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Cheap Talk and Cooperation in Stackelberg Games

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Abstract

Previous literature on cheap talk suggests that it is used to increase cooperation. We study cheap talk and the effect of the leader's private payoff information in new repeated Stackelberg game settings. Our results confirm earlier studies that the players cooperate in repeated Stackelberg games with complete payoff information. In the cheap talk setting the follower has the actual first mover advantage and should in theory benefit from it, but we find that many followers cooperate instead. Similarly, many leaders do not use cheap talk for cheating but commit to symmetric joint-optimum quantities. The leader's private payoff information results in a low frequency of cooperation but in the presence of cheap talk players do cooperate.

Keywords: Cheap talk; Stackelberg game; cooperation; experiments; private information

1. Introduction

The role of cheap talk and other kinds of pre-play announcements has been of interest in game theory for a long time. The fact that cheap talk is costless and does not require any commitments raises the essential question related to its use. Is cheap talk used to create mutual cooperation by creating trust or to gain individual advantage by cheating? The literature on cheap talk based on theoretical models (Farrell 1987; Rabin 1994; Ellingsen and Östling 2010) as well as on experiments (Cooper et al. 1992; Crawford 1998; Charness 2000; Charness and Rabin 2005) supports the conclusion that cheap talk is used more often for cooperation and less often for gaining individual advantage when these two are in conflict.

In this paper we extend the studies to a new setting which has an explicit opportunity to use cheap talk for cheating. We consider a Stackelberg setting where the leader is in a stronger position. The Stackelberg game is used to model duopoly in the industrial organization literature where the stronger position results from such characteristics as market power, incumbency, or excess production capacity. However, there are plenty of applications for the Stackelberg setting outside of economics, ranging from supply chain contracting (Loch and Wu 2008) to coordinating political resistance (Cason and Mui 2007). The setting is also closely related to Ultimatum and Dictator Games, as well as sequential Prisoner's Dilemmas and Public Goods Games, where one player is in a stronger position due to a first mover advantage. The questions raised in our study aim to shed new light to behavior in an asymmetric game situation. In particular we are interested in how the costless cheap talk signal is used. Do we observe usage of cheap talk for selfish purposes even though the setting also allows the possibility for cooperation?

Our study follows the theoretical model proposed by Hämäläinen (1981), which discusses cheating by the leader in a Stackelberg game and describes two possibilities. In the model of Hämäläinen (1981), "general cheating" refers to a situation in which the leader optimizes the cheap talk announcement such that when the follower best responds to it the leader can reach his overall

optimum by re-optimizing after the follower's best response. In "second-play cheating" the leader announces the Stackelberg leader decision. These settings refer to the Stackelberg game with cheap talk where the leader is not committed to his initial announcement and the follower does not know the leader's payoff function. Thus in this original model it is assumed that the follower reacts by best response to the leader's cheap talk.

Our experiment has Stackelberg and cheap talk treatments where payoff information is known by both the leader and the follower. In the cheap talk treatments the leader announces a decision to the follower and makes a new decision after the follower's decision. To make the leader's position even stronger and more asymmetric in relation to the follower, we also include treatments where the follower does not have information about the leader's payoffs in the payoff matrix. In theory, this kind of leader's private information should not affect the follower's behavior. This is because in order to best respond the follower only needs to know the leader's decision, not his payoffs. In these treatments the follower does not possess probabilistic information about the leader's payoffs, but can learn them after each round. These treatments are thus closer to real-life settings where probabilistic information is generally not available at every interaction (see the same argument in Mason and Phillips 1997 p. 290).

Theoretically the game changes in the cheap talk treatments because the leader has the possibility to make a non-committing cheap talk announcement of his decision and re-evaluate it only after the follower has responded. In a game theoretic sense the follower then becomes the actual leader because he is the first to commit, giving the follower the first mover advantage. This raises an interesting question that motivates the experiment described in this paper: do the followers recognize this opportunity and use their first mover advantage in practice?

We study how these alterations to the stronger position of the leader affect cooperation. To allow cooperation to evolve our experiment also has repeated interactions. Using repeated interactions generalizes our model to a wider range of real-world situations, because very often actual interactions are repeated rather than one-shot. Earlier literature (e.g. Crawford 1998) suggests

that pre-play communication by cheap talk would be used to increase cooperation by trust-building. The leader's private payoff information, on the other hand, is likely to decrease trust and consequently decrease cooperation. Our experiments confirm these assumptions and we see that a high share of players cooperate when the leaders use cheap talk. The cooperation rate is low when the leaders' payoff information is private, but only when the leaders do not use cheap talk. With cheap talk and private information the cooperation rate is high.

2. Related Literature

Many experiments find that cheap talk increases cooperation and coordination (see also the reviews of Crawford 1998 and Balliet 2010). In repeated Cournot duopoly and oligopoly experiments cheap talk price announcements (Cason 1995; Fonseca and Normann 2012) and cheap talk quantity announcements (Waichman et al. 2014) increase cooperation. Some repeated (Müller 2006) and one-shot (Roy 2012) Cournot duopoly experiments also show that the opportunity to revise initially announced quantities does not lead to more competitive results. Cason and Mui (2007, 2014) show how cheap talk between followers can coordinate the follower decisions and deter leaders from transgressing the followers. Results from regular Stackelberg games show that Stackelberg equilibria are rare and cooperation is frequent when players play repeatedly in fixed pairs (Huck et al. 2001; Huck et al. 2002; Müller and Tan 2013), and this is also observed in other repeated play games (e.g. Clark and Sefton, 2001). Cournot equilibria are more frequent than Stackelberg equilibria in Stackelberg experiments where the players are in one-shot interactions (Huck et al. 2001; Fonseca et al. 2005; Cardella and Chiu 2012). This behavior is generally explained by the follower's reactions that reward the leader's cooperative behavior and punish the leader's attempts to exploit his strategic advantage (Huck and Wallace 2002; Müller and Tan 2013). Such other-regarding behavior can be attributed to social preferences, such as inequity aversion (Fehr and Schmidt 1999) and reciprocity (Charness and Rabin 2002; Cox et al. 2007; Cox et al.

2008). Recently cheap talk has also been studied experimentally in stag hunt games (McDaniel 2011) and principal-agent games (Rasmussen 2014) with coordination as the key focus.

The literature on the effects of private information in games is rich. Many repeated Cournot duopoly experiments support the conclusion that players cooperate less or have lower payoffs when they are not informed of each other's payoffs than when payoff information is available (e.g. Fouraker and Siegel 1963 Ch. 9; Mason and Phillips 1997; Friedman et al. 2004; see also review by Potters and Suetens 2013). The theoretical literature on private and asymmetric information in Stackelberg games is also extensive (see e.g. Albaek 1990; and Mailath 1993). Theoretical models on private and asymmetric information usually assume one-shot interactions and a commonly known probability distribution for the source of information. This assumption, as Mason and Phillips (1997) argue, may be unrealistic in markets with repeated interactions, where probabilistic information is generally not available at every new interaction. As a summary, although private information in repeated Cournot duopoly games is well studied, there is no experimental research on the effect of private information in Stackelberg games. The only experiments on the effects of information in the Stackelberg duopoly concern the follower's noisy information on the leader's decisions (see e.g. Morgan and Várdy 2004, Güth et al. 2006).

The interaction of cheap talk communication and private information has received much interest in the information sharing literature. Initial research on communication of private information argued that players will always misrepresent their private information in the presence of the incentives to do so (Akerlof 1970; Holmström 1979, Crawford and Sobel 1982), but experiments have shown that people are actually averse to the harm that misrepresentation may cause to others (Gneezy 2005; Hurkens and Kartik 2009; Erat and Gneezy 2012). On the other hand, costly punishments are taken if a deceptive message is received (Brandts and Charness 2003). Although our setting is not an actual sender-receiver setting where one player sends a message and the other takes an action upon receiving that message, this literature is relevant because it demonstrates that social preferences influence communication behavior.

3. Methods and Procedures

3.1 The experiment

All treatments in our experiment are based on the same Stackelberg duopoly game as in Huck et al. (2001) and Müller and Tan (2013). The payoff matrix (Fig. 1) used in our experiment is the same one used by Huck et al. (2001), Huck and Wallace (2002), Huck et al. (2002), Fonseca et al. (2005), Fonseca et al. (2006), and Müller and Tan (2013). There is a leader (player A) and a follower (player B) who choose production quantities in a sequence. The joint production quantity determines the payoffs, that are $f(x, y) = x(24 - x - y)$ for player A and $s(x, y) = y(24 - x - y)$ for player B, where x is A's production quantity and y is B's production quantity. We denote A's cheap talk production quantity $\hat{x}$. The production quantities are decisions that the players make in the duopoly games. The games are played in repeated interactions with fixed pairs where the results of each round are observed before continuing to the next round. The two games are the Stackelberg game and the cheap talk Stackelberg game where player A's cheap talk is given before the Stackelberg game is played in a reverse order. The 4 treatments in our experiment are:

- **S:** The Stackelberg game where player A first makes a committing decision and then player B observes this and makes a committing decision.
- **CT:** The cheap talk Stackelberg game where player A first announces a non-committing decision to player B, who then observes the announcement and makes a committing decision. Then player A observes B's decision and makes a committing decision.
- **S-PI:** The Stackelberg game where B does not know A's payoffs
- **CT-PI:** The cheap talk Stackelberg game where B does not know A's payoffs

In the S-PI and CT-PI treatments player B does not see player A's payoffs in the payoff matrix, but B sees A's payoffs after each round. Thus, even though B does not know all A's payoffs, he can learn those payoffs that have resulted on previous rounds.

Theoretically in a one shot game there are the following interesting payoff matrix entries that are highlighted in the payoff matrix in Fig. 1:

- The Cournot-Nash equilibrium (N)
- The symmetric joint-optimum (JO)
- The Stackelberg equilibrium (L)
- The Stackelberg equilibrium where the follower (player B) is the leader (F)
- The general cheating strategy (LS) where player A chooses the cheap talk announcement with the assumption that player B best responds, and then re-optimizes after B's best response.

---- Fig. 1 ----

The payoff matrix has certain characteristics that need to be taken into account in the interpretation of the results. For player A, the Stackelberg equilibrium (L) payoff and the symmetric joint-optimum (JO) payoff are the same, 72. For player B, the Cournot-Nash equilibrium (N) payoff is 64 and this is lower than the symmetric joint-optimum payoff, 72, but higher than B's Stackelberg equilibrium payoff, 36. Thus, player A does not lose anything by playing the symmetric joint-optimum rather than the Stackelberg equilibrium, but player B will gain in the symmetric joint-optimum compared to the Stackelberg equilibrium. If player A in the CT and CT-PI treatments optimizes his cheap talk announcement against a player B who responds by best response to that announcement, A can optimize the response and general cheating (LS) results. In the LS result the leader first announces $\hat{x} = 14$ or $\hat{x} = 15$, to which B's best response is $y = 5$. After the

B's response A optimizes again and chooses $x = 10$. The payoffs in the LS result (90,45) are better for both players than in the Stackelberg equilibrium (L) (72,36) and player A has an essentially higher payoff than in the symmetric joint-optimum. Thus there is a strong interest for A to use cheap talk to reach this result rather than the Stackelberg equilibrium. This would suggest that for both players, general cheating is a more desirable result than the Stackelberg equilibrium.

However, in a repeated game any of the results that have equal or better payoffs than those in the Cournot-Nash equilibrium can be supported as equilibria in each round if the players are patient enough to value the long-term payoffs over the short-term payoffs (the folk theorem, see e.g. Fudenberg and Levine 1998). In other words, the players are likely to focus on long-term goals of cooperating (the symmetric joint-optimum JO) rather than to one-shot benefits that result from equilibrium play (the Stackelberg equilibria L and F, or the general cheating strategy LS). In the private information treatments player A has hidden payoff information and therefore less incentive for joint-optimum play. Therefore in the private information treatments we expect to see more Stackelberg equilibrium behavior (in the S-PI treatment) and general cheating behavior (in the CT-PI treatment) than joint-optimum play. The Cournot-Nash equilibrium serves as a safe alternative for the asymmetric Stackelberg equilibria as it has equal payoffs.

3.2 Procedures

The experiment was conducted on computers in a classroom. The choices were made in the payoff matrix shown on the screen. In the sidebars of their computer screens the subjects also saw their results from the previous rounds. Screenshots of the interface are shown in the Appendix.

The experiment was arranged in 10 sessions. The subjects were Finnish speaking university students. They were randomly paired and randomly given either the role of A or B. Each pair remained fixed for the entire session. At the beginning of each session the subjects were told the approximate duration of the session, but the exact number of rounds was not revealed, and the ending of the session came as a surprise. Therefore, the subjects did not know precisely when the

game was going to end. To reduce the effects that the subjects discussing the length of the game outside of the laboratory may have on their behavior in the laboratory, the length of each session was actually randomized between 20 to 24 rounds. However, to make the sessions comparable we only use the first 20 rounds from each session in the analysis of the results. The session lengths in the S and the S-PI treatments were approximately 50 minutes on average and the CT and CT-PI treatment sessions were about 10 minutes longer. The experiment was conducted in Finnish and the translations of the instructions in English are given in the Appendix.

Table 1 describes the treatments and the numbers of subject pairs in them. Each subject participated in only one treatment. The subjects were paid a cash reward based on their individual payoffs in 2 rounds that were randomly drawn from the final 10 rounds. The reward was calculated as a sum of these 2 rounds' payoffs and divided by 20. The average reward was 7.05 euros. The subjects also received course credit as a show-up reward. The experimenters did not belong to the course staff.

---- Table 1 ----

4. Results

Player A is the leader in the S and S-PI treatments and the one who makes the cheap talk announcement in the CT and CT-PI treatments, and player B is the follower. In the private information treatments player B does not see player A's payoffs in the payoff matrix. We focus on two key questions:

- 1) Does player A use cheap talk to create cooperation or to gain own advantage?
- 2) How does player A's private payoff information affect cooperation?

We refer to the payoffs that result for one pair during one round as a 'result'. We use linear mixed effects regression models to study the differences in choice behavior, payoffs, and

cooperation rates. The subject-wise heterogeneity in the decision behavior is accounted for in these models by including the subjects as random effects. It is also possible that the decisions are serially correlated, i.e. a decision in one round may be explained in part by the decisions on the previous rounds. Therefore we allow the residuals an autoregressive correlation structure (see Pinheiro and Bates 2000). We use a 5 round lag in this autoregressive correlation structure because this is the typical duration of cooperation. We analyze data from all rounds 1-20, but we also include robustness checks to separately analyze data in the first half (rounds 1-10) and second half (rounds 11-20) of the experiment.

The descriptive statistics are presented in Table 2 and the production quantity distributions are shown in Fig. 2. To study the differences in the production quantity distributions, we run nonparametric Epps-Singleton (1986) two-sided tests that are based on the characteristic functions of the empirical cumulative distribution functions. We use the Epps-Singleton test because it has better power over several alternative nonparametric tests and it is applicable to discrete data (see also Forsythe et al. 1994, for a discussion of this test). Given that the null hypothesis states that the production quantities come from the same distribution, this test indicates differences in decision behavior. Within all treatments, A and B-players have significantly different production quantity distributions at the 0.05 level. Also, the cheap talk production quantities of A-players are significantly different from their actual production quantities in the CT and CT-PI treatments at the 0.001 level. When the behavior of the players in the same role (A or B) is compared between the treatments we find that the distributions of both A's cheap talk production quantities as well as their actual production quantities are significantly different between the different treatments at the 0.05 level. Also, the distributions of B's production quantities are significantly different between the different treatments at the 0.01 level except in 2 cases where the significance is marginal. These 2 cases are the S and S-PI treatments (Epps-Singleton test statistic 8.75, $p = 0.07$) and the CT and CT-PI treatments (Epps-Singleton test statistic 8.47, $p = 0.08$). Therefore, we can conclude that private information significantly changes the A-players' behavior but it changes the B-players' behavior

only marginally. The descriptive statistics for the first half the second half of the experiment are available in Table 6 in the Appendix. This Table shows that the mean quantities are slightly larger for both players in the first half in all treatments and therefore the mean payoffs are slightly smaller than in the second half of the experiment.

---- Table 2 ----

---- Fig. 2 ----

The development of the mean payoffs over the rounds is shown in Fig. 3. It is clear from this figure, as well as from Table 2, that the S-PI treatment has the worst payoffs of all the treatments. Fig. 4 shows how the shares of results with equal payoffs develop over time. Here we see that the share of symmetric joint-optimum results increases over time in all treatments except in the S-PI treatment. Another way to compare the levels of cooperation between treatments is to use the cooperation index of Müller and Tan (2013). The cooperation index of a result is calculated as $(P_{\text{tot}} - P_{\text{se}}) / (P_{\text{jo}} - P_{\text{se}})$ where P_{tot} is the total payoff of the result, P_{se} is the Stackelberg equilibrium total payoff (i.e. 108) and P_{jo} is the symmetric joint-optimum total payoff (i.e. 144). Using these numbers the cooperation index reduces to $(P_{\text{tot}} - 108) / 36$. The more cooperation there is, the closer the cooperation index is to one, and the cooperation index of the Stackelberg result is zero. The mean cooperation indices are reported in Table 2. By comparing the cooperation index across treatments with a linear mixed effects model that omits the intercept and compares the treatment means to zero we find that CT-PI is the only treatment that has a mean cooperation index that is significantly different from zero at the 0.05 level (0.43 ± 0.21 (s.e) units above zero, $t(49) = 2.04$, $p = 0.05$, intercept s.e = 0.49, residual s.d = 1.26).

---- Fig. 3 and Fig. 4 ----

4.1 Question 1

As seen from Table 2 row 3, the A-players in the CT treatment choose on average more cooperative cheap talk production quantities than what they actually play, i.e. on average $\hat{x} < x$. This difference is significant at the 0.05 level, as the estimation results from a linear mixed effects model indicate that the mean production quantity in the CT treatment is significantly higher than the mean cheap talk production quantity of that treatment (Table 3 row 1). However, in about one third of all the rounds (95 out of 280) in the CT treatment player A's first-stage announcement and second-stage choice are equal to the symmetric joint-optimum quantity ($\hat{x} = x = 6$). In contrast, there are only 30 rounds out of 280 where player A's first-stage announcement and second-stage choice are the same but not the symmetric joint-optimum quantity ($\hat{x} = x \neq 6$). The difference between these proportions is significant (Yates' chi-squared test, $\chi^2(1) = 42.18, p = 0.00$). Therefore, even though A's cheap talk announcement is more cooperative than the subsequent choice, the A-players are more prone to choose the cheap talk quantity also at the second stage when it is cooperative. This, and the fact that the B-players behave cooperatively, is why there are not LS or F outcomes in the CT treatment.

---- Table 3 ----

To study if this cooperative use of cheap talk results in the A-players being better off when they use cheap talk than when they do not use it, we run a linear mixed effects model comparing A's payoffs between the S and CT treatments. The estimation results from the model suggest that A's mean payoffs are not significantly different between the treatments (Table 3 row 2). A similar model comparing B's payoffs between the same treatments implies that their mean payoffs are not significantly different either (Table 3 row 3).

If cheap talk does not increase the payoffs, does it increase cooperation? We reported earlier that the mean cooperation indices in these treatments are not significantly different from zero. To study whether the mean cooperation indices are significantly different between the S and CT treatments we run a linear mixed effects model comparing the cooperation indices between the treatments. We find that the mean cooperation indices are not significantly different between these treatments (Table 3 row 4). Therefore, cheap talk does not significantly change the level of cooperation either.

Table 7 in the Appendix shows the analyses conducted in Table 3 separately for the first half and the second half of the experiment. As seen from Table 7 row 1, the only reported significant difference in Table 3, i.e. the difference between player A's cheap talk quantity and actual quantity, is significant only for the first half and not the second half.

Answer. A-players use cheap talk more frequently for cooperation than for gaining own advantage. Those who aim for the joint-optimum show commitment to it in their cheap talk announcements. However, cheap talk does not significantly increase joint-optimum play and it does not significantly change the mean payoffs of the players.

4.2 Question 2

When player A's payoffs are private, cheap talk has more effect on cooperation and on the payoffs than in the full information case. The cooperation rate is low in the S-PI treatment and high in the CT-PI treatment. This is seen by comparing the cooperation indices as well as the mean total payoffs between these treatments (Table 2 rows 2 and 4). To test the hypothesis that cooperation is less frequent in S-PI than in CT-PI, we compare the cooperation indices with a linear mixed effects model between the 2 treatments. The results of the model estimate the mean cooperation index in the CT-PI treatment to be significantly larger than in the S-PI treatment (Table 4 row 4). Therefore, cheap talk increases cooperation under private information.

To test the hypothesis that A's payoffs are better in CT-PI than in S-PI, we run linear mixed effects models comparing the payoffs between these treatments. We find that the A's mean payoffs are higher in CT-PI than in S-PI, although this difference is only marginally significant at the conventional 0.05 level of significance (Table 4 row 2). Similarly, we find that B's mean payoffs are higher in CT-PI than in S-PI (Table 4 row 3). These results imply that in addition to increasing cooperation, cheap talk increases both players' payoffs when player A has private payoff information.

---- Table 4 ----

Similarly as in the CT treatment, the A-players in the CT-PI treatment are prone to announce and choose the joint-optimum quantity. In about a third (96 out of 280) of all the rounds in the CT-PI treatment player A's first-stage announcement and second-stage choice are equal to the symmetric joint-optimum quantity ($\hat{x} = x = 6$), and there are only 36 rounds out of 280 where player A's first-stage announcement and second-stage choice are the same but not the symmetric joint-optimum quantity ($\hat{x} = x \neq 6$). This behavior does not significantly differ from that in the CT treatment (Yates' chi-squared test, $\chi^2(1) = 0.21, p = 0.65$).¹

As we see from Fig. 2 the distributions of the cheap talk production quantities in the CT-PI treatment are slightly different from those in the CT treatment. We also see from Table 2 that these announcements are on average higher under private information. Whereas in the CT treatment A's mean cheap talk production quantity is lower than his actual production quantity, this relationship is opposite in the CT-PI treatment. There player A's mean cheap talk quantity is higher than the actual production quantity, although the difference is only marginally significant at the conventional 0.05

¹ The private information treatment also raises the question whether A-players avoid cheating because of the private payoffs. However, comparing first-round cheap talk announcements between CT and CT-PI treatments reveals that the announcement distributions are not significantly different (Epps-Singleton test statistic 2.87, $p = 0.58$).

level of significance (linear mixed effects model, see Table 4 row 1). This suggests that the private payoff information motivates the A-players to try to gain advantage with cheap talk. To some extent they succeed in this, as nearly a quarter (67 out of 280) of B's production quantity choices are best responses to cheap talk in the CT-PI treatment, compared to less than 10 % (25 out of 280) in the CT treatment. These proportions are significantly different between the 2 treatments (Yates' chi-squared test, $\chi^2(1) = 21.86, p = 0.00$). Therefore it is interesting to ask if A's mean payoffs are higher in the CT-PI treatment than in the CT treatment. The estimation results from linear mixed effects models comparing the CT and the CT-PI treatments show that A's mean payoffs are not significantly different (Table 4 row 5). B's mean payoffs are not significantly different either (Table 4 row 6) between these 2 treatments. Therefore, we cannot confirm that private information significantly changes the payoffs in the CT and CT-PI treatments.

Table 8 in the Appendix shows the analyses conducted in Table 4 separately for the first half and the second half. As seen from Table 8, the two reported significant differences in Table 4, i.e. the difference in player B's payoffs between treatments S-PI and CT-PI and the difference in cooperation indices between these treatments, are significant for the first half of the experiment but not for the second half. Additionally, we see from Table 8 that player A's payoffs are significantly different between treatments S-PI and CT-PI for the first half of the experiment.

In the industrial organization literature our results relate to the studies on the effects of information in duopoly markets (e.g. Mason and Phillips 1997). One implication would be that harmful collusion can be prevented when payoff information is private but only if the market leader cannot revise its production quantity after the follower.

***Answer.** When comparing the treatments where player A has private payoffs, the cooperation rate is higher in the cheap talk Stackelberg game than in the Stackelberg game. Unlike under complete payoff information, cheap talk increases both players' payoffs when A has private*

payoff information. As in the CT treatment, those A-players who aim for the joint-optimum show commitment to it in their cheap talk announcements in the CT-PI treatment.

4.3 The response behavior of the players

In this section we first compare the best response behavior of the players between the different treatments. Then we model the response behavior more generally by employing first a linear model between a choice and its response and then a nonlinear model that can explain altruism.

Myopic self-regarding players can be assumed to respond by best responses because this gives them the highest payoff. Players aiming at cooperation display reciprocal behavior, i.e. they reciprocate cooperative low production quantities by low quantities and non-cooperative high quantities by high quantities. The S, CT, and CT-PI treatments have only moderate amounts of best responses (18.6 %, 21.1 %, and 25.0 %, respectively). In the S-PI treatment almost half (47.1 %) of the production quantities are best responses. Thus, there is clearly more self-regarding best response behavior when B does not know A's payoffs in the Stackelberg game. But even in the S-PI treatment half of the time the B-players do not best respond and therefore not all responses are self-regarding.

We can learn more about the response behavior by investigating all the responses, not just those that are best responses. If the players are myopic and self-regarding, they always respond to high production quantities with low production quantities and vice versa, because this maximizes their own payoffs. Furthermore, as the payoff functions are quadratic in the players' own production quantities and linear in the others' production quantities, the best responses are linear. Therefore, B's production quantity should decrease with A's production quantity in the S and S-PI treatments and the A's production quantity should decrease with B's production quantity in the CT and CT-PI treatments. However, this is not the case in the S and S-PI treatments and in the CT-PI treatment. Table 5 (Model 1) shows regression results from a linear mixed effects model that is

used to study these relationships. We see that CT is the only treatment where A's committing production quantity has a significant linear relationship with B's production quantity. But surprisingly, A's production quantity *increases* with B's production quantity. This provides an additional indicator that the round-level behavior is not myopic and self-regarding but cooperative. In reciprocal cooperation low production quantities are rewarded with low production quantities and high production quantities are punished with high production quantities. These results are similar to the findings of Huck et al. (2001) and Müller and Tan (2013), where the followers behave in this way. Lau and Leung (2010) use maximum likelihood methods on the data of the experiment by Huck et al. (2001) and find that the data fits better to the model of disadvantageous inequity aversion (Fehr and Schmidt, 1999) than to the standard model of self-regarding behavior. Santos-Pinto (2008) suggests that such behavior arises because the 'inequity cost' of an inequity averse player keeps him from making a selfish deviation.

The preceding linear regression analysis between the production quantities assumes that the response either increases or decreases with all values of the other's production quantity. However, as Huck et al. (2001) and Müller and Tan (2013) show, the response decreases with some values of the other's production quantity and increases with other values of the other's production quantity. Therefore, a model that allows a non-linear relationship needs to be used. Cox et al. (2008) present a theory that predicts, in the standard Stackelberg game, that B's *altruism* increases as A's production quantity decreases and that B's deviation from best response decreases as A's production quantity decreases. Player B's altruism means that he is willing to pay his own potential payoff to attain a cooperative result with A. Altruism is denoted by the variable W and defined by $W = (24 - x - 2y)/x$. The deviation from best response is defined by $D = y - BR(x)$, where BR denotes the best response function. For example, if player A in the standard Stackelberg game chooses the joint-optimum quantity of 6, then player B's choice of 10 indicates that $W = -1/3$ and $D = 1$ whereas player B's choice of 6 indicates that $W = 1$ and $D = -3$. In the CT and CT-PI treatments

player A's response to B's choice is analyzed and thus the production quantities x and y are reversed in the preceding formulae for W and D .

The revealed altruism theory is estimated with linear mixed effects models and the results are shown in Table 5 (Models 2 and 3). We see from Table 5 that W decreases (negative coefficient) and D increases (positive coefficient) in all treatments. It is notable that the coefficient of W is more negative in the CT and CT-PI treatments than in the S and S-PI treatments. This implies that the A-players are more cooperative in the CT and CT-PI treatments than the B-players in the S and S-PI treatments. Cox et al. (2008) obtain similar results with the Huck et al. (2001) Stackelberg data based on one-shot interactions. There the regression coefficients for W and D are -0.046 and 0.32, respectively. These are closer to zero than in our case, indicating less cooperative B-players. This is expected as their data is from one-shot interactions where there is less cooperation anyway.

We can also conduct the above analysis to study how B responds to A's cheap talk in the CT and CT-PI treatments. However, this analysis should be evaluated with caution as A's cheap talk production quantity does not bind A and B is the actual first mover. Rather, B needs to evaluate whether he should trust A or not. Yet it is interesting to see how the A-players respond to cheap talk. The first analysis with the linear model finds that the B-players are reciprocal to the A-players' cheap talk production quantities in the CT treatment but not in the CT-PI treatment (Table 5 Model 1). This is in line with the earlier observation we made about the higher best response rate (i.e. a non-reciprocal relationship) to cheap talk under A's private payoff information than under complete information. We can then use the coefficients from Models 2 and 3 in Table 5 to compare how the B-players respond to cheap talk in the CT and CT-PI treatments and how the B-players respond to the A-players' committing production quantities in the S and S-PI treatments. The observation is that the behavior is more cooperative as response to cheap talk than as response to the committing production quantity. We therefore conclude that the B-players' behavior is more cooperative in the CT and CT-PI treatments than in the S and S-PI treatments despite the fact that B is the first to choose a committing production quantity.

---- Table 5 ----

5. Conclusions

Cheap talk increases cooperation in the repeated Stackelberg duopoly game when player A (the Stackelberg leader) has private payoff information. When player A's payoffs are private, the cooperation rate is high with cheap talk and low without cheap talk. This result shows an interesting connection between player A's cheap talk and private information. It suggests that cheap talk can substitute private information, i.e. remedy cooperation rates when B remains uninformed of A's payoffs. In the absence of cheap talk, private information reduces cooperation. In all treatments the players respond cooperatively when evaluated with the revealed altruism theory of Cox et al. (2008). This cooperative behavior is more pronounced in the cheap talk treatments than in the Stackelberg treatments.

Our results from the CT and CT-PI treatments confirm the cooperation-enhancing effect of cheap talk in earlier oligopoly literature (e.g. Waichman et al. 2014) and show that this effect can be present also when the players have a commitment asymmetry, i.e. when they do not commit to their production quantities simultaneously. On the other hand, our results from the S-PI treatment are in line with literature that finds that private information can deter cooperation (Potters and Suetens 2013). Player A's role in coordinating the symmetric joint-optimum outcomes reminds of cheap talk coordination games conducted in the literature. This literature agrees that cheap talk can help coordinating a preferred outcome in games where there are multiple equilibria (see e.g. Crawford 1998 and Balliet 2010). McDaniel (2011) shows that cheap talk serves in an assurance role at coordinating socially preferred and risk dominant outcomes in repeated interactions. In line with our result, McDaniel (2011) finds that cheap talk is not used for individual advantage even when the receiver of the cheap talk message does not have full payoff information.

Due to the repeated interactions, both player A and player B have an important role in driving cooperation. Player A does not use cheap talk for gaining by cheating. Instead, player A is cooperative and signals his willingness to act cooperatively by announcing the symmetric joint-optimum production quantity and then committing to it. This happens in the CT treatment but it is noteworthy that this happens also in the CT-PI treatment where player B does not know A's payoffs. This commitment behavior of player A assures player B also in the CT-PI treatment of A's cooperativeness. It could be that player A's commitment to the joint-optimum quantity serves as a self-commitment mechanism (e.g. Schelling 1992) such that breaking that commitment would deter player B's trust on A. On the other hand, with our design we cannot separate this effect from the signaling effect that is arguably present in the cheap talk games. However, in the absence of the cheap talk opportunity in the S-PI treatment the joint-optimum play rate plummets, indicating that one or both of these effects provided by cheap talk is essential for cooperation under the informational asymmetry.

One could argue that our setting may not represent duopolistic firms' behavior in markets in general as player B is expected to react to player A's cheap talk and as A's payoff information is assumed private. However, it is relevant as a model of cooperative behavior where there is a commitment asymmetry between the players. The more detailed study of the interaction of cheap talk and private information in repeated games remains an interesting research topic for future studies.

Appendix

Translated instructions

Welcome to the market experiment

In the market experiment, we study human behavior in experimental markets consisting of two firms. Both firms make choices on production quantities of the same product. The total

production quantity ending up in the market affects the payoffs of the firms. By making deliberate choices, the firms (=participants) can earn euros from the markets.

You represent a firm, and you encounter another firm in a market situation. This is repeated several times. Each time, you encounter the same person representing the other firm. The persons remain anonymous.

The consequences of production choices are displayed in the payoff table. (Both firms see the payoffs of both firms.) / (Firm A has better knowledge of the market, and it sees payoffs of both firms, while firm B knows only its own payoff.) (Firm A can re-evaluate its choice after Firm B's choice.) One round thus consists of the following (two) / (three) stages:

- Firm A chooses its production quantity, firm B will observe this
- Firm B chooses its production quantity, (firm A will observe this)
- (- Firm A chooses its final production quantity)

The round ends and both firms see the final choices and payoffs for each of them. The results and choices made in the previous rounds are at all times displayed during the subsequent rounds. There will be several rounds, and the program will let you know when the experiment ends.

The personal payoffs are calculated as follows: two rounds are selected randomly out of the ten last ones. The average payoff of these two rounds is calculated. This average is divided by ten, which is the payoff in euros. The experiment supervisor will inform you how the payoff will be given to you.

Use a moment to familiarize yourself with this setting.

--- Fig 5 ---

--- Fig 6 ---

--- Table 6 ---

--- Table 7 ---

--- Table 8 ---

References

- Akerlof GA (1970) The market for 'lemons': Quality, uncertainty, and the market mechanism. *Q J Econ* 84:488–500
- Albaek S (1990) Stackelberg leadership as a natural solution under cost uncertainty. *J Ind Econ* 38:335–347. doi:10.2307/2098502
- Balliet D (2010) Communication and cooperation in social dilemmas: A meta-analytic review. *J Conflict Resolut* 54:39–57. doi:10.1177/0022002709352443
- Brandts J, Charness G (2003) Truth or consequences: An experiment. *Manage Sci* 49:116–130
- Cardella E, Chiu R (2012) Stackelberg in the lab: The effect of group decision making and “cooling-off” periods. *J Econ Psychol* 33:1070–1083. doi:10.1016/j.joep.2012.07.004
- Cason TN (1995) Cheap talk price signaling in laboratory markets. *Inf Econ Policy* 7:183–204. doi:10.1016/0167-6245(94)00041-4
- Cason TN, Mui V-L (2007) Communication and coordination in the laboratory collective resistance game. *Exp Econ* 10:251–267
- Cason TN, Mui V-L (2014) Coordinating resistance through communication and repeated interaction. *Econ J* 124:F226–F256. doi:10.1111/eoj.12088
- Charness G (2000) Self-serving cheap talk: A test of Aumann's conjecture. *Games Econ Behav* 33, 177–194. doi:10.1006/game.1999.0776
- Charness G, Rabin M (2002) Understanding social preferences with simple tests. *Q J Econ* 117:817–869

- Charness G, Rabin M (2005) Expressed preferences and behavior in experimental games. *Games Econ Behav* 53:151–169. doi:10.1016/j.geb.2004.09.010
- Clark K, Sefton M (2001) Repetition and signalling: experimental evidence from games with efficient equilibria. *Econ Lett* 70:357–362.
- Cooper R, DeJong DV, Forsythe R, Ross TW (1992) Communication in coordination games. *Q J Econ* 107:739–771
- Cox JC, Friedman D, Gjerstad S (2007) A tractable model of reciprocity and fairness. *Games Econ Behav* 59:17–45. doi:10.1016/j.geb.2006.05.001.
- Cox JC, Friedman D, Sadiraj V (2008) Revealed altruism. *Econometrica* 76:31–69. doi:10.1111/j.0012-9682.2008.00817.x
- Crawford VP, Sobel J (1982) Strategic information transmission. *Econometrica* 50:1431–1451
- Crawford VP (1998) A survey of experiments on communication via cheap talk. *J Econ Theory* 78:286–298. doi:10.1006/jeth.1997.2359
- Ellingsen T, Östling R (2010) When does communication improve coordination? *Am Econ Rev* 100:1695–1724. doi:10.1257/aer.100.4.1695
- Epps TW, Singleton KJ (1986) An omnibus test for the two-sample problem using the empirical characteristic function. *J Stat Comput Sim* 26:177–203. doi:10.1080/00949658608810963
- Erat S, Gneezy U (2012) White lies. *Manage Sci* 58:723–733
- Farrell J (1987) Cheap talk, coordination, and entry. *Rand J Econ* 18:34–39
- Fehr E, Schmidt KM (1999) A theory of fairness, competition, and cooperation. *Q J Econ* 114:817–868

- Fonseca MA, Huck S, Normann H-T (2005) Playing Cournot although they shouldn't. Endogenous timing in experimental duopolies with asymmetric cost. *Econ Theory* 25:669–677
- Fonseca MA, Müller W, Normann H-T (2006) Endogenous timing in duopoly: Experimental evidence. *Int J Game Theory* 34:443–456. doi:10.1007/s00182-006-0027-4
- Fonseca MA, Normann H-T (2012) Explicit vs. tacit collusion—The impact of communication in oligopoly experiments. *Eur Econ Rev* 56:1759–1772. doi:10.1016/j.euroecorev.2012.09.002
- Forsythe R, Horowitz JL, Savin NE, Sefton M (1994) Fairness in simple bargaining experiments. *Games Econ Behav* 6:347–369. doi:10.1006/game.1994.1021
- Fouraker LE, Siegel S (1963) *Bargaining Behavior*. McGraw-Hill, New York
- Friedman E, Shor M, Shenker S, Sopher B (2004) An experiment on learning with limited information: Nonconvergence, experimentation cascades, and the advantage of being slow. *Games Econ Behav* 47:325–352. doi:10.1016/S0899-8256(03)00183-0
- Fudenberg D, Levine DK (1998) *The Theory of Learning in Games*. The MIT Press, Cambridge
- Gneezy U (2005) Deception: The role of consequences. *Am Econ Rev* 95:384–394
- Güth W, Müller W, Spiegel Y (2006) Noisy leadership: An experimental approach. *Games Econ Behav* 57:37–62. doi:10.1016/j.geb.2006.05.004
- Holmström B (1979) Moral hazard and observability. *Bell J Econ* 10:74–91
- Huck S, Müller W, Normann H-T (2001) Stackelberg beats Cournot—On collusion and efficiency in experimental markets. *Econ J* 111:749–765. doi:10.1111/1468-0297.00658
- Huck S, Müller W, Normann H-T (2002) To commit or not to commit: Endogenous timing in experimental duopoly markets. *Games Econ Behav* 38:240–264. doi:10.1006/game.2001.0889

- Huck S, Wallace B (2002) Reciprocal strategies and aspiration levels in a Cournot-Stackelberg experiment. *Economics Bulletin* 3:1–7
- Hurkens S, Kartik N (2009) Would I lie to you? On social preferences and lying aversion. *Exp Econ* 12:180–192
- Hämäläinen RP (1981) On the cheating problem in Stackelberg games. *Int J Syst Sci* 12:753–770. doi:10.1080/00207728108963781
- Lau S-HP, Leung F (2010) Estimating a parsimonious model of inequality aversion in Stackelberg duopoly experiments. *Oxford B Econ Stat* 72:669–686. doi:10.1111/j.1468-0084.2010.00592.x
- Loch CH, Wu Y (2008) Social preferences and supply chain performance: an experimental study. *Management Science* 54:1835–1849.
- Mailath G (1993) Endogenous sequencing of firm decisions. *J Econ Theory* 59:169–182. doi:10.1006/jeth.1993.1010
- Mason CF, Phillips OR (1997) Information and cost asymmetry in experimental duopoly markets. *Rev Econ Stat* 79:290–299. doi:10.1162/003465397556647
- McDaniel TM (2011) Coordination in games with incomplete information: Experimental results. *Int Game Theory Rev* 13:461–474. doi:10.1142/S021919891100309X
- Morgan J, Várdy F (2004) An experimental study of commitment in Stackelberg games with observation costs. *Games Econ Behav* 49:401–423. doi:10.1016/j.geb.2004.04.005
- Müller W (2006) Allowing for two production periods in the Cournot duopoly: Experimental evidence. *J Econ Behav Organ* 60:100–111. doi:10.1016/j.jebo.2004.06.025

- Müller W, Tan F (2013) Who acts more like a game theorist? Group and individual play in a sequential market game and the effect of the time horizon. *Games Econ Behav* 82:658 – 674. doi:10.1016/j.geb.2013.09.007
- Pinheiro JC, Bates DM (2000) *Mixed-Effects Models in S and S-PLUS*. Springer, New York
- Potters J, Suetens S (2013) Oligopoly experiments in the current millennium. *J Econ Surv* 27:439–460. doi:10.1111/joes.12025
- Rabin M (1994) A model of pre-game communication. *J Econ Theory* 63:370–391. doi:10.1006/jeth.1994.1047
- Rasmussen A (2014) The influence of face-to-face communication: A principal-agent experiment. *Cent Europ J Oper Re* 22:73–88. doi:10.1007/s10100-012-0270-7
- Roy N (2012) Revision and cooperation: Evidence from Cournot duopoly experiments. Manuscript. <http://www.hss.caltech.edu/~royn/revisionandcooperation.pdf>
- Santos-Pinto L (2008) Making sense of the experimental evidence on endogenous timing in duopoly markets. *J Econ Behav Organ* 68:657–666. doi:10.1016/j.jebo.2008.06.005
- Schelling T (1992) Self-command: A new discipline. In: Elster J, Loewenstein G (eds) *Choice over time*. Russell Sage, New York, pp 167–176.
- Waichman I, Requate T, Siang CK (2014) Communication in Cournot competition: An experimental study. *J Econ Psychol* 42:1–16. doi:10.1016/j.joep.2014.02.005

A	B													
	Production quantity	3	4	5	6	7	8	9	10	11	12	13	14	15
3	54	54	68	80	90	98	104	108	109	110	108	104	98	90
4	68	51	64	75	84	91	96	99	100	99	96	91	84	75
5	80	48	75	60	70	78	84	88	89	90	88	84	78	60
6	90	45	84	56	72	72	66	80	48	41	36	30	24	18
7	98	42	91	52	60	77	70	71	49	42	35	28	21	14
8	104	39	96	48	55	63	64	63	48	40	32	24	16	8
9	108	36	99	44	50	55	56	54	45	36	27	18	9	0
10	109	33	100	40	45	49	48	45	40	30	20	10	0	-10
11	110	30	99	36	40	41	40	36	33	22	11	0	-11	-22
12	108	27	96	32	35	36	32	27	24	12	0	-12	-24	-36
13	104	24	91	28	29	30	28	24	18	0	-13	-26	-39	-52
14	98	21	84	24	25	24	21	16	9	-14	-28	-42	-56	-70
15	90	18	75	19	20	18	14	8	0	-30	-45	-60	-75	-90

Fig. 1 The payoff matrix

Note: The highlighted payoff matrix entries are the Cournot-Nash equilibrium (N), the symmetric joint-optimum (JO), the Stackelberg equilibrium (L), the Stackelberg equilibrium where the follower is the leader (F), and the general cheating strategy (LS). These entries were not highlighted in the payoff matrices shown to the experimental subjects. One payoff point was subtracted from a total of 14 outcomes in order to ensure uniqueness of equilibria (see Huck et al. 2001).

Fig. 2 The production quantity distributions by treatment

Fig. 3 Mean payoffs over all rounds (error bars represent standard errors)

Fig. 4 Shares of results that have equal payoffs, symmetric joint-optima, and Cournot-Nash equilibria, over all rounds

Note: In the S-PI treatment the share of symmetric joint-optima is significantly lower than in the other treatments ($p < 0.001$, one-tail Wilcoxon signed-rank test that compares round-wise matched samples). Similarly, in the S-PI treatment the share of Cournot-Nash equilibria is significantly higher than in other treatments ($p < 0.005$, one-tail Wilcoxon signed-rank test). The differences are clear even though the tests do not account for serial correlation.

Firm A: choose your final production, i.e. select a row
Your first stage choice and B's choice are highlighted in yellow.

The firm B you encounter
is the same in every round

Results from the previous rounds

		Choices by stages		Payoffs	
#		A	B	A	B
1	8	8	11	55	40
2	4	10	9	45	50
3	10	10	6	48	80
4	11	11	6	41	76
5	9	9			

Payoff table

Payoffs A/B	3	4	5	6	7	8	9	10	11	12	13	14	15
3	54/54	51/68	48/80	45/90	42/98	39/104	36/108	33/109	30/110	27/108	24/104	21/98	18/90
4	68/51	64/64	60/75	56/84	52/91	48/96	44/99	40/100	36/99	32/96	28/91	24/84	19/75
5	80/48	75/60	70/70	65/78	60/84	55/88	50/89	45/90	40/88	35/84	29/78	25/70	20/60
6	90/45	84/56	78/65	72/72	66/77	60/80	54/81	48/80	41/77	36/72	30/65	24/56	18/45
7	98/42	91/52	84/60	77/66	70/70	63/72	55/71	49/70	42/66	35/60	28/52	21/42	14/30
8	104/39	96/48	88/55	80/60	72/63	64/64	56/63	48/60	40/55	32/48	24/39	16/28	8/15
9	108/36	99/44	89/50	81/54	71/55	63/56	54/54	45/50	36/44	27/36	18/26	9/14	0/0
10	109/33	100/40	90/45	80/48	70/49	60/48	50/45	40/40	30/33	20/24	10/13	0/0	-10/-15
11	110/30	99/36	88/40	77/41	66/42	55/40	44/36	33/30	22/22	11/12	0/0	-11/-14	-22/-30
12	108/27	96/32	84/35	72/36	60/35	48/32	36/27	24/20	12/11	0/0	-12/-13	-24/-28	-36/-45
13	104/24	91/28	78/29	65/30	52/28	39/24	26/18	13/10	0/0	-13/-12	-26/-26	-39/-42	-52/-60
14	98/21	84/24	70/25	56/24	42/21	28/16	14/9	0/0	-14/-11	-28/-24	-42/-39	-56/-56	-70/-75
15	90/18	75/19	60/20	45/18	30/14	15/8	0/0	-15/-10	-30/-22	-45/-36	-60/-52	-75/-70	-90/-90

Ready

Fig. 5 Screenshot of the leader's choice screen (translated from Finnish)

Fig. 6 Screenshot of the leader's waiting screen (translated from Finnish)

Fig. 1 and Figs. 5-6 are produced with Microsoft Office. Figs. 2-4 are produced with the statistical package R.

Table 1. The treatments

Treatment	Game	Private information?	Number of pairs (summed over sessions)
S	Stackelberg	No	7+4 = 11
S-PI	Stackelberg	Yes	9+5 = 14
CT	Cheap talk Stackelberg	No	7+7 = 14
CT-PI	Cheap talk Stackelberg	Yes	4+4+4+2 = 14

Notes.

In the S, S-PI, and CT treatments there were two sessions, and in the CT-PI treatment there were four sessions.

Table 2. Descriptive statistics

Treatment	Mean quantity		Mean	Mean payoff		Total mean payoff	Mean $x - \hat{x}$	Mean cooperation index
	x	y	$\hat{x}$	A	B			
S	7.83 (2.75)	8.23 (2.39)	-	52.87 (27.83)	57.94 (30.64)	110.81 (55.16)	-	0.08 (1.53)
S-PI	9.35 (2.56)	8.23 (2.41)	-	52.19 (31.14)	45.69 (29.45)	97.88 (56.19)	-	-0.28 (1.56)
CT	8.05 (2.27)	7.73 (2.41)	7.14 (2.28)	58.36 (24.71)	55.08 (23.33)	113.44 (45.83)	0.90 (2.68)	0.15 (1.27)
CT-PI	7.74 (2.18)	7.29 (2.29)	8.59 (3.22)	64.07 (20.50)	59.61 (19.50)	123.68 (35.13)	-0.85 (2.56)	0.44 (0.98)

Notes.

The variable x is player A's quantity choice, the variable y is player B's quantity choice, and the variable $\hat{x}$ is player A's cheap talk quantity. Standard deviations are in parentheses.

Table 3. Estimation results from linear mixed effects models

Treatments included	Dependent variable	Estimated coefficient (s.e)	Statistics
1. CT	$x - \hat{x}$	0.90 (0.42)	$t(266) = 2.18, \sigma_0 = 2.29,$ $p = 0.03, \sigma_1 = 1.44$
2. S, CT	A's payoff	6.53 (5.26)	$t(23) = 1.24, \sigma_0 = 26.15,$ $p = 0.23, \sigma_1 = 0.01$
3. S, CT	B's payoff	-1.32 (6.03)	$t(23) = -0.22, \sigma_0 = 24.90,$ $p = 0.83, \sigma_1 = 10.25$
4. S, CT	Cooperation index	0.16 (0.31)	$t(23) = 0.51, \sigma_0 = 1.34,$ $p = 0.62, \sigma_1 = 0.39$

Notes.

The variable x is player A's quantity choice and the variable $\hat{x}$ is player A's cheap talk quantity. In the first row the fixed effect is a constant slope and in the other rows it is a dichotomous variable that has value 0 for the first treatment and 1 for the second treatment. Random effects are the subject id's. AR(5) correlation structure is included in the model. The estimated coefficient is the slope estimate, intercept estimates are not reported. Standard deviations of the random effects for intercept are denoted σ_1 and residual standard deviations as σ_0 .

Table 4. Estimation results from linear mixed effects models

Treatments included	Dependent variable	Estimated coefficient (s.e)	Statistics
1. CT-PI	$x - \hat{x}$	-0.84 (0.44)	$t(266) = -1.92, \sigma_0 = 2.12, p = 0.06, \sigma_1 = 1.48$
2. S-PI, CT-PI	A's payoff	10.69 (6.11)	$t(26) = 1.75, \sigma_0 = 23.50, p = 0.09, \sigma_1 = 12.36$
3. S-PI, CT-PI	B's payoff	13.14 (6.13)	$t(26) = 2.14, \sigma_0 = 22.00, p = 0.04, \sigma_1 = 11.96$
4. S-PI, CT-PI	Cooperation index	0.65 (0.31)	$t(26) = 2.12, \sigma_0 = 1.18, p = 0.04, \sigma_1 = 0.57$
5. CT, CT-PI	A's payoff	5.40 (3.75)	$t(26) = 1.44, \sigma_0 = 22.70, p = 0.16, \sigma_1 = 0.00$
6. CT, CT-PI	B's payoff	3.82 (4.61)	$t(26) = 0.83, \sigma_0 = 21.33, p = 0.41, \sigma_1 = 0.00$

Notes.

The variable x is player A's quantity choice and the variable $\hat{x}$ is player A's cheap talk quantity. In the first row the fixed effect is a constant slope and in the other rows it is a dichotomous variable that has value 0 for the first treatment and 1 for the second treatment. Random effects are the subject id's. AR(5) correlation structure is included in the model. The estimated coefficient is the slope estimate, intercept estimates are not reported. Standard deviations of the random effects for intercept are denoted σ_1 and residual standard deviations as σ_0 .

Table 5. Estimation results and regression statistics from linear mixed effects models for the linear relationship between the production quantities (Model 1) and the assumptions of the revealed altruism theory of Cox et al. (2008) (Models 2 and 3)

S and S-PI treatments	Model 1		Model 2		Model 3	
	y		W		D	
Intercept	8.34	(0.45)	0.67	(0.11)	-3.49	(0.46)
	$t = 18.39$	$p = 0.00$	$t = 6.09$	$p = 0.00$	$t = -7.66$	$p = 0.00$
x :treatment(S)	0.01	(0.05)	-0.08	(0.01)	0.48	(0.05)
	$t = 0.15$	$p = 0.88$	$t = -7.58$	$p = 0.00$	$t = 10.03$	$p = 0.00$
x :treatment(S-PI)	-0.03	(0.05)	-0.08	(0.01)	0.45	(0.05)
	$t = -0.55$	$p = 0.58$	$t = -6.68$	$p = 0.00$	$t = 9.42$	$p = 0.00$
DF	473		473		473	
σ_0 (residual s.d)	2.17		0.60		2.20	
σ_1 (intercept s.d)	1.10		0.00		1.06	
CT and CT-PI treatments	x		W		D	
Intercept	7.04	(0.35)	1.16	(0.10)	-4.73	(0.35)
	$t = 19.99$	$p = 0.00$	$t = 11.42$	$p = 0.00$	$t = -13.55$	$p = 0.00$
y :treatment(CT)	0.17	(0.04)	-0.13	(0.01)	0.63	(0.04)
	$t = 4.46$	$p = 0.00$	$t = -12.26$	$p = 0.00$	$t = 16.58$	$p = 0.00$
y :treatment(CT-PI)	0.04	(0.04)	-0.11	(0.01)	0.51	(0.04)
	$t = 1.01$	$p = 0.31$	$t = -10.24$	$p = 0.00$	$t = 12.80$	$p = 0.00$
DF	530		530		530	
σ_0 (residual s.d)	2.01		0.62		2.00	
σ_1 (intercept s.d)	0.64		0.00		0.61	
CT and CT-PI treatments	y		W		D	
Intercept	6.93	(0.38)	1.42	(0.12)	-4.93	(0.38)
	$t = 18.18$	$p = 0.00$	$t = 12.31$	$p = 0.00$	$t = -12.92$	$p = 0.00$
$\hat{x}$:treatment(CT)	0.15	(0.05)	-0.16	(0.02)	0.63	(0.05)
	$t = 3.00$	$p = 0.00$	$t = -10.65$	$p = 0.00$	$t = 12.63$	$p = 0.00$
$\hat{x}$:treatment(CT-PI)	0.02	(0.04)	-0.13	(0.01)	0.50	(0.04)
	$t = 0.55$	$p = 0.58$	$t = -9.96$	$p = 0.00$	$t = 11.55$	$p = 0.00$
DF	530		530		530	
σ_0 (residual s.d)	2.34		0.70		2.33	
σ_1 (intercept s.d)	0.00		0.00		0.00	

Notes.

Each model's dependent variable is given in the respective column. The variable x is player A's quantity choice and the variable y is player B's quantity choice. For each model the Table shows the estimate, the standard error (in parentheses), the t-value and the p-value on the same row as the intercept or the fixed effect. The assumptions of the models are that W and D depend linearly on A's production quantity in the S and S-PI treatments and on B's production quantity in the CT and

CT-PI treatments. The subjects are entered in the models as random effects. AR(5) correlation structure is included in the models.

Table 6. Robustness check for Table 2

Treatment	Rounds	Mean quantity		Mean $\hat{x}$	Mean payoff		Mean $x - \hat{x}$	Mean cooperation index
		x	y		A	B		
S	1-10	8.05 (2.77)	8.25 (2.34)	-	54.28 (20.48)	58.04 (23.79)	-	0.12 (1.06)
	11-20	7.60 (2.71)	8.20 (2.44)	-	51.45 (33.64)	57.84 (36.33)	-	0.04 (1.89)
S-PI	1-10	9.56 (2.48)	8.51 (2.46)	-	50.41 (29.70)	44.34 (29.39)	-	-0.37 (1.51)
	11-20	9.15 (2.63)	7.94 (2.34)	-	53.96 (32.52)	47.04 (29.56)	-	-0.19 (1.61)
CT	1-10	8.48 (2.37)	8.01 (2.40)	7.43 (2.54)	55.5 (26.90)	51.76 (25.41)	1.05 (2.86)	-0.02 (1.38)
	11-20	7.61 (2.07)	7.45 (2.40)	6.85 (1.95)	61.21 (22.04)	58.39 (20.60)	0.76 (2.49)	0.32 (1.13)
CT-PI	1-10	8.15 (2.08)	7.51 (2.22)	9.05 (3.43)	63.48 (20.54)	57.51 (18.56)	-0.9 (2.73)	0.36 (1.00)
	11-20	7.32 (2.21)	7.07 (2.33)	8.12 (2.93)	64.66 (20.51)	61.70 (20.24)	-0.8 (2.39)	0.51 (1.04)

Notes.

The variable x is player A's quantity choice, the variable y is player B's quantity choice, and the variable $\hat{x}$ is player A's cheap talk quantity. Standard deviations are in parentheses.

Table 7. Robustness check for Table 3

Treatments included	Dependent variable	Rounds	Estimated coefficient (s.e)	Statistics
1. CT	$x - \hat{x}$	1-10	1.08 (0.41)	$t(126) = 2.57, \sigma_0 = 2.57,$ $p = 0.01, \sigma_1 = 1.33$
		11-20	0.75 (0.46)	$t(126) = 1.63, \sigma_0 = 1.88,$ $p = 0.11, \sigma_1 = 1.66$
2. S, CT	A's payoff	1-10	3.04 (5.28)	$t(23) = 0.57, \sigma_0 = 23.97,$ $p = 0.57, \sigma_1 = 4.16$
		11-20	8.19 (7.41)	$t(23) = 1.10, \sigma_0 = 26.56,$ $p = 0.28, \sigma_1 = 8.45$
3. S, CT	B's payoff	1-10	-6.02 (5.64)	$t(23) = -1.07, \sigma_0 = 23.17,$ $p = 0.29, \sigma_1 = 8.93$
		11-20	-2.17 (7.75)	$t(23) = -0.28, \sigma_0 = 27.77,$ $p = 0.78, \sigma_1 = 0.01$
4. S, CT	Cooperation index	1-10	-0.10 (0.29)	$t(23) = -0.33, \sigma_0 = 1.15,$ $p = 0.74, \sigma_1 = 0.50$
		11-20	0.16 (0.41)	$t(23) = 0.38, \sigma_0 = 1.52,$ $p = 0.71, \sigma_1 = 0.00$

Notes.

The variable x is player A's quantity choice and the variable $\hat{x}$ is player A's cheap talk quantity. In the first row the fixed effect is a constant slope and in the other rows it is a dichotomous variable that has value 0 for the first treatment and 1 for the second treatment. Random effects are the subject id's. AR(5) correlation structure is included in the model. The estimated coefficient is the slope estimate, intercept estimates are not reported. Standard deviations of the random effects for intercept are denoted σ_1 and residual standard deviations as σ_0 .

Table 8. Robustness check for Table 4

Treatments included	Dependent variable	Rounds	Estimated coefficient (s.e)	Statistics
1. CT-PI	$x - \hat{x}$	1-10	-0.85 (0.47)	$t(126) = -1.82, \sigma_0 = 2.76, p = 0.07, \sigma_1 = 0.00$
		11-20	-0.79 (0.50)	$t(126) = -1.58, \sigma_0 = 1.59, p = 0.11, \sigma_1 = 1.84$
2. S-PI, CT-PI	A's payoff	1-10	12.53 (5.73)	$t(26) = 2.18, \sigma_0 = 22.10, p = 0.04, \sigma_1 = 12.96$
		11-20	10.69 (8.59)	$t(26) = 1.25, \sigma_0 = 16.66, p = 0.22, \sigma_1 = 22.18$
3. S-PI, CT-PI	B's payoff	1-10	12.04 (5.91)	$t(26) = 2.03, \sigma_0 = 21.39, p = 0.05, \sigma_1 = 12.04$
		11-20	14.79 (8.04)	$t(26) = 1.84, \sigma_0 = 15.41, p = 0.08, \sigma_1 = 20.76$
4. S-PI, CT-PI	Cooperation index	1-10	0.67 (0.29)	$t(26) = 2.32, \sigma_0 = 1.07, p = 0.03, \sigma_1 = 0.62$
		11-20	0.71 (0.43)	$t(26) = 1.64, \sigma_0 = 0.82, p = 0.11, \sigma_1 = 1.12$
5. CT, CT-PI	A's payoff	1-10	6.93 (4.35)	$t(26) = 1.59, \sigma_0 = 23.95, p = 0.12, \sigma_1 = 0.00$
		11-20	4.44 (5.57)	$t(26) = 0.80, \sigma_0 = 21.62, p = 0.43, \sigma_1 = 0.01$
6. CT, CT-PI	B's payoff	1-10	5.84 (5.31)	$t(26) = 1.10, \sigma_0 = 18.57, p = 0.28, \sigma_1 = 12.68$
		11-20	5.63 (6.08)	$t(26) = 0.93, \sigma_0 = 21.14, p = 0.36, \sigma_1 = 0.00$

Notes.

The variable x is player A's quantity choice and the variable $\hat{x}$ is player A's cheap talk quantity. In the first row the fixed effect is a constant slope and in the other rows it is a dichotomous variable that has value 0 for the first treatment and 1 for the second treatment. Random effects are the subject id's. AR(5) correlation structure is included in the model. The estimated coefficient is the slope estimate, intercept estimates are not reported. Standard deviations of the random effects for intercept are denoted σ_1 and residual standard deviations as σ_0 .