s$
T1 *optimal mechanism under selfish preferences*	f for $(\underline{\theta}_b, \underline{\theta}_s)$	63	0	63	0
	f for $(\underline{\theta}_b, \overline{\theta}_s)$	63	0	0	63
	f for $(\overline{\theta}_b, \underline{\theta}_s)$	8	55	63	0
	f for $(\overline{\theta}_b, \overline{\theta}_s)$	10	53	1	62
T2 *externality-free mechanism*	f' for $(\underline{\theta}_b, \underline{\theta}_s)$	64	0	62	2
	f' for $(\underline{\theta}_b, \overline{\theta}_s)$	64	0	0	64
	f' for $(\overline{\theta}_b, \underline{\theta}_s)$	1	63	64	0
	f' for $(\overline{\theta}_b, \overline{\theta}_s)$	2	62	0	64

The table describes the behavior that we observed in the experiments. The first half of the table gives the observations for treatment 1 that was based on the social choice function f, characterized in Example 1, that would be optimal if all agents were selfish. The first line gives the outcome of the game that is induced by f on a complete information type space with a low valuation buyer and a low cost seller. All 63 buyers truthfully revealed their valuation, and all 63 sellers truthfully revealed their cost. The second line gives the outcome of the game induced by f on a complete information type space with a low valuation buyer and a high cost seller. Again, all buyers and sellers revealed their types. The third line documents the outcome for a high valuation buyer and a low cost seller. Of the 63 buyers, 8 understated and 55 revealed their valuation. All sellers revealed their cost truthfully. Line 4 documents the outcome for a high valuation buyer and a high cost seller: 10 buyers understated their valuation and one seller understated her cost. The lower half of the table gives analogous observations for treatment 2 that was based on the externality-free social choice function f' characterized in Example 2. There are some deviations from truth-telling, but they are less frequent.

This pattern of buyer and seller behavior is in line with models of social preferences. In particular, for T1, which is based on an optimal mechanism for selfish agents, these models imply that high type buyers cannot be expected to always make truthful reports. By contrast, for $T2$, which is based on an optimal externality-free mechanism, these models unambiguously predict truthful behavior. We observe significantly higher shares of truthful high type buyer reports in T2 in comparison to T1 (two-sided Fisher's exact test, $p = 0.017$ for the games with a low type seller and $p = 0.014$ for the games with a high type seller).

4.5 Which mechanism is more profitable?

We now turn to the question which of the two mechanisms the designer would prefer. We focus on expected profits as the measure of profitability which implies that no explicit weight is given to the individuals' social preferences. As we argued earlier, this makes the case for externality-freeness most difficult. We first clarify the conditions under which the optimal mechanism for selfish agents outperforms the optimal externality-free mechanism. We then check whether these conditions are satisfied in our experiment data.

Based on our experiment results, we introduce a distinction between different *behavioral types* of buyers. There is the "truthful type" and the "understatement type". The former communicates his valuation truthfully in all the complete information games induced by the optimal robust mechanism f. The latter communicates a low valuation in all such games. We assume throughout that the seller always behaves truthfully, which is also what we observed in the experiment. We denote the probability that a buyer is of the "truthful type" by σ. We denote by $\Pi^f(\sigma)$ the expected profits that are realized under f. We denote by $\Pi^{f'}$ the expected profits that are realized under the optimal externality-free social choice function f', under the assumption that the buyer and the seller behave truthfully in all complete information games.

Proposition 4. *Suppose that* $\Pi^f(0) < \Pi^{f'}$. *Then there is a critical value* $\hat{\sigma}$ *so that* $\Pi^f(\sigma) \geq \Pi^{f'}$ *if and only if* $\sigma \geq \hat{\sigma}$.

Proof. We first note that

$$\begin{aligned}\Pi^f(\sigma) &= \sum_{\Theta_b \times \Theta_s} g(\theta_b, \theta_s) \Big\{ \sigma(p_b^f(\theta_b, \theta_s) - \theta_s k(q^f(\theta_b, \theta_s))) \\ &\qquad + (1-\sigma)(p_b^f(\underline{\theta}_b, \theta_s) - \theta_s k(q^f(\underline{\theta}_b, \theta_s))) \Big\} \\ &= \sigma \Pi^f(1) + (1-\sigma)\Pi^f(0) \,.\end{aligned}$$

We also note that $\Pi^f(1) > \Pi^{f'}$ since $\Pi^f(1)$ gives expected profits if there are only truthful buyer types, which is the situation in which f is the optimal mechanism.

The term $\sigma\Pi^f(1) + (1-\sigma)\Pi^f(0)$ is a continuous function of σ. It exceeds $\Pi^{f'}$ for σ close to one. If $\Pi^f(0) < \Pi^{f'}$, it falls short of $\Pi^{f'}$ for σ close to zero. Hence, there is $\hat{\sigma} \in (0,1)$ so that $\Pi^f(\sigma) = \sigma\Pi^f(1) + (1-\sigma)\Pi^f(0)$ exceeds $\Pi^{f'}$ if and only if σ exceeds $\hat{\sigma}$. $\square$

Our experiment data revisited. For the Examples 1 and 2 on which our experiments were based, the premise of Proposition 4 that $\Pi^f(0) < \Pi^{f'}$ is fulfilled. Specifically,

$$\Pi^f(0) = 4.54\ ,\ \Pi^f(1) = 4.91\ ,\ \Pi^f(\sigma) = 4.91 - 0.37\sigma\ ,\ \Pi^{f'} = 4.77\ \text{ and } \hat{\sigma} = 0.62$$

Thus, the fraction of deviating buyers must rise above 38% if the optimal externality-free mechanism is to outperform the optimal robust mechanism. In our experiment data, however, the fraction of deviating buyer types was only 14%. As a consequence, actual average seller profits are smaller under the externality-free mechanism (4.77) than under the optimal robust mechanism (4.82). This difference was not found to be statistically significant, though (two-sided t-test based on independent average profits, $p = 0.143$).

One might have expected more deviations from truth-telling. For instance, the social preference model by Fehr and Schmidt (1999) is consistent with truthful buyers only for one special case, namely the case in which buyers are completely selfish so that $\alpha_b = 0$, and Fehr and Schmidt estimate that often roughly 50% of subjects behave in a fair way. This would have been more than enough to make the externality-free mechanism more profitable. However, the degree of selfishness may vary with the framing of the context, size of payments, etc., and moreover not all social preference models predict deviations. For instance, according to the model of Charness and Rabin (2002), individuals have a concern for welfare, so that an efficiency-damaging action such as communicating a low valuation instead of high valuation seems less attractive. This uncontrolled uncertainty about the mix of preferences among negotiators in a specific context justifies our approach to not further specify (beliefs about) social preferences.

A superior mechanism. Our experiment has shown that the optimal social choice function for selfish agents provokes deviations from truth-telling. A certain fraction of high valuation buyers deviates, whereas all other agents behave truthfully. As we now argue, this observation can be used to construct a mechanism that outperforms both the conventional mechanism in Example 1 and the externality-free mechanism in Example 2. In deriving this mechanism we do not follow the axiomatic approach that is germane to the theory of mechanism design. Instead, we engage in behavioral "engineering" (see Roth (2002) and Bolton and Ockenfels (2012)) and use the insights from our laboratory experiments for a revision of the design problem.

As deviations from truth-telling were tempting only for buyers we consider a mechanism design problem in which the requirement of externality-freeness is imposed only locally, namely such that the buyer is unable to influence the seller's payoff. Formally, we require that, for all $\theta_s \in \Theta_s$,

$$\pi_s(\theta_s, f(\underline{\theta}_b, \theta_s)) = \pi_s(\theta_s, f(\bar{\theta}_b, \theta_s)) \ . \tag{4.9}$$

Remember that the optimal social choice function that we characterize in Proposition 1 leaves degrees of freedom for the specification of the payments to the seller. In particular, the payments can be chosen so that the local externality-freeness condition (4.9) is satisfied. Hence, local externality-freeness can be ensured without having to sacrifice performance. This is stated formally in the following Proposition that we prove in part B of the Appendix.

Proposition 5. *There is a solution to the relaxed problem of robust mechanism design, characterized in Proposition 1, that satisfies (4.9).*

Proposition 5 shows that if everybody is selfish then an optimal mechanism that satisfies *ex post* budget balance (as in Example 1 above) and an optimal mechanism that satisfies local externality-freeness (as in Example 3 in Appendix 4.E) are equivalent in terms of the expected profits that they generate. However, if the locally externality-free mechanism eliminates deviations that occur under *ex post* budget balance, it will perform strictly better. This hypothesis was confirmed in a laboratory treatment (T3), see the Supplementary Material in Appendix 4.E for details.

4.6 Redistributive income taxation

We now turn to another application of mechanism design, namely redistributive income taxation. Our motivation for looking at this is twofold: First, for this application, what can be achieved with an externality-free mechanism has a natural interpretation: Such allocations can be decentralized by means of a non-linear income tax schedule. This raises the question how these "natural" mechanisms perform relative to ones that are not externality-free and predicted to generate more welfare if all individuals are selfish. Second, this case serves as an important robustness check for our results: A general theory of social-preference-robust mechanism design is appealing only if the fraction of individuals who act according to social preferences does not depend on the specific application.

As in our analysis of the bilateral trade problem, we consider an economy with two individuals, $I = \{1, 2\}$. Individual i derives utility from private goods consumption, or after-tax-income, c_i, and dislikes productive effort. Individual i's productive effort is measured by $\frac{y_i}{\omega_i}$, where y_i denotes the individual's contribution to the economy's output, or pre-tax-income, and ω_i is a measure of the individual's productive abilities. Thus, an individual with high productive abilities can generate a given level of output with less effort than an individual with low productive abilities. We assume that individual preferences can be represented by an additively separable utility function $u(c_i) - v\left(\frac{y_i}{\omega_i}\right)$, where u is an increasing and concave function, and v is an increasing and convex function. Both functions are assumed to satisfy the usual Inada conditions. Note that the individuals' preferences satisfy the single-crossing property: For any point in a (y, c)-diagram the indifference curve of an individual with low abilities through this point is steeper than the indifference curve of an individual with high abilities.

We assume that ω_i is the realization of a random variable that is privately observed by individual i. This random variable either takes a high value, ω_h, or a low value, ω_l. A state of the economy is a pair $\omega = (\omega_1, \omega_2)$ which specifies the productive ability of individual 1 and the productive ability of individual 2. The set of states is equal to $\{\omega_l, \omega_h\}^2$. A social choice function or direct mechanism consists of functions $c_i : \{\omega_l, \omega_h\}^2 \to \mathbb{R}_+$ and $y_i : \{\omega_l, \omega_h\}^2 \to \mathbb{R}_+$ which specify, for each state of the economy, and for each individual, a consumption and an output level.

An important benchmark is the first-best utilitarian welfare optimum. This is the social choice function which is obtained by choosing, separately for each state ω, $c_1(\omega)$, $c_2(\omega)$, $y_1(\omega)$ and $y_2(\omega)$ so as to maximize the sum of utilities,

$$u(c_1(\omega)) - v\left(\frac{y_1(\omega)}{\omega_1}\right) + u(c_2(\omega)) - v\left(\frac{y_2(\omega)}{\omega_2}\right) ,$$

subject to the economy's resource constraint,

$$c_1(\omega) + c_2(\omega) \leq y_1(\omega) + y_2(\omega) .$$

For a state where one individual is high-skilled and one is low-skilled this has the following implication: Both individuals get the same consumption level because marginal consumption utilities ought to be equalized. However, the high-skilled individual has to deliver more output than the low-skilled individual because marginal costs of effort ought to be equalized as well.

It will prove useful to have specific notation which refers to the first-best utilitarian welfare maximum for an economy with one highly productive and one less productive individual. The former is assigned an income requirement of y_h^* and a consumption level of c_h^*. The latter gets a lower income requirement, denoted by y_l^*, but receives the same consumption level $c_l^* = c_h^*$.

This social choice function raises questions of incentive compatibility. Clearly, the high-skilled individual would prefer the outcome intended for the low-skilled individual since the latter has the same consumption level but a smaller workload. As we will describe in the following, whether or not the first-best utilitarian welfare optimum can be reached in the presence of private information on productive abilities depends on the economy's information structure and on whether or not we impose a condition of externality-freeness.

Information structure. We assume that it is commonly known that, with probability 1, one individual is high-skilled and one individual is low-skilled. This setup is due to Piketty (1993). We investigate the Mirrleesian approach under the same information structure. That is to say, only the states (ω_l, ω_h) and (ω_h, ω_l) have positive probability, whereas the states (ω_l, ω_l) and (ω_h, ω_h) have probability zero. This implies that any one individual knows the other individual's type: If individual 1 observes that the own productive ability is high, then she can infer that the productive ability of individual 2 is low and vice versa. Put differently, each possible state of the economy gives rise to a complete information type space, with the mechanism designer as the only uninformed party.

The Mirrleesian approach. A Mirrleesian analysis imposes externality-freeness and anonymity. Externality-freeness requires that the outcome for any one individual depends only on that individual's productive ability and not on the productive ability of the other person. Anonymity requires that these outcomes are identical across individuals, so that e.g., the outcome specified for person 1 in case that $\omega_1 = \omega_l$, equals the outcome specified for person 2 in case that $\omega_2 = \omega_l$. Consequently, a social choice function can be represented by two bundles (y_l, c_l) and (y_h, c_h) so that, for all i,

$$(y_i(\omega), c_i(\omega)) = \begin{cases} (y_l, c_l) & \text{whenever} \quad \omega_i = \omega_l \ , \\ (y_h, c_h) & \text{whenever} \quad \omega_i = \omega_h \ . \end{cases}$$

Incentive compatibility then requires that an individual with low productive ability prefers (y_l, c_l) over (y_h, c_h), and that an individual with high productive ability prefers (y_h, c_h) over (y_l, c_l). According to the Taxation Principle, see Hammond (1979) and Guesnerie (1995), these incentive constraints are equivalent to the possibility to reach a social choice function by specifying a tax schedule $T : y \mapsto T(y)$ so that any one individual i chooses c_i and y_i so as to maximize utility subject to the constraint that $c_i \leq y_i - T(y_i)$. Formally,

$$u(c_l) - v\left(\frac{y_l}{w_l}\right) \geq u(c_h) - v\left(\frac{y_h}{w_l}\right) \quad \text{and} \quad u(c_h) - v\left(\frac{y_h}{w_h}\right) \geq u(c_l) - v\left(\frac{y_l}{w_h}\right) . \tag{4.10}$$

Obviously, these Mirrleesian incentive constraints are violated by the first-best utilitarian welfare maximum. An optimal Mirrleesian allocation is obtained by choosing (c_l, y_l) and (c_h, y_h) so as to maximize the sum of utilities

$$u(c_l) - v\left(\frac{y_l}{\omega_l}\right) + u(c_h) - v\left(\frac{y_h}{w_h}\right) ,$$

subject to the incentive constraints in (4.10) and the resource constraint

$$c_l + c_h \leq y_l + y_h.$$

Piketty's approach. Piketty (1993) constructs a mechanism which achieves the first-best utilitarian outcome in dominant strategies. This mechanism is anonymous, but not externality-free. The construction is illustrated in Figure 1. In this Figure, point A is the outcome for any one individual if it reports ω_l and the other individual reports ω_h. Point B is the outcome for an individual that reports ω_h if the other individual reports ω_l. Point C is the outcome for an individual that reports ω_h if the other individual also reports ω_h. Analogously, D is the outcome for an individual that reports ω_l if the other individual also reports ω_l. It can easily be verified that truth-telling is a dominant strategy for selfish individuals if (i) point C lies above point A and between the two individuals' indifference curves through A, and (ii) point D lies below point B and between the two individuals' indifference curves through B. Also note that this is incompatible with externality-freeness which would require that $A = D$ and $B = C$.

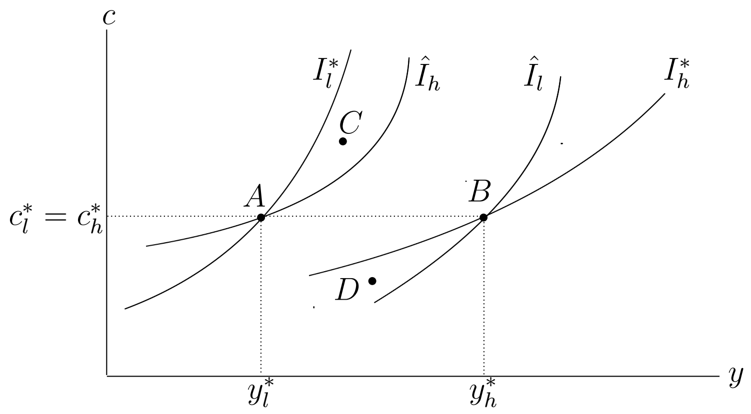


Figure 1. The Figure illustrates how the first-best utilitarian welfare maximum can be achieved with a mechanism that is not externality-free. I_l^* is the less able individual's indifference curve through $A = (y_l^*, c_l^*)$. Analogously, I_h^* is the more able individual's indifference curve trough $B = (y_h^*, c_h^*)$. The less able individual's indifference curve through B is denoted by $\hat{I}_l$, and the more able individual's indifference curve through A is denoted by $\hat{I}_h$.

Social preferences. Models of social preferences can rationalize deviations from this dominant strategy equilibrium. Consider first a model with intentions, such as Rabin (1993). The high-skilled individual might reason in the following way: The other individual could have reported a high ability type, in which case I would have gotten point C. This would have been good for me. So, the other individual is unkind since she did not make use of this possibility to increase my payoff. I am therefore willing to give up own payoff, so as to reciprocally harm the other individual. So, I should declare to be of the low ability type. In this case we both get D. This clearly harms myself and the other person. However, the point D is not that much worse for me, so the possibility to harm the other person is worth the sacrifice. Alternatively, we may consider a model with inequity aversion such as the Fehr-Schmidt-model. In this case, the same deviation could be rationalized by the observation that if both get D, their outcomes are equal, whereas they are very unequal in the dominant strategy equilibrium. Again, if point D is sufficiently close to B achieving this gain in equity is not too costly for an individual with high ability. With the Mirrleesian approach, by contrast, models of social preferences would predict truthful behavior. Since the Mirrleesian mechanism is externality-free, Proposition 2 implies that it is social-preference-robust.

An experiment. In the following we report on a laboratory experiment so as to check whether Piketty's approach does indeed provoke more deviations from truth-telling, and, if, yes, what this implies for the levels of utilitarian welfare that are generated by the two mechanisms. The experiment was based on functional form assumptions and parameter choices that are detailed in the following example.

Example 4. We impose the following functional form assumption on preferences:

$$U_i = u(c_i) - v\left(\frac{y_i}{\omega_i}\right) = \sqrt{c_i} - \frac{1}{2}\left(\frac{y_i}{w_i}\right)^2 .$$

In addition, we let $\omega_l = 4$ and $\omega_h = 6$. Under these assumptions, the optimal Mirrleesian allocation is given by $(c_l^M, y_l^M) = (4.19, 3.66)$ and $(c_h^M, y_h^M) = (6.52, 7.05)$. The normal form game that is induced by the Mirrleesian mechanism on a complete information type space so that individual 1 is of low ability and individual 2 is of high ability is summarized in the following table. The entries in the matrix are the players' utility levels under the assumption of selfish preferences.

Table 6: The game induced by the Mirrleesian mechanism for $(\omega_1, \omega_2) = (\omega_l, \omega_h)$.

$(\tilde{U}_1, \tilde{U}_2)$	ω_l	ω_h
ω_l	$(3.26, 3.70)$	$(3.26, 3.72)$
ω_h	$(1.99, 3.70)$	$(1.99, 3.72)$

The payoffs in this matrix are based on an affine transformation of utilities, $\tilde{U}_j = \alpha\, U_j + \beta$ with $\alpha = 2$ and $\beta = 0$. To see that incentive compatibility holds note that first that player 1 does not benefit from claiming to be of high ability if player 2 behaves truthfully. His payoff would drop from 3.26 to 1.99. Analogously, if player 1 behaves truthfully, player 2 does not benefit from understating her ability, her payoff would drop from 3.72 to 3.70. In addition, externality-freeness holds: If player 1 communicates her low type truthfully, then she gets a payoff of 3.26 irrespectively of whether player 2 communicates a high or a low type. Also, if player 2 reveals his high type, he gets 3.72 irrespectively of whether player 1 communicates a high or a low valuation.

Piketty's mechanism is characterized by four points A, B, C and D, as illustrated in Figure 2. Points A and B coincide with the first-best utilitarian welfare maximum, so that

$$A = (c_l^*, y_l^*) = (5.53, 3.40) \quad \text{and} \quad B = (c_h^*, y_h^*) = (5.53, 7.66) .$$

There is a degree of freedom for the location of the points C and D. To have a completely specified example we need to determine these points in a specific way.

We do this so as to capture the desire for welfare-maximizing redistribution which is the basic premise of an analysis of optimal income tax systems. In particular, suppose that there is a small probability, possibly zero, that both types have low abilities. In this case truth-telling of both individuals yields point D. Also suppose that there is an equally small probability that both types have high abilities, which would yield point C. We now allow for the possibility to redistribute resources away from the lucky state in which everybody is of high ability to the unlucky state in which everybody is of low ability. Moreover, we maximize this level of redistribution subject to the constraint of satisfying the principles of Piketty's construction. More formally, we choose point $C = (y^C, c^C)$ so that we extract a maximal tax payment subject to the constraint that C lies above point A and between the two relevant indifference curves through A.[10] We then choose point $D = (y^D, c^D)$ so as to maximize $u(c^D) - v\left(\frac{y^D}{w_l}\right)$ subject to the constraint that $c^D - y^D = y^C - c^C$ and subject to the requirement that point D lies below point B and between the two relevant indifference curves through B. This construction is illustrated in Figure 3. It yields the following numerical values

$$C = (c^C, y^C) = (7.74, 6.47) \quad \text{and} \quad D = (c^D, y^D) = (3.32, 4.59) \,.$$

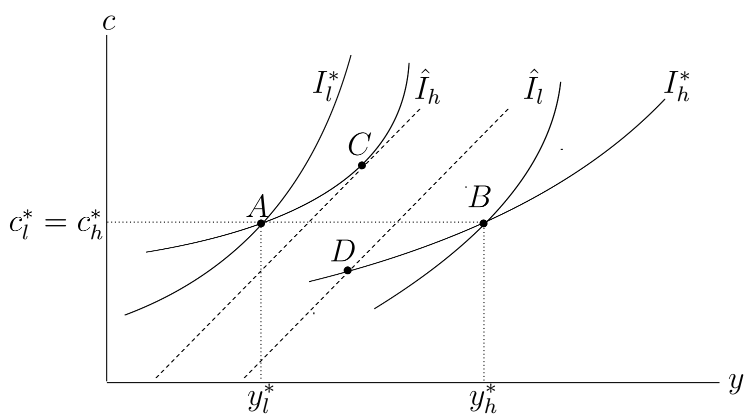


Figure 2. The Figure illustrates a specific Piketty mechanism. Point C is chosen so as to extract maximal tax revenues which yields the tangency condition that is shown in the Figure. These tax revenues are then used to make point D as attractive as possible, so that D is determined by the intersection of indifference curve I_h^* and a line with slope 1 and intercept $y^C - c^C$.

[10]Formally, it is obtained as a solution to the following problem: Maximize $y^C - c^C$, s.t.

$$u(c^C) - v\left(\frac{y^C}{w_h}\right) \geq u(c^A) - v\left(\frac{y^A}{w_h}\right) \quad \text{and} \quad u(c^C) - v\left(\frac{y^C}{w_l}\right) \leq u(c^A) - v\left(\frac{y^A}{w_l}\right) .$$

The normal form game that is induced by this version of a Piketty mechanism on a complete information type space, so that individual 1 is of low ability and individual 2 is of high ability, is summarized in Table 7. Again, the entries in the matrix are the players utility levels under the assumption of selfish preferences.

Table 7: The game induced by the Piketty mechanism in Figure 2 for $(\omega_1, \omega_2) = (\omega_l, \omega_h)$.

$(\tilde{U}_1, \tilde{U}_2)$	ω_l	ω_h
ω_l	$(2.32, 3.06)$	$(3.98, 3.08)$
ω_h	$(1.04, 4.38)$	$(2.94, 4.40)$

Again, the payoffs in this matrix are based on an affine transformation of utilities, $\tilde{U}_j = \alpha\, U_j + \beta$ with $\alpha = 2$ and $\beta = 0$. Truth-telling is a dominant strategy equilibrium under the assumption of selfish preferences. Externality-freeness is violated: If player 1 truthfully communicates a low ability type, his payoff depends on what player 2 communicates. Likewise, if player 2 communicates her high ability type truthfully, then her payoff depends on the type declared by player 1.

We conducted two laboratory treatments, one for the Mirrleesian approach and one for Piketty's approach.[11] As expected, we find hardly any deviations from truth-telling with the Mirrleesian approach: 124 of 126 low skilled individuals and 122 of 126 high skilled individuals truthfully report their ability. With Piketty's approach we also find almost no deviations from truth-telling for low skilled individuals, 121 of 126 reports are truthful. This changes with high skilled individuals in Piketty's approach where we observed 21 of 126 individuals to understate their skill level. This is a significantly larger proportion of deviations than with the Mirrleesian approach (two-sided Fisher's exact test, $p<0.001$). As a result, the Mirrleesian approach reaches an average welfare level that is with 6.93 significantly larger than the average welfare level of 6.78 which results from Piketty's approach (two-sided t-test, $p = 0.014$).

Again, this welfare comparison does not take social preferences into account. An inspection of Tables 6 and 7 shows once more that equilibrium payoffs are more equal under the externality-free Mirrleesian outcome. Hence, if the social welfare function incorporated social preferences with inequity aversion, the preference for

[11] In Piketty's approach only states with a low and a high skilled individual have a positive probability in theory. Despite this, we asked subjects to report actions for all four skill combinations in order to use the same procedures as in our other treatments. The results reported in this section are based on the two states with positive probability. The full experiment data can be found in Appendix 4.E.

the Mirrleesian outcome would be even more pronounced. As explained earlier, the same would be true with intention-based social preferences in the welfare function since equilibrium kindness is zero with an externality-free mechanism and negative otherwise.

At first glance, our results seem to suggest that insisting on externality-freeness is a good idea for a problem of income taxation, but a bad idea for the bilateral trade problem. Yet, in fact, social behavior is robust across applications: The fraction of individuals who deviated from selfish behavior was 14 % in our bilateral trade application and with 17 % for the income tax application not significantly different.[12] These numbers are clearly below the corresponding threshold for the profitability of the externality-free mechanism in bilateral trade (34 %), yet clearly above the threshold in taxation (5 %). We conclude that behavior is robust against our different mechanism design contexts, but the mechanisms systematically differ in their robustness towards social behavior.

4.7 Concluding remarks

This paper shows how social preferences can be taken into account in robust mechanism design. We have first characterized optimal mechanisms for a bilateral trade problem and a problem of redistributive income taxation under selfish preferences. We have argued theoretically that such a mechanism will not generally produce the desired behavior if individuals have social preferences, and we have illustrated in a laboratory experiment that deviations from the intended behavior indeed occur. We have then introduced an additional constraint on mechanism design, which we termed externality-freeness. We have shown theoretically that such a mechanism does generate the intended behavior if individuals are motivated by social preferences, without a need to specify (beliefs about) the nature and intensity of social preferences. We have finally confirmed in a series of experiments, taking other assumptions in mechanism design for granted (see below), that an externality-free mechanism does indeed generate the intended behavior.

We also investigated under which conditions externality-freeness improves the performance of a mechanism. Our specification of the bilateral trade problem was such that, to justify externality-freeness, many deviations from selfish behavior were required. By contrast, for our income tax application, a small number of deviations was sufficient. We found that the fraction of deviating individuals was the

[12]The difference between these two fractions was not found to be statistically different from zero (two-sided Fisher's exact test, $p = 0.728$).

same across applications, and moreover that this number was high enough to make externality-freeness desirable for the income tax application, but not high enough to make it desirable for the bilateral trade problem.

Externality-freeness is a sufficient but not a necessary condition for the ability to predict behavior. Its advantage is that it successfully controls the underlying motivations across a wide variety of social preferences discussed in the literature, as well as the frequently observed large heterogeneity in parameter values across individuals. It is not guaranteed, however, that externality-freeness also improves the performance of a mechanism. An alternative to imposing externality-freeness is a mechanism design approach that elicits not only the monetary payoffs of individuals but also the precise functional form of their social preferences. However, a need to specify the details of the nature and intensity of social preferences, which typically differ across individuals and contexts, would work against our goal to develop robust mechanisms in the spirit of the Wilson doctrine. We leave the question what can and what cannot be reached with a fine-tuned approach to future research.

As an alternative to such an axiomatic approach one might simply try to identify the relevant deviations from selfish behavior empirically, e.g., with a laboratory experiment, and then impose externality-freeness conditions only locally so as to eliminate the specific deviations that pose problems for the mechanism design problem at hand. This approach has the advantage that it does not impose as many additional constraints on the mechanism design problem. The disadvantage is that it does not eliminate all the deviations from selfish behavior that can be rationalized by models of social preferences. Thus, it is not as robust as an externality-free mechanism. We demonstrated the attractiveness of such an engineering approach in the context of the bilateral trade problem. Imposing externality-freeness only locally enabled us to find a mechanism that outperformed both an optimal mechanism for selfish agents and an optimal externality-free mechanism.

Adding behavioral aspects to the mechanism design literature is a promising line of research. That said, we caution that our study cannot, of course, capture all behavioral aspects that seem relevant. For instance, our experiments do not shed light on social preference robustness with incomplete information about monetary payoffs. As a first step, we rather take the theoretically predicted equivalence of implementability in all complete information environments and implementability in all incomplete information environments, as well as the revelation principle, for granted. This way, we can focus on the role of social preferences under certainty in mechanism design, abstracting away from other potential influencing behavioral factors which may arise in cognitively and socially more demanding environments.

For instance, recent evidence and theory suggest that some patterns of risk-taking in social context are not easily explained by either standard models of decision making under uncertainty nor standard models of social preferences (e.g., Bohnet et al. (2008), Bolton et al. (2015), Saito (2013), Ockenfels et al. (2014)). The implications of such findings for robust mechanism design need further attention. By the same token, our approach leaves open the question whether we can generate the behavior that is needed to implement a given social choice function also with an indirect mechanism, which may be empirically more plausible, than a direct revelation mechanism, e.g. one that simply asks individuals whether they are willing to trade at particular prices. These are fundamental questions, and their answers likely generate more important insights on how motivational and cognitive forces affect the behavioral effectiveness and efficiency of economic mechanisms. We are planning to check robustness along those lines in separate studies.

4.A References

Ariely, D., Ockenfels, A., and Roth, A. (2005). An experimental analysis of ending rules in internet auctions. *RAND Journal of Economics*, 36:890–907.

Atkinson, A. and Stiglitz, J. (1976). The design of tax structure: Direct versus indirect taxation. *Journal of Public Economics*, 1:55–75.

Bartling, B. and Netzer, N. (2016). An Externality-Robust Auction: Theory and Experimental Evidence. *Games and Economic Behavior*, 97:186–204.

Becker, G. S. (1974). A Theory of Social Interactions. *Journal of Political Economy*, 82(6):1063–1093.

Bergemann, D. and Morris, S. (2005). Robust Mechanism Design. *Econometrica*, 73:1771–1813.

Bierbrauer, F. (2011). On the Optimality of Optimal Income Taxation. *Journal of Economic Theory*, 146:2105–2116.

Bierbrauer, F. and Netzer, N. (2016). Mechanism Design and Intensions. *Journal of Economic Theory*, forthcoming.

Bohnet, I., Hermann, G., and Zeckhauser, R. (2008). Betrayal aversion: Evidence from Brazil, China, Oman, Switzerland, Turkey, and the United States. *American Economic Review*, 98:249–310.

Bolton, G., Greiner, B., and Ockenfels, A. (2013). Engineering trust - Reciprocity in the production of reputation information. *Management Science*, 59:265–285.

Bolton, G. and Ockenfels, A. (2000). ERC: A Theory of Equity, Reciprocity, and Competition. *American Economic Review*, 90:166–193.

Bolton, G. and Ockenfels, A. (2010). Betrayal aversion: Evidence from Brazil, China, Oman, Switzerland, Turkey, and the United States: Comment. *American Economic Review*, 100:628–633.

Bolton, G. and Ockenfels, A. (2012). Behavioral economic engineering. *Journal of Economic Psychology*, 33:665–676.

Bolton, G., Stauf, J., and Ockenfels, A. (2015). Social responsibility promotes conservative risk behavior. *European Economic Review*, 74:109–127.

Bolton, P. and Dewatripont, M. (2005). *Contract Theory.* Cambridge, MA, MIT Press.

Camerer, C. (1995). Individual Decision Making. In Kagel, J. and Roth, A., editors, *Handbook of Experimental Economics*, chapter 8, pages 587–683. Princeton University Press.

Camerer, C. (2003). *Behavioral Game Theory. Experiments in Strategic Interaction.* Princton University Press.

Charness, A. and Rabin, M. (2002). Understanding Social Preferences with Simple Tests. *Quarterly Journal of Economics*, 117:817–869.

Chen, Y. (2008). Incentive-compatible mechanisms for pure public goods: A survey of experimental literature.

Chen, Y., Harper, M., Konstan, J., and Li, S. (2010). Social comparisons and contributions to online communities. *American Economic Review*, 100:1358–1398.

Chen, Y. and Sönmez, T. (2006). Social choice: An experimental study. *Journal of Economic Theory*, 127:202–231.

Cooper, D. and Kagel, J. (2013). *Other-Regarding preferences: A selective survey of experimental results.* Princton University Press.

Crémer, J. and McLean, R. P. (1985). Optimal Selling Strategies under Uncertainty for a Discriminating Monopolist when Demands are Interdependent. *Econometrica*, 53(2):345–361.

Crémer, J. and McLean, R. P. (1988). Full Extraction of the Surplus in Bayesian and Dominant Strategy Auctions. *Econometrica*, 56:1247–1257.

Dierker, E. and Haller, H. (1990). Tax Systems and Direct Mechanisms in Large Finite Economies. *Journal of Economics*, 52:99–116.

Dufwenberg, M., Heidhues, P., Kirchsteiger, G., Riedel, F., and Sobel, J. (2011). Other-Regarding Preferences in General Equilibrium. *Review of Economic Studies*, 78:613–639.

Dufwenberg, M. and Kirchsteiger, G. (2004). A Theory of Sequential Reciprocity. *Games and Economic Behavior*, 47:268–298.

Falk, A. and Fischbacher, U. (2006). A Theory of Reciprocity. *Games and Economic Behavior*, 54:293–315.

Fehr, E. and Schmidt, K. (1999). A Theory Of Fairness, Competition, and Cooperation. *Quarterly Journal of Economics*, 114:817–868.

Fischbacher, U. (2007). z-Tree: Zurich Toolbox for Ready-made Economic Experiments. *Experimental Economics*, 10:171–178.

Greiner, B. (2015). Subject Pool Recruitment Procedures: Organizing Experiments with ORSEE. *Journal of the Economic Science Association*, 1(1):114–125.

Guesnerie, R. (1995). *A Contribution to the Pure Theory of Taxation*. Cambridge University Press.

Güth, W. and Hellwig, M. (1986). The Private Supply of a Public Good. *Journal of Economics*, Supplement 5:121–159.

Güth, W. and Kocher, M. (2013). More than thirty years of ultimatum bargaining experiments: Motives, variations, and a survey of the recent literature. Jena Economic Research Papers.

Güth, W., Schmittberger, R., and Schwarze, B. (1982). An experimental analysis of ultimatum bargaining. *Journal of Economic Behavior and Organization*, 3:367–388.

Hagerty, K. and Rogerson, W. (1987). Robust trading mechanisms. *Journal of Economic Theory*, 42:94–107.

Hammond, P. (1979). Straightforward Individual Incentive Compatibility in Large Economies. *Review of Economic Studies*, 46:263–282.

Jehiel, P. and Moldovanu, B. (2006). Allocative and Informational Externalities in Auctions and Related Mechanisms. In Blundell, R., Newey, W., and Persson, T., editors, *Proceedings of the 9th World Congress of the Econometric Society*.

Kagel, J. and Roth, A. (2000). The dynamics of reorganization in matching markets: A laboratory experiment motivated by a natural experiment. *Quaterly Journal of Economics*, 115:201–235.

Kagel, J. H., Lien, Y., and Milgrom, P. (2010). Ascending prices and package bidding: A theoretical and experimental analysis. *American Economic Journal: Microeconomics*, 2:160–185.

Kittsteiner, T., Ockenfels, A., and Trhal, N. (2012). Heterogeneity and partnership dissolution mechanisms: Theory and lab evidence. *Economics Letters*, 117:394–396.

Kosenok, G. and Severinov, S. (2008). Individually rational, budget-balanced mechanisms and allocation of surplus. *Journal of Economic Theory*, 140(1):126 – 161.

Mailath, G. and Postlewaite, A. (1990). Asymmetric Bargaining Procedures With Many Agents. *Review of Economic Studies*, 57:351–367.

Mirrlees, J. (1971). An Exploration in the Theory of Optimum Income Taxation. *Review of Economic Studies*, 38:175–208.

Mussa, M. and Rosen, S. (1978). Monopoly and Product Quality. *Journal of Economic Theory*, 18:301–317.

Myerson, R. and Satterthwaite, M. (1983). Efficient Mechanisms for Bilateral Trading. *Journal of Economic Theory*, 28:265–281.

Netzer, N. and Volk, A. (2014). Intentions and Ex-Post Implementation. Mimeo, University of Zurich.

Ockenfels, A., Sliwka, D., and Werner, P. (2014). Bonus Payments and Reference Point Violations. *Management Science*, 61(7):1496–1513.

Piketty, T. (1993). Implementation of First-Best Allocations Via Generalized Tax Schedules. *Journal of Economic Theory*, 61:23–41.

Rabin, M. (1993). Incorporating Fairness Into Game Theory and Economics. *American Economic Review*, 83:1281–1302.

Radner, R. and Schotter, A. (1989). The sealed-bid mechanism: An experimental study. *Journal of Economic Theory*, 48:179–220.

Roth, A. (2002). The economist as engineer: Game theory, experimentation, and computation as tool for design economics. *Econometrica*, 70:1341–1378.

Roth, A. (2012). Experiments in market design. mimeo.

Saito, K. (2013). Social Preferences under risk: Equality of opportunity vs. equality of outcome. *American Economic Review*, 7:3084–3101.

Sobel, J. (2005). Interdependent Preferences and Reciprocity. *Journal of Economic Literature*, 43:392–436.

Stiglitz, J. (1982). Self-Selection and Pareto-Efficient Taxation. *Journal of Public Economics*, 17:213–240.

Valley, K., Thompson, L., Gibbons, R., and Bazerman, M. (2002). How communication improves efficiency in bargaining games. *Games and Economic Behavior*, 38:127–155.

Wilson, R. (1987). Game-theoretic analyses of trading processes. In *Advances in Economic Theory*, pages 33–70. Cambridge University Press. Cambridge Books Online.

4.B Proofs

Proof of Proposition 1. The relaxed problem imposes only the buyer's *ex post* participation and incentive constraints, as well as the constraint that the expected payments to the seller are equal to the expected payments of the buyer, with expectations computed using the designer's subjective beliefs. Thus, the problem is to choose, for every state $(\theta_b, \theta_s) \in \Theta_b \times \Theta_s$, $q^f(\theta_b, \theta_s)$, $p_b^f(\theta_b, \theta_s)$ and $p_s^f(\theta_b, \theta_s)$ so as to maximize

$$\sum_{\Theta_b \times \Theta_s} g(\theta_b, \theta_s) \left(p_s^f(\theta_b, \theta_s) - \theta_s k(q^f(\theta_b, \theta_s))\right)$$

subject to the following constraints: (i) the resource constraint

$$\sum_{\Theta_b \times \Theta_s} g(\theta_b, \theta_s) p_b^f(\theta_b, \theta_s) \geq \sum_{\Theta_b \times \Theta_s} g(\theta_b, \theta_s) p_s^f(\theta_b, \theta_s) \; , \tag{4.11}$$

(ii) the incentive and participation constraints for the buyer that are relevant if the seller is of the high cost type,

$$\underline{\theta}_b \; q^f(\underline{\theta}_b, \overline{\theta}_s) - p_b^f(\underline{\theta}_b, \overline{\theta}_s) \geq 0 \; , \tag{4.12}$$

$$\overline{\theta}_b \; q^f(\overline{\theta}_b, \overline{\theta}_s) - p_b^f(\overline{\theta}_b, \overline{\theta}_s) \geq 0 \; , \tag{4.13}$$

$$\underline{\theta}_b \; q^f(\underline{\theta}_b, \overline{\theta}_s) - p_b^f(\underline{\theta}_b, \overline{\theta}_s) \geq \underline{\theta}_b \; q^f(\overline{\theta}_b, \overline{\theta}_s) - p_b^f(\overline{\theta}_b, \overline{\theta}_s) \; , \tag{4.14}$$

and

$$\overline{\theta}_b \; q^f(\overline{\theta}_b, \overline{\theta}_s) - p_b^f(\overline{\theta}_b, \overline{\theta}_s) \geq \overline{\theta}_b \; q^f(\underline{\theta}_b, \overline{\theta}_s) - p_b^f(\underline{\theta}_b, \overline{\theta}_s) \; , \tag{4.15}$$

and finally (iii) the incentive and participation constraints for the buyer that are relevant if the seller is of the low cost type. These constraints have the same structure as those in (4.12)-(4.15), except that $\overline{\theta}_s$ is everywhere replaced by $\underline{\theta}_s$.

Obviously, the resource constraint will be binding, so that the objective becomes to maximize

$$\sum_{\Theta_b \times \Theta_s} g(\theta_b, \theta_s) \left(p_b^f(\theta_b, \theta_s) - \theta_s k(q^f(\theta_b, \theta_s))\right)$$

subject to the constraints in (ii) and (iii). The solution can be obtained by solving a separate optimization problem for each seller type. Thus, optimality requires that $q^f(\underline{\theta}_b, \overline{\theta}_s)$, $q^f(\overline{\theta}_b, \overline{\theta}_s)$, $p_b^f(\underline{\theta}_b, \overline{\theta}_s)$, and $p_f^f(\overline{\theta}_b, \overline{\theta}_s)$ are chosen so as to maximize

$$\sum_{\Theta_b} g(\theta_b, \overline{\theta}_s) \left(p_b^f(\theta_b, \overline{\theta}_s) - \theta_s k(q^f(\theta_b, \overline{\theta}_s))\right)$$

subject to the constraints in (ii); likewise $q^f(\underline{\theta}_b, \underline{\theta}_s)$, $q^f(\overline{\theta}_b, \underline{\theta}_s)$, $p_b^f(\underline{\theta}_b, \underline{\theta}_s)$, and $p_f^f(\overline{\theta}_b, \underline{\theta}_s)$ are chosen so as to maximize

$$\sum_{\Theta_b} g(\theta_b, \underline{\theta}_s) \left(p_b^f(\theta_b, \underline{\theta}_s) - \theta_s k(q^f(\theta_b, \underline{\theta}_s)) \right)$$

subject to the constraints in (iii).

The solution to these problems is well-known, see e.g., Bolton and Dewatripont (2005). Thus, at a solution, the high-valuation buyer's incentive constraint and the low-valuation buyer's participation constraints bind and the other constraints are slack. For example, if $\theta_s = \overline{\theta}_s$, then (4.12) and (4.15) bind, and (4.13) and (4.14) are not binding. The optimal quantities are then obtained by substituting

$$p_b^f(\underline{\theta}_b, \overline{\theta}_s) = \underline{\theta}_b q^f(\underline{\theta}_b, \overline{\theta}_s)$$

and

$$p_b^f(\overline{\theta}_b, \overline{\theta}_s) = \overline{\theta}_b q^f(\overline{\theta}_b, \overline{\theta}_s) - (\overline{\theta}_b - \underline{\theta}_b) q^f(\underline{\theta}_b, \overline{\theta}_s)$$

into the objective function which yields

$$g(\underline{\theta}_b, \overline{\theta}_s) \left(\left(\underline{\theta}_b - \tfrac{g(\overline{\theta}_b, \overline{\theta}_s)}{g(\underline{\theta}_b, \overline{\theta}_s)} (\overline{\theta}_b - \underline{\theta}_b) \right) q^f(\underline{\theta}_b, \overline{\theta}_s) - \overline{\theta}_s k(q^f(\underline{\theta}_b, \overline{\theta}_s)) \right)$$

$$+ g(\overline{\theta}_b, \overline{\theta}_s) \left(\overline{\theta}_b q^f(\overline{\theta}_b, \overline{\theta}_s) - \overline{\theta}_s k(q^f(\overline{\theta}_b, \overline{\theta}_s)) \right) .$$

Choosing $q^f(\underline{\theta}_b, \overline{\theta}_s)$ and $q^f(\overline{\theta}_b, \overline{\theta}_s)$ to maximize this expression yields the optimality conditions that are stated in Proposition 1 in the body of the text. □

Proof of Proposition 3. For the relaxed problem of optimal externality-free mechanism design the objective is, again, the maximization of

$$\sum_{\Theta_b \times \Theta_s} g(\theta_b, \theta_s) \left(p_s^f(\theta_b, \theta_s) - \theta_s k(q^f(\theta_b, \theta_s)) \right) .$$

The resource constraint in (4.11) is binding at a solution to this problem, so that the objective can be equivalently written as

$$\sum_{\Theta_b \times \Theta_s} g(\theta_b, \theta_s) \left(p_b^f(\theta_b, \theta_s) - \theta_s k(q^f(\theta_b, \theta_s)) \right)$$

The constraints are the low valuation buyer's *ex post* participation constraints,

$$\underline{\theta}_b q^f(\underline{\theta}_b, \underline{\theta}_s) - p_b^f(\underline{\theta}_b, \underline{\theta}_s) \geq 0 \;, \tag{4.16}$$

and

$$\underline{\theta}_b q^f(\underline{\theta}_b, \overline{\theta}_s) - p_b^f(\underline{\theta}_b, \overline{\theta}_s) \geq 0 \;; \tag{4.17}$$

the incentive constraint for a high type buyer who faces a low cost seller,

$$\overline{\theta}_b q^f(\overline{\theta}_b, \underline{\theta}_s) - p_b^f(\overline{\theta}_b, \underline{\theta}_s) \geq \overline{\theta}_b q^f(\underline{\theta}_b, \underline{\theta}_s) - p_b^f(\underline{\theta}_b, \underline{\theta}_s) \;, \tag{4.18}$$

and the constraint, that the seller must not be able to influence the high valuation buyer's payoff,

$$\overline{\theta}_b q^f(\overline{\theta}_b, \underline{\theta}_s) - p_b^f(\overline{\theta}_b, \underline{\theta}_s) = \overline{\theta}_b q^f(\overline{\theta}_b, \overline{\theta}_s) - p_b^f(\overline{\theta}_b, \overline{\theta}_s) \;. \tag{4.19}$$

Note first that the constraint in (4.17) has to bind at a solution to this problem. The payment $p_b^f(\underline{\theta}_b, \overline{\theta}_s)$ enters only in this constraint. Hence, if we hypothesize a solution to the optimization problem with slack in (4.17), we can raise $p_b^f(\underline{\theta}_b, \overline{\theta}_s)$ without violating any constraint, thereby arriving at a contradiction to the assumption that the initial situation has been an optimum.

Second, the constraint in (4.16) binds as well. Suppose otherwise, then it is possible to raise $p_b^f(\underline{\theta}_b, \underline{\theta}_s)$ by some small $\varepsilon > 0$, without violating this constraint. If at the same time, $p_b^f(\overline{\theta}_b, \underline{\theta}_s)$ and $p_b^f(\overline{\theta}_b, \overline{\theta}_s)$ are also raised by ε, then also the constraints in (4.18) and (4.19) remain satisfied. These increases of the buyer's payments raise the objective function, again contradicting the assumption that the initial situation has been optimal.

Third, the constraint in (4.18) has to be binding. Otherwise, it would be possible to raise $p_b^f(\overline{\theta}_b, \underline{\theta}_s)$ without violating this constraint. If at the same time, $p_b^f(\overline{\theta}_b, \overline{\theta}_s)$ is raised by ε, then also (4.19) remains satisfied. One more time, this contradicts the assumption that the initial situation has been optimal.

These observations enables to express the buyer's payments as functions of the traded quantities, so that

$$p_b^f(\underline{\theta}_b, \underline{\theta}_s) = \underline{\theta}_b q^f(\underline{\theta}_b, \underline{\theta}_s) \;,$$

$$p_b^f(\underline{\theta}_b, \overline{\theta}_s) = \underline{\theta}_b q^f(\underline{\theta}_b, \overline{\theta}_s) \;,$$

$$p_b^f(\overline{\theta}_b, \underline{\theta}_s) = \overline{\theta}_b q^f(\overline{\theta}_b, \underline{\theta}_s) - (\overline{\theta}_b - \underline{\theta}_b) q^f(\underline{\theta}_b, \underline{\theta}_s) \;,$$

and

$$p_b^f(\overline{\theta}_b,\overline{\theta}_s)=\overline{\theta}_b q^f(\overline{\theta}_b,\overline{\theta}_s)-(\overline{\theta}_b-\underline{\theta}_b)q^f(\underline{\theta}_b,\underline{\theta}_s)\ .$$

Substituting these payments into the objective function yields

$$g(\underline{\theta}_b,\underline{\theta}_s)\left(\left(\underline{\theta}_b-\tfrac{g(\overline{\theta}_b,\underline{\theta}_s)+g(\overline{\theta}_b,\overline{\theta}_s)}{g(\underline{\theta}_b,\underline{\theta}_s)}(\overline{\theta}_b-\underline{\theta}_b)\right)q^f(\underline{\theta}_b,\underline{\theta}_s)-\underline{\theta}_s k(q^f(\underline{\theta}_b,\underline{\theta}_s))\right)$$

$$+g(\overline{\theta}_b,\underline{\theta}_s)(\overline{\theta}_b q^f(\overline{\theta}_b,\underline{\theta}_s)-\underline{\theta}_s k(q^f(\overline{\theta}_b,\underline{\theta}_s)))$$

$$+g(\underline{\theta}_b,\overline{\theta}_s)(\underline{\theta}_b q^f(\underline{\theta}_b,\overline{\theta}_s)-\overline{\theta}_s k(q^f(\underline{\theta}_b,\overline{\theta}_s)))$$

$$+g(\overline{\theta}_b,\overline{\theta}_s)(\overline{\theta}_b q^f(\overline{\theta}_b,\overline{\theta}_s)-\overline{\theta}_s k(q^f(\overline{\theta}_b,\overline{\theta}_s))))\ .$$

Choosing $q^f(\underline{\theta}_b,\underline{\theta}_s)$, $q^f(\overline{\theta}_b,\underline{\theta}_s)$, $q^f(\underline{\theta}_b,\overline{\theta}_s)$ and $q^f(\overline{\theta}_b,\overline{\theta}_s)$ so as to maximize this expression yields the optimality conditions stated in Proposition 3. □

Proof of Proposition 5. We need to show that there is a solution to the optimization problem in Proposition 1 that satisfies

$$p_s^f(\underline{\theta}_b,\underline{\theta}_s)-\underline{\theta}_s k(q^f(\underline{\theta}_b,\underline{\theta}_s))=p_s^f(\overline{\theta}_b,\underline{\theta}_s)-\underline{\theta}_s k(q^f(\overline{\theta}_b,\underline{\theta}_s))\ ,$$

and

$$p_s^f(\underline{\theta}_b,\overline{\theta}_s)-\overline{\theta}_s k(q^f(\underline{\theta}_b,\overline{\theta}_s))=p_s^f(\overline{\theta}_b,\overline{\theta}_s)-\overline{\theta}_s k(q^f(\overline{\theta}_b,\overline{\theta}_s))\ ,$$

or, equivalently,

$$p_s^f(\underline{\theta}_b,\underline{\theta}_s)-p_s^f(\overline{\theta}_b,\underline{\theta}_s)=\underline{\theta}_s k(q^f(\underline{\theta}_b,\underline{\theta}_s))-\underline{\theta}_s k(q^f(\overline{\theta}_b,\underline{\theta}_s))\ , \tag{4.20}$$

and

$$p_s^f(\underline{\theta}_b,\overline{\theta}_s)-p_s^f(\overline{\theta}_b,\overline{\theta}_s)=\overline{\theta}_s k(q^f(\underline{\theta}_b,\overline{\theta}_s))-\underline{\theta}_s k(q^f(\overline{\theta}_b,\overline{\theta}_s))\ . \tag{4.21}$$

The right-hand-side of equations (4.20) and (4.21) is pinned down by the characterization in Proposition 1. However, this solution leaves degrees of freedom with respect to the specification of the seller's payments. It only requires that the resource constraint binds which implies that

$$\sum_{\Theta_b\times\Theta_s} g(\theta_b,\theta_s)p_s^f(\theta_b,\theta_s)=\sum_{\Theta_b\times\Theta_s} g(\theta_b,\theta_s)p_b^f(\theta_b,\theta_s)\ . \tag{4.22}$$

Again the right-hand side of this equation is pinned down by the characterization in Proposition 1. Thus, the four payments to the seller $p_s^f(\underline{\theta}_b,\underline{\theta}_s)$, $p_s^f(\overline{\theta}_b,\underline{\theta}_s)$, $p_s^f(\underline{\theta}_b,\overline{\theta}_s)$

and $p_s^f(\overline{\theta}_b, \overline{\theta}_s)$ need to satisfy the three linear equations in (4.20), (4.21) and (4.22). Obviously, there will be more than one combination of payments to the seller that satisfy all of these conditions. $\square$

4.C Other models of social preferences

In the body of the text, we have shown that the model of Fehr and Schmidt (1999) predicts deviations from truth-telling in certain situations (see *Observation 1*). Below, we present analogous findings for two other models of social preferences, Rabin (1993) and Falk and Fischbacher (2006). The Rabin (1993)-model is an example of intention-based social preferences, as opposed to the outcome-based model of Fehr and Schmidt (1999). The model by Falk and Fischbacher (2006) is a hybrid that combines considerations that are outcome-based with considerations that are intention-based. We show that these models also satisfy *Assumption 1*, i.e. selfishness in the absence of externalities.

Similar exercises could be undertaken for other models, such as Charness and Rabin (2002), and Dufwenberg and Kirchsteiger (2004). Whether or not these models would predict deviations from truth-telling under the optimal mechanism for selfish agents depends on the values of specific parameters in these models. To avoid a lengthy exposition, we do not present these details here. The preferences in Charness and Rabin (2002), and Dufwenberg and Kirchsteiger (2004) do, however satisfy the assumption of selfishness in the absence of externalities (*Assumption 1*).

Rabin (1993). The utility function of any one player i utility takes the form in (4.6). Rabin models the kindness terms in this expression in a particular way. Kindness intended by i towards j is the difference between j's actual material payoff and an equitable reference payoff,

$$\kappa_i(r_i, r_i^b, r_i^{bb}) = \pi_j(r_i, r_i^b) - \pi_j^{e_i}(r_i^b). \tag{4.23}$$

The equitable payoff $\pi_j^{e_i}(r_i^b)$ is to be interpreted as a norm, or a payoff that j deserves from i's perspective. According to Rabin (1993), this reference point is the average of the best and the worst player i could do to player j, i.e.

$$\pi_j^{e_i}(r_i^b) = \frac{1}{2}\left(max_{r_i \in E_{ij}(r_i^b)} \pi_j(\theta_j, f(r_i, r_i^b)) + min_{r_i \in E_{ij}(r_i^b)} \pi_j(\theta_j, f(r_i, r_i^b)) \right),$$

where $E_{ij}(r_i)$ is the set of Pareto-efficient reports: A report r_i belongs to $E_{ij}(r_i^b)$ if and only if there is no alternative report r_i' so that $\pi_i(r_i', r_i^b) \geq \pi_i(r_i, r_i^b)$ and

$\pi_j(r_i', r_i^b) \geq \pi_j(r_i, r_i^b)$, with at least one inequality being strict. Rabin models the beliefs of player i about the kindness intended by j in a symmetric way. Thus,

$$\kappa_j(r_i^b, r_i^{bb}) = \pi_i(r_i^b, r_i^{bb}) - \pi_i^{e_j}(r_i^{bb}).$$

For later reference, it is useful to note that by equation (4.23), $\kappa_i(r_i, r_i^b, r_i^{bb})$ does not explicitly depend on r_i^{bb}. In the context of Rabin's model, we can therefore simplify notation and write $\kappa_i(r_i, r_i^b)$ rather than $\kappa_i(r_i, r_i^b, r_i^{bb})$.

Observation 3. *Let f be a social choice function that solves a problem of optimal robust mechanism design as defined in Section 4.3.2. Consider a complete information types space for state $(\overline{\theta}_b, \underline{\theta}_s)$ and suppose that $\theta_b = \bar{\theta}_b$. Suppose that f is such that*

$$\pi_b(\overline{\theta}_b, f(\overline{\theta}_b, \underline{\theta}_s)) = \pi_b(\overline{\theta}_b, f(\underline{\theta}_b, \underline{\theta}_s)) > \pi_b(\overline{\theta}_b, f(\overline{\theta}_b, \overline{\theta}_s)) = \pi_b(\overline{\theta}_b, f(\underline{\theta}_b, \overline{\theta}_s)) \ . \qquad (4.24)$$

Suppose that the buyer's and the seller's first and second order beliefs are as in a truth-telling equilibrium. Also suppose that the buyer has Rabin (1993)-preferences with $y_b \neq 0$. Then the buyer's best response is to truthfully reveal his valuation.

The social choice function in Example 1 fulfills Condition (4.24). Consider Table 3. The buyer's incentive constraint binds. Moreover, if the buyer understates his valuation this harms the seller. Since the seller's intention, when truthfully reporting his type, is perceived as kind, the buyer maximizes utility by rewarding the seller. By (4.8), the buyer will therefore announce his type truth-fully *for all y_b*.

Observation 4. *Let f be a social choice function that solves a problem of optimal robust mechanism design as defined in Section 4.3.2. Consider a complete information types space for state $(\overline{\theta}_b, \overline{\theta}_s)$ and suppose that $\theta_b = \bar{\theta}_b$. Suppose that f is such that (4.24) holds. Suppose that the buyer's and the seller's first and second order beliefs are as in a truth-telling equilibrium. Also suppose that the buyer has Rabin (1993)-preferences with $y_b \neq 0$. Then the buyer's best response is to understate his valuation.*

The social choice function in Example 1 fulfills Condition (4.24). Consider Table 4. We hypothesize that truth-telling is an equilibrium and show that this leads to a contradiction unless the buyer is selfish: The buyer's incentive constraint binds. Moreover, if the buyer understates his valuation this harms the seller. Since the seller's intention, when truthfully reporting his type, is perceived as unkind, the buyer maximizes utility by punishing the seller. By (4.8), the buyer will therefore understate his type *for all* $y_b \neq 0$. Hence, the Rabin model predicts that the buyer will deviate from truth-telling, *for all* $y_b \neq 0$. Put differently, truth-telling is a best response for the buyer only if $y_b = 0$, i.e. only if the buyer is selfish.

Finally, we note that the utility function in the Rabin (1993) model satisfies Assumption 1 for all possible parametrization of the model. The reason is that two actions which have the same implications for the other player generate the same kindness. The one that is better for the own payoff is thus weakly preferred.

Observation 5. *Suppose the buyer and the seller have preferences as in (4.6) with parameters y_b and y_s, respectively. The utility functions U_b and U_s satisfy Assumption 1, for all $y_b \neq 0$ and for all $y_s \neq 0$,*

Falk and Fischbacher (2006). We present a version of the Falk-Fischbacher-model that is adapted to the two player simultaneous move games that we study. The utility function takes again the general form in (4.6). The kindness intended by player i is now given as

$$\kappa_i(r_i, r_i^b, r_i^{bb}) = \pi_j(r_i, r_i^b) - \pi_j(r_i^b, r_i^{bb}) \ ,$$

Moreover, $\kappa_j(r_i^b, r_i^{bb})$ is modeled by Falk and Fischbacher in such a way that

$$\kappa_j(r_i^b, r_i^{bb}) \leq 0 \ , \tag{4.25}$$

whenever $\pi_i(r_i^b, r_i^{bb}) - \pi_j(r_i^b, r_i^{bb}) \leq 0$. More specifically, the following assumptions are imposed:

(a) If $\pi_i(r_i^b, r_i^{bb}) - \pi_j(r_i^b, r_i^{bb}) = 0$, then $\kappa_j(r_i^b, r_i^{bb}) = 0$.

(b) The inequality in (4.25) is strict whenever $\pi_i(r_i^b, r_i^{bb}) - \pi_j(r_i^b, r_i^{bb}) < 0$ and there exists r_j so that $\pi_i(r_j, r_i^{bb}) > \pi_i(r_i^b, r_i^{bb})$.

(c) If $\pi_i(r_i^b, r_i^{bb}) - \pi_j(r_i^b, r_i^{bb}) < 0$ and there is no r_j so that $\pi_i(r_j, r_i^{bb}) > \pi_i(r_i^b, r_i^{bb})$, then $\kappa_j(r_i^b, r_i^{bb})$ may be zero or positive.

The case distinction in (c) is decisive for the predictions of the Falk-Fischbacher-model. If $\kappa_j(r_i^b, r_i^{bb}) > 0$, then Observation 1 for the Fehr-Schmidt-model also holds for the Falk-Fischbacher-model. If, by contrast, $\kappa_j(r_i^b, r_i^{bb}) = 0$, then Observations 3 and 4 for the Rabin-model also hold for the Falk-Fischbacher-model. In any case, the Falk-Fischbacher satisfies Assumption 1, the assumption of selfishness in the absence of externalities.

Observation 6. *Suppose the buyer and the seller have preferences as in the model of Falk and Fischbacher (2006) with parameters y_b and y_s, respectively. The utility functions U_b and U_s satisfy Assumption 1, for all $y_b \neq 0$ and for all $y_s \neq 0$.*

This follows since $\pi_j(r_i, r_i^b) = \pi_j(r_i', r_i^b)$ implies that $\kappa_i(r_i, r_i^b, r_i^{bb}) = \kappa_i(r_i', r_i^b, r_i^{bb})$. Consequently, two actions that yield the same payoff for the other player generate the same value of $\kappa_i(r_i, r_i^b, r_i^{bb})\kappa_j(r_i^b, r_i^{bb})$.

4.D Externality-freeness as a necessary condition.

Proposition 6 below states a condition under which externality-freeness and incentive-compatibility are not only sufficient, but also necessary for social-preference robustness. To prove Proposition 6 we focus on a specific model of social preferences, namely the one by Rabin (1993), and work with the solution concept of a *fairness equilibrium* that has been introduced in that paper. We require that a social choice function is robustly implementable as a fairness equilibrium, i.e. we require that there is a mechanism that reaches this social function on every complete information type space, and for each possible specification of the weights y_1 and y_2 that players 1 and 2 assign to kindness in their overall utility function in (4.6). We provide necessary conditions for robust implementability as a fairness equilibrium. Robust implementability as a fairness equilibrium is in turn a necessary condition for social-preference-robustness.

Robust implementability as a fairness equilibrium. There are two agents $I = \{1, 2\}$. We seek to implement a social choice function $f : \Theta_1 \times \Theta_2 \to X$, where X is an abstract set of economic outcomes. Thus, given a profile of preferences parameters (θ_1, θ_2), the material payoff for agent 1 is denoted by $\pi_1(\theta_1, f(\theta_1, \theta_2))$ and the material payoff for agent 2 by $\pi_2(\theta_2, f(\theta_1, \theta_2))$.

In the context of Rabin's model of social preferences, the validity of the revelation principle cannot be taken for granted, see Bierbrauer and Netzer (2016). We therefore consider the implementation of the social choice function f by means of an arbitrary allocation mechanism that consists of a set of reports R_1, with typical entry r_1, for player 1, a set of reports R_2, with typical entry r_2, for player 2 and an outcome function $g : R_1 \times R_2 \to X$ that assigns an economic outcome to each profile of reports.

The utility that individual i realizes can be written as

$$U_i(r_i \mid \theta_i, y_i, r_i^b, r_i^{bb}) = \pi_i(\theta_i, f(r_i, r_i^b)) + y_i\, \kappa_i(r_i, r_i^b)\, \kappa_j(r_i^b, r_i^{bb}) \;, \tag{4.26}$$

where y_i is the weight that agent i assigns to kindness sensations. This notation emphasizes that individual i chooses r_i and that θ_i, y_i, r_i^b and r_i^{bb} are parameters that enter individual i's utility function. The weights y_1 and y_2 take values in the sets $\mathbb{R}_{0+}$. In the special case with $y_1 = y_2 = 0$, both individuals are selfish.

We consider complete information type spaces where both the profile of preference parameters (θ_1, θ_2) and the kindness weights (y_1, y_2) are commonly known among the individuals. A mechanism $\mathcal{M} = [R_1, R_2, g]$ implements a social choice function f on such a type space if there exist reports $r_1^*(\theta_1, y_1)$ and $r_2^*(\theta_2, y_2)$ such that (i) the social choice function is reached, i.e.

$$g(r_1^*(\theta_1, y_1), r_2^*(\theta_2, y_2)) = f(\theta_1, \theta_2) \tag{4.27}$$

and (ii) given correct first and second order beliefs, $r_1^*(\theta_1, y_1)$ is the utility-maximizing report for player 1 and $r_2^*(\theta_2, y_2))$ is the utility-maximizing report for player 2. More formally, for all i and $j \neq i$,

$$r_i^*(\theta_i, y_i) \quad \in \quad \text{argmax}_{r_i \in R_i} \quad U_i(r_i \mid \theta_i, y_i, r_j^*(\theta_j, y_j)), r_i^*(\theta_i, y_i)) \; . \tag{4.28}$$

We say that f is robustly implementable as a fairness equilibrium if there exists a mechanism $\mathcal{M} = [R_1, R_2, g]$, and a pair of functions $r_1^* : \Theta_1 \times Y_1 \to R_1$ and $r_2^* : \Theta_2 \times Y_2 \to R_2$ so that (4.27) and (4.28) hold for all $(\theta_1, y_1) \in \Theta_1 \times \mathbb{R}_{0+}$ and all $(\theta_2, y_2) \in \Theta_2 \times \mathbb{R}_{0+}$.

A necessary condition. Consider a specific violation of externality-freeness so that player 1 has an influence on the payoff of player 2, and player 2 has a chance to lower the payoff of player 1. Part B of Proposition 6 below asserts that, if a social choice function violates externality-freeness in this specific way, then it is not robustly implementable as a fairness equilibrium. The specific violation of externality-freeness covers, in particular, environments with two types per player. With a more general structure of type spaces, a social choice function f violates externality-freeness in this way as soon as there is a type profile (θ_1, θ_2) so that, for both players, truth-telling is neither entirely selfish, nor entirely selfless, i.e. as soon as there exist (θ_1', θ_2') and (θ_1'', θ_2'') such that

$$\pi_2(\theta_2, f(\theta_1', \theta_2)) < \pi_2(\theta_2, f(\theta_1, \theta_2)) < \pi_2(\theta_2, f(\theta_1'', \theta_2))$$

and

$$\pi_1(\theta_1, f(\theta_1, \theta_2')) < \pi_1(\theta_1, f(\theta_1, \theta_2)) < \pi_1(\theta_1, f(\theta_1, \theta_2'')) \; .$$

Externality-freeness, by contrast, requires that, for all i and all θ_j,

$$\min_{\theta_i \in \Theta_i} \pi_j(\theta_j, f(\theta_i, \theta_j)) = \max_{\theta_i \in \Theta_i} \pi_j(\theta_j, f(\theta_i, \theta_j)) \ .$$

Definition 2. *We say that social choice function f violates externality-freeness in a specific way if there is a complete information type space (θ_1, θ_2) and a pair of alternative types (θ_1', θ_2') such that $\pi_2(\theta_2, f(\theta_1, \theta_2)) < \pi_2(\theta_2, f(\theta_1', \theta_2))$ and $\pi_1(\theta_1, f(\theta_1, \theta_2)) > \pi_1(\theta_1, f(\theta_1, \theta_2'))$.*

Proposition 6.

A. If f is robustly implementable as a fairness equilibrium, then f is incentive compatible.

B. If f violates externality-freeness in a specific way, then f is not robustly implementable as a fairness equilibrium.

Proof of Proposition 6. *A.* We first show that robust implementability of f as a fairness equilibrium implies that f is incentive-compatible. Let $y_i = 0$, then implementability requires that

$$r_i^*(\theta_i, 0) \quad \in \quad \text{argmax}_{r_i \in R_i} \quad \pi_i(\theta_i, g(r_i, r_j^*(\theta_j, y_j))) \ . \tag{4.29}$$

for all $\theta_i \in \Theta_i$ and all $(\theta_j, y_j) \in \Theta_j \times \mathbb{R}_{0+}$. In particular, this implies that for all θ_i, all (θ_i', y_i') and all (θ_j, y_j),

$$\pi_i(\theta_i, g(r_i^*(\theta_i, 0), r_j^*(\theta_j, y_j))) \geq \pi_i(\theta_i, g(r_i^*(\theta_i', y_i'), r_j^*(\theta_j, y_j))) \ .$$

Because of (4.27) this implies that, for all θ_i, all θ_i' and all θ_j,

$$\pi_i(\theta_i, f(\theta_i, \theta_j)) \geq \pi_i(\theta_i, f(\theta_i', \theta_j)) \ .$$

Thus, f is incentive compatible.

B. Let f be a social choice function that violates externality-freeness in a specific way. We will show that this implies that there is a threshold $\hat{y}_2$ so that conditions (4.27) and (4.28) are incompatible whenever $y_2 \geq \hat{y}_2$. To establish this claim we have to go through a number of intermediate steps.

Step 1. We show that conditions (4.27) and (4.28) imply that every type of every player behaves selfishly, i.e. that for all i, all (θ_i, y_i) and all (θ_j, y_j),

$$r_i^*(\theta_i, y_i) \quad \in \quad \text{argmax}_{r_i \in R_i} \quad \pi_i(\theta_i, g(r_i, r_j^*(\theta_j, y_j))) \ , \tag{4.30}$$

and that, as a consequence, equilibrium kindness is bounded from above by 0, i.e. that

$$\kappa_i(r_i^*(\theta_i, y_i), r_j^*(\theta_j, y_j)) \leq 0 \ , \tag{4.31}$$

for all (θ_i, y_i) and (θ_j, y_j).

If (4.30) was violated for some type (θ_i, y_i) of player i, then this type could reach a higher material payoff by deviating from $r_i^*(\theta_i, y_i)$ to some other report. However, by (4.27) the payoff consequence of choosing message $r_i^*(\theta_i, y_i)$ is the same as the payoff consequence of choosing message $r_i^*(\theta_i, 0)$. Thus, if type (θ_i, y_i) can reach a higher a higher material payoff by deviating from $r_i^*(\theta_i, y_i)$ then also type $(\theta_i, 0)$ can reach a higher payoff by deviating from $r_i^*(\theta_i, 0)$. But this would contradict (4.29).

Step 2. Fix a pair (y_1, y_2) and consider a complete information type space on which externality freeness is violated in the sense of Definition 2. If player 1 behaves according to r_1^*, then player 1's equilibrium kindness is strictly negative. To see this, note that by *Step 1*, player 1 behaves selfishly. Hence, he chooses the action that minimizes player 2's payoff from the set of Pareto-efficient action profiles $E_{12}(r_2^*(\theta_2, y_2))$. Hence,

$$\pi_2(\theta_2, f(\theta_1, \theta_2)) = \pi_2(\theta_2, g(r_1^*(\theta_1, y_1), r_2^*(\theta_2, y_2))) = \min_{r_1 \in E_{12}(r_2^*(\theta_2, y_2))} \pi_2(\theta_2, g(r_1, r_2^*(\theta_2, y_2))) \ .$$

By the specific violation of externality-freeness,

$$\min_{r_1 \in E_{12}(r_2^*(\theta_2, y_2))} \pi_2(\theta_2, g(r_1, r_2^*(\theta_2, y_2))) < \min_{r_1 \in E_{12}(r_2^*(\theta_2, y_2))} \pi_2(\theta_2, g(r_1, r_2^*(\theta_2, y_2))) \ ,$$

as player 1 could increase player 2's payoff be choosing action $r_1^*(\theta_1', y_1)$ rather than action $r_1^*(\theta_1, y_1)$. Consequently $\kappa_1(r_1^*(\theta_1, y_1), r_2^*(\theta_2, y_2) < 0$, for all (y_1, y_2).

Step 3. Consider the type profile (θ_1, θ_2) for which the specific violation of externality-freeness occurs and a hypothetical fairness equilibrium in which player 1 behaves according to $r_1^*(\theta_1, y_1)$ and player 2 behaves according to $r_2^*(\theta_2, y_2)$. Given correct first- and second-order beliefs, the best response problem for player 2 looks as follows: Choose $r_2 \in R_2$, so as to maximize

$$\pi_2(\theta_2, g(r_1^*(\theta_1, y_1), r_2)) + y_2 \ \kappa_1^* \ \pi_1(\theta_1, g(r_1^*(\theta_1, y_1), r_2))$$

where we omitted some constant terms from the objective function that do not affect the solution of the optimization problem, and $\kappa_1^* < 0$ is a shorthand for $\kappa_1(r_1^*(\theta_1, y_1), r_2^*(\theta_2, y_2))$, i.e. the kindness of player 1 in the hypothetical equilibrium.

Now, if player 2 behaves according to $r_2^*(\theta_2, y_2)$, then, by *Step 1*, this yields the maximal value of $\pi_2(\theta_2, g(r_1^*(\theta_1, y_1), r_2))$ over R_2. If player 2 behaves according to

$r_2^*(\theta_2', y_2)$, then because of (4.27), this yields a lower value of $\pi_1(\theta_1, g(r_1^*(\theta_1, y_1), r_2))$ than behaving according to $r_2^*(\theta_2, y_2)$. Moreover, if y_2 is sufficiently large, overall utility will then be larger if the action $r_2^*(\theta_2', y_2)$ is taken. But this contradicts the best response condition in (4.28).

□

4.E Supplementary material

The locally externality-free social choice function

Example 3: An optimal robust and locally externality-free social choice function. We illustrate Proposition 5 in the context of our numerical example. The payoff functions, parameter values, and traded quantities are as in Example 1. We denote the optimal mechanism that is locally externality-free by f''. Under f'', payments to the seller are given by

$$p_s^{f''}(\underline{\theta}_b, \underline{\theta}_s) = 3.955,\ p_s^{f''}(\underline{\theta}_b, \bar{\theta}_s) = 1.215,\ p_s^{f''}(\bar{\theta}_b, \underline{\theta}_s) = 6.955 \text{ and } p_s^{f''}(\bar{\theta}_b, \bar{\theta}_s) = 2.14\,.$$

Below is a detailed description of the normal form games that f'' induces on the four different complete information type spaces and also a detailed description of the experiment results in Treatment 3 which was based on f''. They can be summarized as follows: As predicted, all low valuation buyers communicated their types truthfully, just as in T1. For the states with high valuation buyers the locally externality-free mechanism has less deviations from truth-telling than the mechanism in Example 1. The difference is significantly different from zero for the states with a low type seller (two-sided Fisher's exact test, $p = 0.033$). It therefore also generates higher expected seller profits ($\Pi^{f''} = 4.90$) than both the mechanism in Example 1 ($\Pi^f = 4.82$) and the globally externality-free mechanism in Example 2 ($\Pi^{f'} = 4.77$). Both welfare comparisons are statistically significant (two-sided t-test, $p_{T1\,vs.\,T3} = 0.037$ and $p_{T2\,vs.\,T3} < 0.001$).

Table 1": The game induced by f'' for $(\theta_b, \theta_s) = (\underline{\theta}_b, \underline{\theta}_s)$.

(π_b, π_s)	$\underline{\theta}_s$	$\bar{\theta}_s$
$\underline{\theta}_b$	$(2.68, 6.09)$	$(2.68, 4.05)$
$\bar{\theta}_b$	$(0.97, 6.09)$	$(2.66, 4.86)$

Table 2": The game induced by f'' for $(\theta_b, \theta_s) = (\underline{\theta}_b, \overline{\theta}_s)$.

(π_b, π_s)	$\underline{\theta}_s$	$\overline{\theta}_s$
$\underline{\theta}_b$	$(2.68, 2.65)$	$(2.68, 3.73)$
$\overline{\theta}_b$	$(0.97, -5.79)$	$(2.66, 3.73)$

Table 3": The game induced by f'' for $(\theta_b, \theta_s) = (\overline{\theta}_b, \underline{\theta}_s)$.

(π_b, π_s)	$\underline{\theta}_s$	$\overline{\theta}_s$
$\underline{\theta}_b$	$(3.41, 6.09)$	$(3.24, 4.05)$
$\overline{\theta}_b$	$(3.43, 6.09)$	$(3.43, 4.86)$

Table 4": The game induced by f'' for $(\theta_b, \theta_s) = (\overline{\theta}_b, \overline{\theta}_s)$.

(π_b, π_s)	$\underline{\theta}_s$	$\overline{\theta}_s$
$\underline{\theta}_b$	$(3.41, 2.65)$	$(3.24, 3.73)$
$\overline{\theta}_b$	$(3.43, -5.79)$	$(3.43, 3.73)$

Choice data T3

		Buyer		*Seller*	
	Game induced by	$\underline{\theta}_b$	$\overline{\theta}_b$	$\underline{\theta}_s$	$\overline{\theta}_s$
T3 *locally externality-free mechanism*	f'' for $(\underline{\theta}_b, \underline{\theta}_s)$	63	0	62	1
	f'' for $(\underline{\theta}_b, \overline{\theta}_s)$	63	0	0	63
	f'' for $(\overline{\theta}_b, \underline{\theta}_s)$	1	62	63	0
	f'' for $(\overline{\theta}_b, \overline{\theta}_s)$	7	56	0	63

Normal form games which are induced by the Mirrleesian mechanism

The game induced by the Mirrleesian mechanism for $(\omega_1, \omega_2) = (\omega_l, \omega_l)$.

(U_1, U_2)	ω_l	ω_h
ω_l	$(3.26, 3.26)$	$(3.26, 1.99)$
ω_h	$(1.99, 3.26)$	$(1.99, 1.99)$

The game induced by the Mirrleesian mechanism for $(\omega_1, \omega_2) = (\omega_l, \omega_h)$.

(U_1, U_2)	ω_l	ω_h
ω_l	$(3.26, 3.70)$	$(3.26, 3.72)$
ω_h	$(1.99, 3.70)$	$(1.99, 3.72)$

The game induced by the Mirrleesian mechanism for $(\omega_1, \omega_2) = (\omega_h, \omega_l)$.

(U_1, U_2)	ω_l	ω_h
ω_l	$(3.70, 3.26)$	$(3.70, 1.99)$
ω_h	$(3.72, 3.26)$	$(3.72, 1.99)$

The game induced by the Mirrleesian mechanism for $(\omega_1, \omega_2) = (\omega_h, \omega_h)$.

(U_1, U_2)	ω_l	ω_h
ω_l	$(3.70, 3.70)$	$(3.70, 3.72)$
ω_h	$(3.72, 3.70)$	$(3.72, 3.72)$

Normal form games which are induced by the Piketty mechanism

The game induced by the Piketty mechanism for $(\omega_1, \omega_2) = (\omega_l, \omega_l)$.

(U_1, U_2)	ω_l	ω_h
ω_l	$(2.32, 2.32)$	$(3.98, 1.04)$
ω_h	$(1.04, 3.98)$	$(2.94, 2.94)$

The game induced by the Piketty mechanism for $(\omega_1, \omega_2) = (\omega_l, \omega_h)$.

(U_1, U_2)	ω_l	ω_h
ω_l	$(2.32, 3.06)$	$(3.98, 3.08)$
ω_h	$(1.04, 4.38)$	$(2.94, 4.40)$

The game induced by the Piketty mechanism for $(\omega_1, \omega_2) = (\omega_h, \omega_l)$.

(U_1, U_2)	ω_l	ω_h
ω_l	$(3.06, 2.32)$	$(4.38, 1.04)$
ω_h	$(3.08, 3.98)$	$(4.40, 2.94)$

The game induced by the Piketty mechanism for $(\omega_1, \omega_2) = (\omega_h, \omega_h)$.

(U_1, U_2)	ω_l	ω_h
ω_l	$(3.06, 3.06)$	$(4.38, 3.08)$
ω_h	$(3.08, 4.38)$	$(4.40, 4.40)$

Choice data T4 and T5

		Individual 1		*Individual* 2	
	Game induced by	ω_l^1	ω_h^1	ω_l^2	ω_h^2
T4 *Mirrleesian approach*	(ω_l, ω_l)	62	1	62	1
	(ω_l, ω_h)	62	1	2	61
	(ω_h, ω_l)	2	61	62	1
	(ω_h, ω_h)	2	61	2	61
T5 *Piketty's approach*	(ω_l, ω_l)	57	6	55	8
	(ω_l, ω_h)	60	3	14	49
	(ω_h, ω_l)	7	56	61	2
	(ω_h, ω_h)	2	61	9	54

4.F English Instructions (translated)

The following instructions are a translation of the instructions used in the experiment, and are identical for all participants in all treatments.

Instructions — General Part

Welcome to the experiment!

You can earn money in this experiment. How much you will earn, depends on your decisions and the decisions of another anonymous participant, who is matched with you. Independent of the decisions made during the experiment you will receive 7.00 € as a lump sum payment. At the end of the experiment, positive and negative amounts earned will be added to or subtracted from these 7.00 €. The resulting total will be paid out in cash at the end of the experiment. All payments will be treated confidentially.

All decisions made during the experiment are anonymous.

From now on, please do not communicate with other participants. If you have any questions now or during the experiment, please raise your hand. We will then come to you and answer your question.

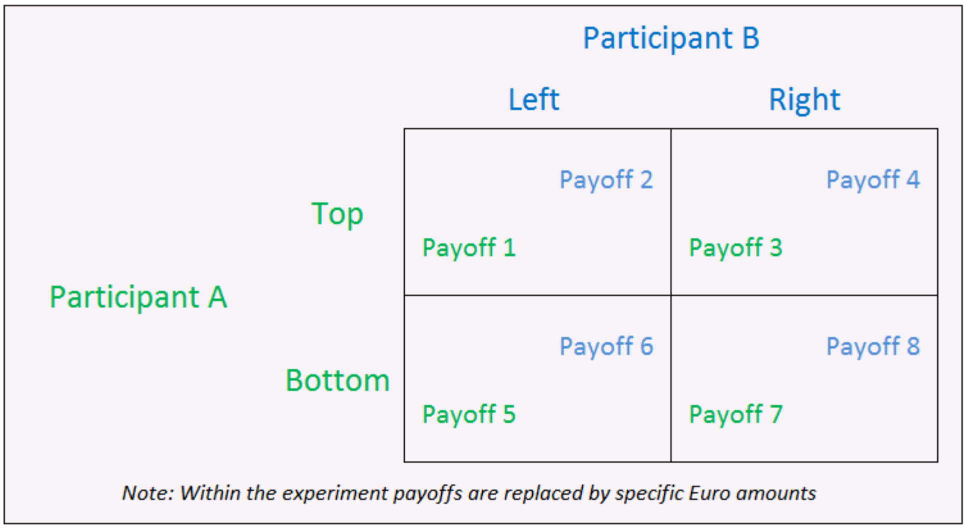
Please switch off your mobile phone during the experiment. Documents (such as books, lecture notes etc.) that do not deal with the experiment are not allowed. In case of violation of these rules you can be excluded from the experiment and all payments.

On the following page you will find the instructions concerning the course of the experiment. After reading these, we ask you to wait at your seat until the experiment starts.

First Part — Presentation of decision settings, reading of payoffs

The purpose of this part of the experiment is to familiarize all participants with the decision settings. This ensures that every participant understands the presentation of the decision settings and can correctly infer the resulting payoffs of specific decision combinations. None of the choices in the first part are payoff-relevant.

In the course of this part, eight different decision settings will be presented to you. In all of them two participants have to make a decision without knowing the decision made by the other participant. The combination of the decisions determines the payoffs of both participants. *[These eight decision settings refer to the four complete information games of the respective social choice function of their specific treatment. Each game was presented twice: First in the original form and then in a strategically identical form where the payoffs of Participant A and B were switched. This explanation is, of course, not part of the original instructions.]*



Exemplary Decision Setting

Participant A, highlighted in green, can decide between *Top* or *Bottom*. Participant B, highlighted in blue, can decide between *Left* and *Right*. The decision of Participant A determines whether the payment results from the upper or lower row in the table. Accordingly, the decision of Participant B determines whether the payment results from the left or right column. Both decisions combined unambiguously determine the cell of the payoff pair.

Each cell contains a payoff pair for both participants. Which payoff is relevant for which participant, is highlighted through their respective color. The green value, which can be found in the lower left corner of every cell, shows the payoff for Participant A. The blue value, which can be found in the upper right corner of every cell, shows the payoff for Participant B.

Please familiarize yourself with the payoff table. Put yourself in the position of both participants and consider possible decisions each participant would make. After a short time for consideration, you can enter a choice combination. The entry can be modified and different constellations can be tried. After choosing two decisions, please enter the payoffs which would result from this constellation. Your entry will then be verified. If your entry is wrong, you will be notified and asked to correct it.

Second Part — Decision Making

At the beginning of the second part you will be assigned to a role which remains constant over the course of the experiment. It will be the role of either Participant A or Participant B. Which role you are assigned to, will be clearly marked on your screen. Please note that the assignment is random, both roles are equally likely. It will be assured that half of the participants are assigned to the role of Participant A and the other half to the role of Participant B.
Simultaneously to the assignment of roles, you are matched with a participant of a different role. This matching is also random. In the course of the remaining experiment you will interact with this participant.

The second part of the experiment consists of four decisions settings. Exactly one decision setting is payoff relevant for you and the other participant matched with you. Which decision setting that is, is determined by chance: Every decision setting has the same chance of being chosen. Hence, please bear in mind that each of the following decision settings can be payoff-relevant.

All decision settings are presented similarly to those of the first part. The difference with respect to the first part is, that you can only make one decision, namely that for your role. Thus, you do not know the decision of the participant matched with you.

Only after you have made a decision for each of the four settings, you will learn which decision setting is relevant for your payoff and the payoff of the participant assigned to you. In addition, you will learn the decisions of the other participant in all decisions settings.

After the resulting payoffs are displayed, the experiment ends. A short questionnaire will appear on your screen while the experimenters prepare the payments. Please fill out this questionnaire and wait at your seat until your number is called.

If you have any questions, please raise your hand.

Thank you for participating in this experiment!

4.G German Instructions (original)

Instruktionen — Allgemeiner Teil

Herzlich Willkommen zum Experiment!

In diesem Experiment können Sie Geld verdienen. Wie viel Sie verdienen werden, hängt von Ihren Entscheidungen und den Entscheidungen eines Ihnen zugeordneten, aber Ihnen unbekannten anderen Experimentteilnehmers ab. Unabhängig von den Entscheidungen während des Experimentes erhalten Sie 7,00 Euro für Ihr Erscheinen. Am Ende des Experimentes werden alle zusätzlich verdienten positiven wie negativen Beträge zu diesen 7,00 Euro hinzuaddiert beziehungsweise abgezogen. Die hieraus errechnete Endsumme wird Ihnen am Ende des Experimentes in bar ausbezahlt. Ihre Auszahlung wird vertraulich behandelt.

Alle Entscheidungen, die Sie während des Experimentes treffen, sind anonym.

Bitte kommunizieren Sie ab sofort nicht mehr mit den anderen Teilnehmern. Falls Sie jetzt oder während des Experimentes eine Frage haben, heben Sie bitte die Hand. Wir werden dann zu Ihnen kommen und Ihre Frage beantworten.

Während des Experimentes bitten wir Sie außerdem Ihr Mobiltelefon auszuschalten. Unterlagen (Bücher, Vorlesungsskripte, etc.), die nichts mit dem Experiment zu tun haben, dürfen während des Experimentes nicht verwendet werden. Bei Verstößen gegen diese Regeln können wir Sie vom Experiment und allen Auszahlungen ausschließen.

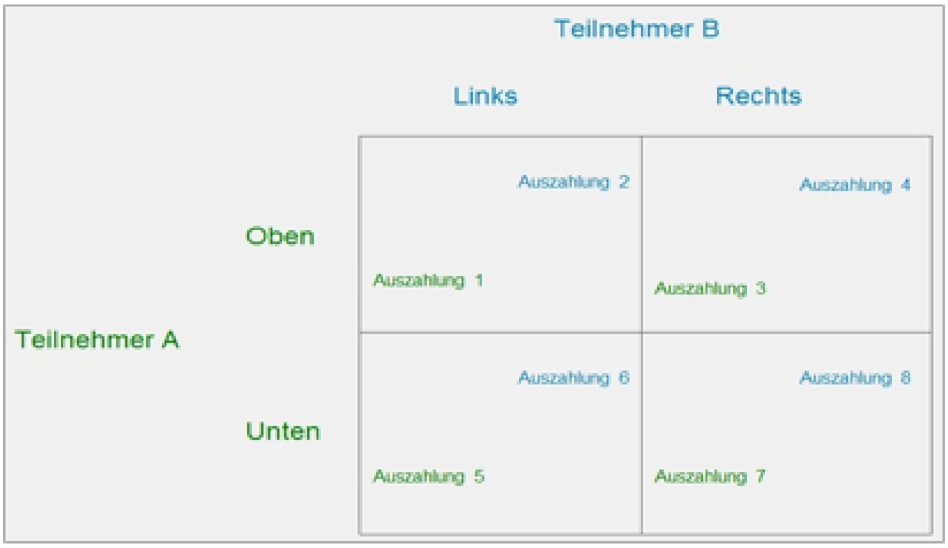
Auf dem nächsten Blatt finden Sie die Instruktionen zum Ablauf des Experiments. Nachdem Sie diese gelesen haben, bitten wir Sie an Ihrem Platz zu warten bis das Experiment gestartet wird.

Erster Teil — Präsentation von Entscheidungssituationen, Ablesen von Auszahlungen

Dieser Teil des Experimentes dient ausschließlich dazu, dass sich alle Teilnehmer mit bestimmten Entscheidungssituationen vertraut machen. Dies stellt sicher, dass jeder Teilnehmer die Darstellung der Entscheidungssituationen versteht und die aus Entscheidungskombinationen resultierenden Auszahlungen korrekt ablesen kann. Entsprechend sind Ihre Entscheidungen im ersten Teil des Experimentes auch nicht auszahlungsrelevant.

Im Folgenden werden Ihnen acht verschiedene Entscheidungssituationen präsentiert. In all diesen Situationen müssen zwei Teilnehmer eine Entscheidung in Unkenntnis der Entscheidung des anderen Teilnehmers treffen. Die Kombinationen der Entscheidungen legen die Auszahlungen für beide Teilnehmer fest.

Abbildung 1: Beispielhafte Entscheidungssituation



Anmerkung: In den Situationen im Experiment sind die Auszahlungen jeweils durch spezifische Euro-Beträge ersetzt.

Teilnehmer A, in grüner Farbe markiert, kann zwischen „Oben“ und „Unten“ wählen. Teilnehmer B, in blauer Farbe markiert, kann zwischen „Links“ und „Rechts“ wählen. Die Entscheidung von Teilnehmer A legt fest, ob die Auszahlungen aus einer Zelle der oberen oder unteren Zeile der Tabelle resultieren. Entsprechend legt die Entscheidung von Teilnehmer B fest, ob die Auszahlungen aus einer Zelle der linken oder rechten Spalte der Tabelle resultieren. Beide Entscheidungen zusammen legen eindeutig fest, aus welcher Zelle das Auszahlungspaar resultiert.

In jeder Zelle ist ein Auszahlungspaar für beide Teilnehmer festgelegt. Welche Auszahlung hierbei für welchen Teilnehmer gilt, ist entsprechend der Farbe der Teilnehmer hervorgehoben. Der grüne Wert, welcher in jeder Zelle in der Ecke unten links zu finden ist, gibt die Auszahlung für Teilnehmer A an. Der blaue Wert, welcher in jeder Zelle in der Ecke oben rechts zu finden ist, gibt die Auszahlung für Teilnehmer B an.

Wir bitten Sie, sich mit den Ihnen präsentierten Auszahlungstabellen vertraut zu machen. Bitte versetzen Sie sich hierfür in die Position der beiden Teilnehmer und überlegen Sie sich, welcher Teilnehmer wohl welche Entscheidung treffen würde. Nach einer kurzen Bedenkzeit können Sie Ihre Eingabe tätigen. Diese können Sie nach Wunsch verändern und so verschiedene Konstellationen ausprobieren. Nachdem Sie zwei Aktionen ausgewählt haben, geben Sie bitte die Auszahlungen ein, welche aus dieser Konstellation resultieren würden. Ihre Eingabe wird hiernach auf Richtigkeit überprüft. Falls Ihre Eingabe fehlerhaft sein sollte, wird Ihnen dies angezeigt und Sie erhalten die Aufforderung Ihre Eingabe zu korrigieren.

Zweiter Teil — Treffen von Entscheidungen

Zu Beginn des zweiten Teils bekommen Sie eine feste Rolle zugewiesen, entweder die Rolle von Teilnehmer A oder von Teilnehmer B. Welche Rolle Sie zugewiesen bekommen, wird auf Ihrem Bildschirm klar gekennzeichnet. Die Zuordnung von Experimentteilnehmern in bestimmte Rollen erfolgt zufällig und jede Rolle ist hierbei gleich wahrscheinlich. Es wird lediglich berücksichtigt, dass die Hälfte der Experimentteilnehmer die Rolle A und die andere Hälfte die Rolle B hat.

Gleichzeitig mit der Zuweisung von Experimentteilnehmern in Rollen wird Ihnen ein Experimentteilnehmer mit einer von Ihnen unterschiedlichen Rolle zugewiesen. Auch diese Zuordnung erfolgt zufällig. Im Verlauf des restlichen Experimentes interagieren Sie mit diesem Experimentteilnehmer.

Der zweite Teil des Experimentes besteht aus vier Entscheidungssituationen. Genau eine der Situationen ist für Sie und für den Ihnen zugeordneten Experimentteilnehmer auszahlungsrelevant. Welche Entscheidung auszahlungsrelevant ist, wird dabei vom Zufall bestimmt: Jede Entscheidungssituation hat die gleiche Wahrscheinlichkeit ausgewählt zu werden. Beachten Sie also, dass jede der folgenden Entscheidungssituationen für Sie auszahlungsrelevant sein könnte.

Alle Entscheidungssituationen gleichen vom Aufbau denen des ersten Teils. Im Unterschied zum ersten Teil können Sie jedoch nur eine Entscheidung treffen, diejenige Ihrer Rolle. Sie kennen die Entscheidung des Ihnen zugeordneten Teilnehmers nicht.

Erst nachdem Sie für alle vier Situationen eine Entscheidung festgelegt haben, erfahren Sie, welche der Entscheidungssituation auszahlungsrelevant war und wie sich der Ihnen zugeordnete Experimentteilnehmer in allen Situationen entschieden hat.

Nachdem alle Entscheidungen getroffen sind, ist das Experiment zu Ende. Es folgt ein kurzer Fragebogen auf Ihrem Bildschirm, während die Experimentatoren die Auszahlungen vorbereiten. Wir bitten Sie diesen Fragebogen auszufüllen. Warten Sie hiernach bitte an Ihrem Platz bis Sie zur Auszahlung aufgerufen werden.

Wenn Sie noch Fragen haben, so heben Sie bitte Ihre Hand.

Vielen Dank für Ihre Teilnahme!

C u r r i c u l u m   V i t a e

P e r s o n a l   D e t a i l s

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E d u c a t i o n

06/2012 – present	**University of Cologne, Germany** Doctoral Candidate in Economics
04/2007 – 06/2012	**University of Cologne, Germany** Diploma with Distinction in Economics and Sociology Final Grade: 1.2 - Best of Class Specializations: Microeconomics, Game Theory, Statistics, Sociology
09/2010 – 11/2010	**University Utrecht, Netherlands** Studies in Sociology
01/2010 – 07/2010	**University Kopenhagen, Denmark** Studies in Economics
09/2003 – 07/2006	**Staatliches Koblenz-Kolleg, Germany** University Entrance Diploma Final Grade: 1.3 - Best of Class
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11/2016 – present	**Academic Advisor, Department Educational Program** Studienstiftung des deutschen Volkes, Bonn, Germany
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07/2014 – 12/2015	**Research Assistant, Department of Economics** Chair Prof. Patrick Schmitz, University of Cologne, Germany
10/2011 – 12/2011	**Internship in an Economic Consultancy** Frontier Economics Ltd., Cologne & London
10/2010 – 08/2011 08/2008 – 02/2010	**Student Research Assistant, Department of Economics** Chair Prof. Axel Ockenfels, University of Cologne, Germany
04/2011 – 07/2011	**Student Teaching Assistant, Department of Statistics** Chair Prof. Friedrich Schmid, University of Cologne, Germany
11/2002 – 08/2003	**Compulsory Community Service** Barmherzige Brüder Saffig (Psychiatry)
06/2000 – 10/2002	**Clerical Assistant, Department of Accounting** Municipal Energy Supplier of Koblenz (KEVAG), RWE-Group
09/1998 – 05/2000	**Professional Training as Industrial Business Management Assistant** Municipal Energy Supplier of Koblenz (KEVAG), RWE-Group

Teaching Experience

Since Summer 2012 **Supervision of Bachelor and Master Theses**

Summer Term 2016 **Microeconomics II, Exercise Class**

Summer Term 2015 **Game Theory, Exercise Class**

Summer Term 2014 **Game Theory, Exercise Class**

Summer Term 2013 **Game Theory, Exercise Class**

Summer Term 2012 **Competition Policy (Bachelor-Seminar), Teaching Assistance**

Summer Term 2011 **Statistical Inference and Probability Models, Tutorial**

Winter Term 2009 **Microeconomics I, Tutorial**

Awards and Memberships

06/2016 **C-SEB Junior Start-Up Grant (€3,000)**, Research Project: *Do Price-Matching Guarantees with Markups Facilitate Tacit Collusion? Theory and Experiment*

Since 2015 **Member of the Center of Social and Economic Behavior (C-SEB)**, **University of Cologne**

06/2012 **Economics Diploma with Distinction, University of Cologne**

02/2010 **Scholarship, Erasmus-Program of the European Union**

11/2009 **Dean's Award of the WiSo-Faculty, University of Cologne**

04/2009 **Oliver Wyman - KölnAlumni Intermediate Diploma Award**

03/2009 **Scholarship, Studienstiftung des deutschen Volkes**

International Conferences

02/2016 **Lenzerheide Seminar on Competition Economics, Parpan, Switzerland**
organized by Prof. Achim Wambach, University of Cologne and
Prof. Alexander Rasch, Düsseldorf Institute for Competition Economics (DICE)

05/2015 **Spring Meeting of Young Economists 2015, Ghent, Belgium**
organized by Ghent University

09/2014 **9th Nordic Conference on Behavioral and Experimental Economics, Aarhus, Denmark**, organized by Aarhus University

05/2014 **Design and Bargaining Workshop, Dallas, Texas, United States of America**
organized by Prof. Tim Salmon, Southern Methodist University and
Prof. Gary Bolton, University of Texas at Dallas

Research Papers

Strategic Disclosure of Demand Information by Duopolists: Theory and Experiment
with Jos Jansen, *Preprints of the Max Planck Institute for Research on Collective Goods Bonn 2015/9.*

Robust Mechanism Design and Social Preferences
with Felix Bierbrauer, Axel Ockenfels and Desiree Rückert, *Journal of Public Economics*, forthcoming.

Do Price-Matching Guarantees with Markups Facilitate Collusion? – Theory and Experiment, mimeo