Collusion in Auctions with Structured Communication: an Experimental Study*

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Abstract

This paper is an experimental study of collusion in a repeated first price sealed bid auction with private values played by two bidders. Efficient collusion in this context requires truthful revelation of values. The bidders communicate with each other anonymously via a computer and permissible messages are limited to value messages (control sessions) or to value messages and bidding proposals (treatment sessions); sidepayments are allowed. Collusion was observed but it was not widespread. Instead, the most frequent bidding behavior corresponds to a Nash equilibrium of the one-shot game, in which collusion is absent and messages do not play any role. The introduction of bidding proposals did not affect average earnings but it led to more extreme values, hinting that communication can have negative as well as positive effects on cooperation.

1 Introduction

This paper is an experimental study of a repeated first price sealed bid auction with private values. Values are drawn independently each round and are private information. In each round of the game, players are allowed to send simultaneously messages about their current value. These messages are cheap talk and have no direct payoff consequences. Moreover, communication is *anonymous* (players do not know the identity of their opponent) and *structured* (the set of possible messages is limited). Players are allowed to stay away from bidding, while retaining the possibility to bid in later rounds; in this way the good can be allocated to the bidder with the highest value at the lowest possible bid. After the object is allocated, the winner can make a sidepayment to the loser; sidepayments can be used to provide incentives for a low value player to stay out from bidding in favor of a high value player.

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The repeated game has several equilibria. Some of them are noncooperative and some of them are collusive;[1] some of them are efficient (in the sense of allocative efficiency: the player with the higher value always gets the good) and some inefficient. The central question is one of equilibrium selection: will players manage to cooperate and if so, will they coordinate on the most profitable collusive equilibrium in which the value messages are informative?

The possibility of sending value messages is (together with the sidepayments) theoretically sufficient for the existence of an efficient collusive equilibrium. However, in the treatment sessions we add one additional cheap talk round: after hearing each other's value message, players can exchange nonbinding bidding proposals. We suggest that the proposals can help the players to coordinate on an efficient equilibrium: first, a player can use the bidding proposals to point the possibility of collusive bidding to the other player; second, messages can serve for the players to reassure each other that they will bid collusively; third, complying with the bidding proposals can be used to build trust in the truthfulness of value messages.

One may expect that if players can communicate before the game, Pareto efficient equilibria will be played. However, Aumann (1990) points out that communication will not always be helpful: a signal about intended play will not help if the player wants it to be believed regardless of what he really intends to do. A message the sender wants to be believed if and only if it is true is called *self-signalling* (see Farrell and Rabin, 1996). An announcement of collusive bidding is not self-signalling in our experiment.

Aumann's conjecture has been tested in one-shot games by Clark et al. (2001). They investigate the effect of preplay communication in two-player coordination games with two equilibria (one risk-dominant and other Pareto dominant). They compare a game in which messages are self-signalling to a game in which each player always prefers that the other chooses the action corresponding to the Pareto dominant equilibrium. The results support Aumann's conjecture: messages about intended play were more effective when they were self-signalling. On the other hand, communication did not always lead to playing the efficient Nash equilibrium even when messages were self-signalling: quite often players announced their intention to play the risk-dominant strategy. In a related experiment, Charness (2000) studies the effectiveness of cheap talk in a game where messages are not self-signalling and finds that messages are less effective when sent after players have chosen their action, supporting a conjecture of Farrell (1988). Duffy and Feltovich (2000) compare one-shot games in which players can observe the previous period choice of their opponent to one-shot games with cheap talk: when messages are not self-signalling, "actions speak louder than words".

There is relatively little known about communication in more complicated games (e.g., games with incomplete information), or about the interaction of cheap talk signalling of future actions and reputation building in repeated games. A one-shot game with incomplete information is studied by Palfrey and Rosenthal (1991). They implement a three-player public good game in which at least two players have to con-

[1] Collusion in auction models usually requires an infinitely repeated game (see McAffee and McMillan, 1992). However, we consider an auction in which collusion can be sustained for the initial rounds if the game is finitely repeated: players may punish defection by switching between different stage game Nash equilibria differing in desirability.

tribute for the public good to be produced and players have private information about their cost of contribution. Without communication, experiments give support to the play of a symmetric cut-point noncooperative equilibrium: a player contributes when his cost does not exceed the cutoff point. When players are allowed to send binary messages ("I intend to/not to spend") new equilibria with higher expected payoffs appear, though miscoordination can still occur. Players conditioned on messages but message behavior was erratic and efficiency gains low. Forsythe et al. (1999) study a two-person one-shot market where only sellers are informed about the quality of the good. Even though the introduction of cheap talk messages does not change the equilibrium set buyers were highly gullible, though they tended to learn after observing dishonesty in others.

Cooperation is easier to achieve in repeated games: cooperative outcomes that are not equilibria of the one-shot game may be equilibria of the repeated game and players may use current actions to signal future intentions. Palfrey and Rosenthal (1994) find that efficiency increases in the repeated public good game (due to increased cut-points) though players could have done better with rotation schemes. Clark and Sefton (2001) found different first round behavior in coordination games depending on whether they were one-shot or repeated.

What is the role of communication in repeated games? The introduction of messages of intention on future play in repeated games might be viewed as redundant: it does not expand the equilibrium set and players can learn more about senders' intentions from observing the history of play. However, intention messages can be used by the players to build (mis)trust.

Face-to-face communication was successful in the public good experiments by Isaac and Walker (1988) and Cason and Kahn (1999) and in the auction games studied by Isaac and Walker (1985), Artale (1997), and Kwasnica (2000). Since face-to-face communication eliminates anonymity and enlarges the message space, one would expect the communication medium to play an important role. Indeed, different levels of efficiency between face-to-face communication and electronic communication have been observed by Frohlich and Oppenheimer (1998) in a prisoner's dilemma game. Nevertheless, electronic communication has also been successful in experiments like the Hotelling games in Brown-Kruse et al. (1993) and Brown-Kruse and Schenk (2000); Brown-Kruse and Schenk also find that efficiency is easier to achieve in a version of the game with a restricted strategy set. Charness and Garoupa (2000) find that reputation effects often lead to truthful revelation of information. In contrast, in a repeated public good game Wilson and Sell (1997) find that allowing players to announce their intended contributions increases efficiency, but suppressing all information (messages and history of play) leads to even better outcomes. Cheap talk was also unsuccessful in the repeated oligopoly studied by Cason (1995).

In most of the experiments dealing with repeated games communication was face-to-face or electronic but freeform. Communication in our experiment was highly structured but the message space was relatively rich: players send value messages directly and (in the treatment sessions) the bidding proposals include a bid for both players. We observed an overall low proportion of players reporting values truthfully and coordinating on the best collusive equilibrium, despite the possibility of truthtelling being incentive compatible. Average earnings were the same in treatment sessions and in control sessions. There was high variability across sessions, especially across treatment sessions, suggesting that communication can have negative as well as positive effects. From the questionnaire data we infer that the lack of widespread collusion cannot be fully explained by cognitive limitations of our subjects: they often described efficient collusive agreements as a desirable mode of bidding behavior. In practice, however, they behaved regularly in a very myopic way: trying to deceive their partners and not sticking to the bidding proposals they made.

The rest of the paper is organized as follows. In section 2, we present the game. In section 3, we discuss the experiment design and in session 4 we present the data collected in the experiment. Section 5 concludes.

2 The game

The stage game is a first price sealed bid auction with private values, limited communication between the bidders and sidepayments. This stage game is repeated for a finite number of rounds. The game is played by two bidders, and we will assume in this section that they are rational, risk neutral and care only about their own material payoffs.

In each round, a unit of a good is put for sale. The value of the good for bidder i, v_i, is his private information and can be either high (H) or low (L) with probabilities p_H and $p_L = 1 - p_H$ respectively. Values are independently and identically distributed across players and rounds.

After the players learn their values for the current round, they simultaneously send *value messages* $m_i \in \{H, L\}$; $i = 1, 2$. In the treatment sessions, after receiving each other's value message each player i sends a *bidding proposal* $b_i = (b_i^i, b_i^j)$ where b_i^i represents the bid a player proposes for himself and b_i^j the bid he proposes for the other player for the current auction round; the set of admissible proposals is $A \times A$, where $A = \{H, L, r, N\}$ (see below). Both the value messages and bidding proposals are sent via computer. This structured communication removes the uncontrolled psychological aspects of face-to-face communication.

After learning each other's bidding proposals, the players simultaneously submit bids. We denote the bid of player i by B_i. The set of possible bids is restricted to the following: N (representing no bid or a bid of zero), r (representing the reservation price of the seller, $0 < r < L$), L and H (the latter only allowed for high-value players). Thus, in designing the game we enforce a "no loss" condition, i.e., players are not allowed to bid above their value.

The good is assigned to the bidder with the highest bid, provided that the highest bid is at least r. If both players submit the same bid, each player gets the good with probability $\frac{1}{2}$.

After bidding, the winner is allowed to send a sidepayment s to the other bidder, up to the amount of payoff earned in the current round. The net payoff for the winner is winner's value minus winner's bid minus sidepayments. The payoff to the loser is the sidepayment received from the winner.

We have assumed a discrete type space and a discrete strategy space. Both of these assumptions are made primarily for experimental reasons, in order to make the game transparent to the subjects. Furthermore, the discrete strategy space plays a role in supporting collusion as an equilibrium of the finitely repeated game.

In our experiment we used the following parameters: $H = 20$, $L = 10$, $r = 2$ and $p_H = p_L = \frac{1}{2}$.

2.1 Nash equilibria of the stage game

An important assumption satisfied by our parameters is

$$L < \frac{1}{2}(H + r) \tag{1}$$

Given this assumption, there are two types of Nash equilibria of the stage game. In the first type, $B_i(H) = L$ and $B_i(L) = r$ for $i = 1, 2$; in the second type $B_i(H) = B_i(L) = L$ for $i = 1, 2$. In both types of equilibria sidepayments are zero; value messages and bidding proposals are not restricted.[2] We will denote the first type of equilibrium by e^u (undominated) and the second by e^w (since it involves a weakly dominated strategy for type L) Equilibrium e^u Pareto dominates equilibrium e^w. Both equilibria are Pareto dominated by the bidding strategies $B_i(H) = B_i(L) = r$ ($i = 1, 2$), but assumption (1) precludes these strategies being an equilibrium.

2.2 Collusion in the repeated game

Any strategies such that the players play a Nash equilibrium of the one-shot game at each round constitute an equilibrium of the finitely repeated game. We refer to this strategy combinations as *noncooperative*.

Our auction game is similar to the prisoner's dilemma in that both players would do better (in expected terms) if they could commit themselves to cooperate with each other (for example, by always bidding the reservation price). However, there is an important difference: the auction stage game has two types of Nash equilibria, e^u and e^w, one of which is better than the other for the players.[3] A "bad" equilibrium can then be used to punish defection and cooperation can be temporarily sustained, even if the game is only finitely repeated. We will briefly discuss two types of collusive strategies: *simple collusion* and *efficient collusion* (the details can be found in the appendix).

2.2.1 Simple collusion

In the cooperative phase of this strategy, players bid the reservation price regardless of their value. If a defection occurs, they revert to the dominated Nash equilibrium of the stage game, i.e., they bid L regardless of their value. This sort of collusion does not require the exchange of any messages.

2.2.2 Efficient collusion

When value messages are possible, players can improve (in expected terms) over the simple collusion strategy in the following way. Each player reveals his value truthfully;

[2] In particular, truthful revelation of values is an equilibrium since players would have no incentive to change their bid if they knew the other player's value.

[3] Here the discrete bidding space plays a role. If players could make any bid, the only equilibrium would be type L bidding L and type H playing a mixed strategy (cf. Athey and Bagwell, 1999).

if the players have different values, the low value stays out and the high value bids r; if they have the same value, both players bid r. Observable defection from these strategies is punished by reverting to a "bad" equilibrium of the stage game.

Since the actual values of the players are never revealed, these bidding strategies can only be part of an equilibrium if there is a reward for the players who reveal a low value and stay out from bidding. A possible reward is a sidepayment from the winner to the loser (to sustain cooperation, it is sufficient that sidepayments are given after the players have announced different values and the low value player has stayed out, but they could also be given in the case of equal announced values). Notice that bidding proposals are not necessary to sustain efficient collusion, since all the information is already in the value messages.

3 The experiment design

Altogether 110 undergraduate students of international business, economics, and leisure studies of Tilburg University participated in 9 experimental sessions conducted in May 2000, February 2001 and May 2001. 46 subjects participated in four control sessions (denoted C1 to C4) without the bidding proposals stage, and 64 subjects participated in five treatment sessions (denoted T1 to T5) with the bidding proposals stage.

In each session, one cohort of 10 to 16 players was matched to play the corresponding repeated game five times, each time to a different anonymous opponent. One game lasted 10 to 15 rounds. After the 10^{th} round, the continuation of the game was determined by a coin flip. We terminated the game as soon as heads occurred, and also if heads did not occur up to the 15^{th} round. Players were informed about the termination rule in advance. At the end of the experiment, two games out of five were drawn at random, and participants were privately paid all their earnings from these two games, plus a 5 NLG participation fee. During the experiment players were shown their earnings in points, and 1 point was worth 25 cents (since the subjects were paid for two games out of five, the expected value of 1 point was 10 cents). Average earnings for the 1.5 hour experiment were around 30 NLG.

In all sessions, the participants were seated in isolated computer cubicles, and any communication besides the computer messages was prohibited. The experiment was fully computerized, with instructions read aloud. After the experiment, subjects answered a questionnaire designed to capture the game understanding, intentions and trust attitudes of the players.[4]

3.1 Hypotheses

We investigate two main hypotheses: on equilibrium selection in the repeated game, and on the role of bidding proposals in the equilibrium selection problem.

We have shown above that the game has several types of equilibria, differing in the role of value messages and sidepayments, and on the conditioning on the history of play. Efficient collusion requires truthful revelation of private information up to a

[4]Instructions and questionnaire can be found at Vyrastekova's homepage (currently http://cwis.kub.nl/~few5/center/phd_stud/vyrastek/).

certain maximal round of game repetition (up to round 9 for the lowest sidepayment of $\frac{L-r}{2}$, up to round 6 for the highest sidepayment of $\frac{H-r}{2}$), believing the received private information signals (i.e. trust) and a reward for staying out from bidding in the form of a sidepayment. Players have to condition behavior on the observed history of the game (bidding, private information signals, and sidepayments) and switch to a punishment phase after any observable deviation. Alternatively, simple collusion gives lower payoffs to the players than efficient collusion (though it practically gives the same payoff as the strategy with efficient collusion up to round 6, corresponding to the highest possible value of the sidepayment), but behavior does not have to be conditioned on the (unverifiable) private information signals, and sidepayments need not be used. These equilibria condition only on the history of the observed bidding behavior. And, finally, the game has low-payoff equilibria (noncooperative equilibria), repetition of the stage game equilibria; in their simplest form players do not condition their behavior on either private information signals or on the history of the game.

The strategies supporting the equilibria with higher payoffs are not only more complex but also involve the risk of being exploited by the other player; this risk is greater when trying to play efficient collusion. Thus, if players are constrained by complexity and risk considerations when selecting the equilibrium to play, we hypothesize that they will be more inclined to play noncooperative equilibria rather than simple collusion, and more inclined to play simple collusion rather than efficient collusion. This is our *selection hypothesis*.

The second hypothesis concerns the role of cheap talk bidding proposals in the repeated game. These proposals, while not allowing players to submit a full strategy for the repeated game, allow them to signal immediate intentions for the bidding stage, thus potentially helping them to coordinate on the more efficient equilibria. In particular, we allow two-way (simultaneous) messages in order to give players the necessary tool for mutual assurance of intentions.

Under our *communication hypothesis*, players will be more likely to coordinate on efficient collusion in sessions with bidding proposals. As a consequence, the average payoff in the control sessions would be lower than the average payoff in the treatment sessions.

The game we implement is quite complex, and the bidding proposals might serve as a teaching tool, when one player in the pair is not aware of the collusive bidding opportunities. For this purpose, admittedly, the communication we allow is very scarce. Under the *teaching hypothesis*, players in the cheap talk sessions will submit bids coinciding with the collusive bidding proposal in the initial rounds of the game even if the current bidding proposal was not coordinated, i.e., the players did not agree on how to play the game. The players reap the gains from teaching in the repeated interaction with the same player in one game.

4 Results

In the analysis that follows, we always use for comparability reasons the data from the first 10 rounds of every repeated game. The results include some statistical tests. It should be noticed, nevertheless, that except in the cases where we take each repeated game as an observation and use only game 1 data, the observations are not independent.

game	*efco*	*sc*	*T1*	*T2*	*T3*	*T4*	*T5*	*C1*	*C2*	*C3*	*C4*
1	1.67	1.35	0.69	0.77	0.74	0.99	0.89	0.59	0.78	0.73	1.00
2	1.51	1.33	0.63	1.08	0.88	1.18	0.91	0.86	1.03	0.93	1.19
3	1.65	1.38	1.02	1.20	0.88	1.35	1.12	0.96	1.01	1.16	1.34
4	1.52	1.30	0.99	1.18	0.85	1.18	1.03	0.96	0.97	0.93	1.30
5	1.65	1.53	0.93	1.09	0.97	1.34	1.23	1.01	0.98	0.99	1.29

Table 1: Average earnings per session and game

4.1 Average earnings

Before analyzing players' behavior in detail, we first have a look at a rough indicator of players' ability to coordinate on efficient collusive equilibria, the average earnings.

Average earnings in control sessions C1 to C4 (without bidding proposals) and treatment sessions T1 to T5 (with bidding proposals) are presented in table 1. We use as a benchmark the expected payoff of the stage game Nash equilibrium in undominated strategies (e^u) played by both players in all 10 rounds. In column "efco" of the table we present the payoff corresponding to the most profitable equilibrium (efficient collusion till round 9 followed by simple collusion at round 10). Column "sc" refers to simple collusion played in all 10 rounds. 1.35 in that column means that by playing simple collusion in all rounds players could earn 1.35 times the benchmark payoff; entries above 1 imply some collusive efforts, and entries below 1 imply the play of dominated strategies. Expected payoffs from a given strategy combination differ across games because of the different frequencies of high and low values, but are the same for all sessions since we generated the values randomly in advance.

Players were (partially) able to collude only in some sessions (T2, T4, T5 and C4). Three of these are sessions with bidding proposals, but the other two treatment sessions are similar to the control sessions C1 to C3. Earnings are highly variable within the same session type, and the differences, if any, between sessions with and without bidding proposals cannot be detected at the aggregate level.

Result 1: Effect of bidding proposals on payoffs There is no difference between average earnings in control and treatment sessions.

A Mann-Whitney U test comparing individual players' payoffs in control and treatment sessions does not give support for rejecting the null hypothesis that players achieve the same median payoffs in both session types.[5]

Result 2: Variability of earnings The variability of earnings was higher in the treatment sessions.

An F-test using each pair as an observation rejects the hypothesis of equal variance at the 1% significance level. This seems to indicate the presence of both positive and negative effects of introducing bidding proposals. In sessions where proposals were mostly collusive and complied with, bidding proposals were helpful; in sessions where

[5] Using data from the first game and taking each repeated game as observation, the two-tailed p value is 0.762. Using data from all five games, $p = 0.809$.

collusive proposals were often followed by noncooperative bidding, this behavior was seen as deceitful and made players give up any attempts to cooperate (cf section 4.3).

Pooling data from all sessions, do players on average succeed in achieving payoffs significantly greater than 1? Only in the last three games.[6] Average payoffs in the last three games are around 1.11, somewhat above the stage game Nash equilibrium but very far from the maximal equilibrium payoffs.

Result 3: Efficiency Players' ability to achieve payoffs above the repetition of the stage game Nash equilibrium in undominated strategies is not widespread. After players gain experience with the game, average payoffs are slightly higher than 1, indicating some collusive bidding.

Can the rarity of collusive bidding be due to cognitive limitations of the subjects? In the post-experiment questionnaires, players were asked to advise an agent who will bid in their name in an auction. Round one scenario, for which we elicited this advice, was such that the agent's own value was 10, he had sent a message of 10 and received a message of 20. In this scenario, around half of the players both in control (52%) and in treatment sessions (48%) advised the agent to submit a bidding proposal according to which he would stay away from bidding. Among them, 91% in control and 73% in treatment sessions indicated that the agent should comply with the bidding proposal.

Observation: Efficient collusion as a desirable mode of behavior One third of the subjects in treatment sessions and one half of the subjects in control sessions recommended the efficient collusion strategy in the questionnaire.

These numbers provide a lower bound for the fraction of the subjects who eventually understood the payoff dominance of efficient collusion; of course, other players may have realized the payoff dominance of efficient collusion while still preferring to recommend the "safer" noncooperative strategy. In particular, the subjects in treatment sessions, who had actually experienced bidding proposals (and defections from them), were less enthusiastic in the questionnaire about trying to implement efficient collusion.

4.2 Bidding behavior

Figure 1 shows the bid frequency for each player type across games. Treatment and control sessions have very similar frequencies. Bidding 0 by low value players is slightly more frequent in treatment sessions, whereas bidding 2 by high value types is slightly more frequent in control sessions. This suggests that collusive efforts in control sessions were more concentrated in simple collusion.

The bid frequency does not alter dramatically across games. As players gain experience, bidding becomes more cooperative and the proportion of players bidding own value is reduced (and disappears completely for high value players). For low value

[6] At a 5% significance level using a t-test. The t-values in the games 1 to 5 are, in sequence, $-4.289, -0.173, 3.164, 1.848, 2.493$. Notice that in the first game payoffs are significantly *lower* than 1.

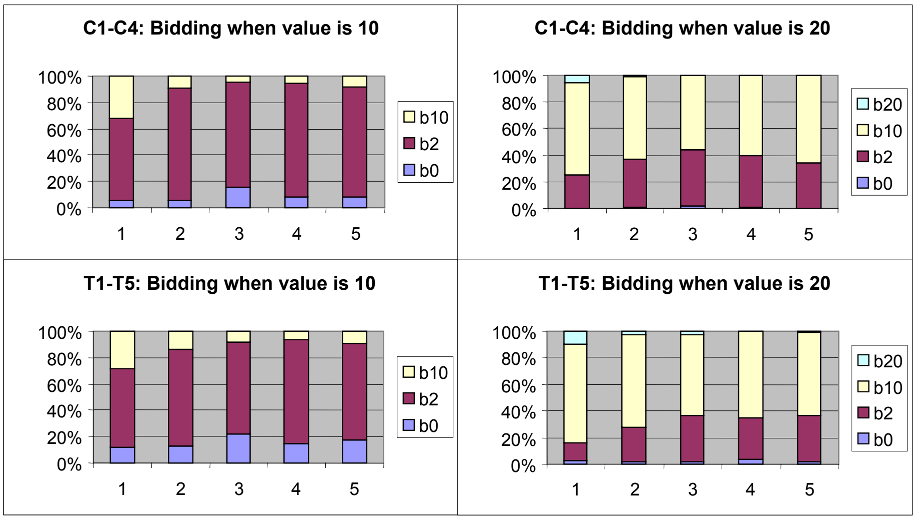

Figure 1: Bid frequency in sessions C1-C4 and T1-T5

players, bidding own value does not completely disappear, and is consistent with the punishment phase of cooperative strategies.[7]

Observation: bidding behavior The most frequent bidding behavior corresponds to the undominated Nash equilibrium of the one-shot game.

The relation of bidding behavior to bidding proposals and value messages is discussed in the next subsections.

4.3 Bidding proposals

4.3.1 Round 1 data

Looking only at round 1 data across all games with bidding proposals, we are interested in the fraction of bidders who made proposals consistent with the collusive strategies we have described: players who propose $(2, 2)$ when both players have announced the same value, and either $(2, 2)$ or the low value player staying out and the high value player bidding 2 when the two players have announced different values. 38% of all proposals were collusive in this sense; of them, 44% were coordinated proposals. Compliance with the proposals was relatively low: 66% of all collusive proposals and 61% of coordinated collusive proposals were complied with. This defection rate is rather high for a repeated game, and we expect it to affect the chances of sustaining cooperation in further rounds.

As we saw in section 4.1, collusion took place only in three of the five treatment sessions (T2, T4 and T5). One may wonder whether this was due to a higher frequency

[7]Bidding own value was correlated with higher bids and lower sidepayments by the other player in the previous round. Nevertheless, some of the bids occurred in the first round of the game (even in latter games), so they cannot be associated with punishment strategies.

	T1	*T2*	*T3*	*T4*	*T5*
proportion of collusive proposals	26%	40%	32%	49%	38%
rate of compliance with collusive proposals	54%	63%	50%	82%	61%

Table 2: Bidding proposals and compliance in round 1

of collusive proposals or to a higher rate of compliance with collusive proposals. It turns out that both effects were present (see table 2).

Observation: Trying to collude At round 1, attempts to collude were not widespread, and the defection rate was relatively high. The frequency of collusive proposals and the rate of compliance with them differed widely across sessions.

It is interesting to compare round 1 bidding behavior in sessions with bidding proposals to round 1 bidding behavior in sessions without bidding proposals. Do players initiate collusion more often in treatment sessions? Players with value 10 who sent a message of 10 and received a message of 20 stayed out more often in treatment sessions (43%) than in control sessions (19%). Differences are smaller in other cases: players with value 20 who sent a message of 20 and received a message of 10 bid 2 41% of the time in treatment sessions and 49% of the time in control sessions; when the message received was 20 the proportions were 42% and 30%.

Observation: Effect of the treatment variable on actual bidding Games with bidding proposals started with a higher inclination towards efficient collusion on the part of low value players.

Nevertheless, we have seen that average earnings were almost identical in both types of sessions. One can hypothesize that the high proportion of defected proposals creates a negative effect that compensates the positive effect of the bidding proposals. An alternative explanation is that positive sidepayments for bidders staying away from bidding were more common in control sessions (75% of the bidders staying out got a positive sidepayment) than in treatment sessions (62%).

4.3.2 Overall data

Looking at table 3, we see that proposals that were cooperative and coordinated were rare, but complied with more often than other proposals.[8]

Compliance with own bid proposal was higher when bidders reported their value truthfully: in 68% of cases when value was reported truthfully, the bidder submitted a bid as in his proposal; the rate of compliance was only 28% when value was misrepresented. This is partly due to the fact that truthtelling and value misrepresenting cases are connected to different proposals made, in particular, value misrepresenting players were more likely to make "unreasonable" proposals (like bidding 20, or

[8]Noncooperative but coordinated proposals that were not complied with were often (coordinated) "babbling": one third of them were clearly "not serious" (involving a bid of 20 by one of the players, or a bid of zero by both, or a bid of 0 for one player and 10 for the other) and one half involved one of the players staying out when he didn't announce a lower value than the opponent. In most of these cases *both* players played the undominated stage Nash equilibrium, supporting the idea that proposals were just babbling.

Taxonomy of proposals	*cooperative*	*noncooperative*
coordinated	21% (74%)	9% (56%)
not coordinated	21% (57%)	49% (40%)

Table 3: Taxonomy of proposals (rate of compliance between brackets)

After (10,10)	*prop. (2,2)*	*bid 2 after prop. (2,2)*	*bid 2 after both prop. (2,2)*
truthtellers	41%	96%	99%
liars	34%	10%	8%

Table 4: Collusive proposals and compliance rates after messages (10,10)

both players bidding 0); these proposals seem to indicate that players do not want to communicate with the other bidder.

Tables 4, 5, 6, 7, 8 and 9 focus on whether players proposed (and complied with) collusive bidding. Each table refers to a different pair of messages and a different collusive strategy.

In table 4 it is interesting to see that only 41% of truthtellers propose $(2, 2)$ (which is both the undominated Nash equilibrium and the ”nondiscriminatory” collusive outcome); another interesting point is that the liars (that is, the players that really had value 20) almost never complied with their proposals: thus, announcing value 10 and proposing to bid 2 was done to fool the other player.

Players with value 10 who revealed their value truthfully and received a message of 20 were much more likely to propose the efficient collusive strategy (44%, in table 5) than the simple collusive strategy (only 11%, in table 6); both proposals were serious in the sense that they were very often complied with. On the other hand, truthtellers with value 20 who got a message of 10 were not only unlikely to propose simple collusion (only 8% of the time) but also unlikely to implement their proposals. Other types of proposals were taken more seriously, as tables 7 and 9 show.

Observation: bidding proposals and compliance with them Proposals that were both cooperative and coordinated were rare, but they were implemented more often than other proposals. Efficient collusion was more often proposed than simple collusion, and more often implemented.

There is some evidence for teaching (or signalling) effects. Let’s consider players with value 10 who tell the truth, receive a value message of 20, propose $(0, 2)$, and receive a different proposal from the other player. Should they bid 0 after all? 52% of the players did it. The reason could be to ”teach” the other player or to signal one’s willingness to cooperate. If this is the case, the teaching effort should decrease over time. Indeed, the rate of compliance is 62% in the first five rounds versus 39%

After (10,20)	*prop. (0,2)*	*bid 0 after prop. (0,2)*	*bid 0 after both prop. (0,2)*
truthtellers	44%	79%	91%
liars	21%	11%	23%

Table 5: Proposals of efficient collusion and compliance rates after messages (10,20)

After (10,20)	*prop. (2,2)*	*bid 2 after prop. (2,2)*	*bid 2 after both prop. (2,2)*
truthtellers	11%	91%	100%
liars	16%	17%	33%

Table 6: Proposals of simple collusion and compliance rates after messages (10,20)

After (20,10)	*prop. (2,0)*	*bid 2 after prop. (2,0)*	*bid 2 after both prop. (2,0)*
truthtellers	55%	74%	92%
liars	21%	85%	83%

Table 7: Proposals of efficient collusion and compliance rates after messages (20,10)

in the last five rounds. Instead, if we look at *all* uncoordinated proposals the rates of compliance are 49% in the first five rounds versus 43% in the last five rounds.

4.4 Value messages

Players were consistently more likely to misrepresent their value when it was high, see Table 10. Due to this fact, in all sessions the value message 20 is more informative. Reporting a lower value might have been connected with trying to induce the other player to bid 2 and win the auction by bidding 10: indeed, players with value 20 were more likely to bid 10 after reporting a value of 10 (see figure 2). We do not find any treatment effect on value messages when looking at the fraction of truthful reports.[9]

Players bid differently depending on whether they are sending truthful messages. After sending truthful messages, players with value 10 stay out more often and players with value 20 bid 2 more often; truthtellers are also less likely to bid own value (see figure 2; this figure pools data from all nine sessions, ignoring possible dynamic effects and treatment effects).

Players also respond to the value message of the other bidder in a different way depending on whether they themselves have told the truth. When we aggregate data from all sessions and games, we observe that truthtelling players with low value are much more likely to bid 0 after receiving a value message of 20 (see figure 3). In all other cases (players with high value and players with low value who send a value message of 20) bids are not conditioned on the received message. This is what one would expect: both collusive strategies (efficient collusion and simple collusion) and the undominated Nash equilibrium of the one-shot game prescribe the same bid for high-value players regardless of the message of the other player.

[9] Remember that we used in all sessions the same randomly pre-generated sequence of valuations, so that the data are directly comparable. Using a two-tailed Mann-Whitney U test for all games, the p-value is 0.327; if considering only game 1, $p = 0.966$.

After (20,10)	*prop. (2,2)*	*bid 2 after prop. (2,2)*	*bid 2 after both prop. (2,2)*
truthtellers	8%	24%	20%
liars	13%	75%	80%

Table 8: Proposals of simple collusion and compliance rates after messages (20,10)

After (20,20)	*prop. (2,2)*	*bid 2 after prop. (2,2)*	*bid 2 after both prop. (2,2)*
truthtellers	29%	79%	90%
liars	14%	59%	100%

Table 9: Proposals of collusion and compliance rates after messages (20,20)

Session	*T1*	*T2*	*T3*	*T4*	*T5*	*C1*	*C2*	*C3*	*C4*
v=10 and m=20	37%	29%	25%	15%	27%	23%	15%	12%	13%
v=20 and m=10	52%	52%	64%	41%	39%	40%	50%	65%	51%

Table 10: Value messages

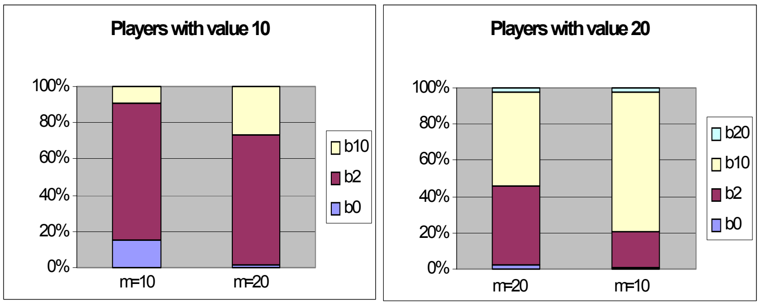

Figure 2: Bidding behavior depending on own value message

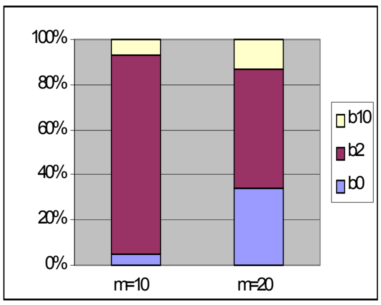

Figure 3: Bidding behavior by low-value truthtellers depending on received value message

Average sidepayments	*in control (C1 to C4)*	*in treatment (T1 to T5)*
overall	1.49 (15%)	1.53 (16%)
given that the loser bids 0	5.12 (37%)	4.97 (36%)
by truthtellers	2.11 (22%)	2.54 (24%)

Table 11: Average sidepayments (with sidepayments as a fraction of earnings between brackets)

	other bids 0	*other says 20 and bids 2*	*other says 10 and bids 2*
treatment	7.30 (7.31)	7.16 (7.00)	4.24 (3.75)
control	8.07 (7.65)	8.21 (7.86)	4.50 (4.00)

Table 12: Average sidepayments by high value truthtellers bidding collusively (average over last three rounds between brackets)

Observation: value messages and bidding Players bid more cooperatively when they are sending truthful value messages. Only low value players sending truthful messages condition their bidding behavior on the other player's value message.

4.5 Sidepayments

If we look at very aggregate data, control and treatment sessions had very similar average sidepayments (see table 11). We see that players who reported value truthfully gave higher sidepayments, and that sidepayments were higher when the other player bids 0. This is partly due to higher earnings in these cases; to control for this, the table also includes the fraction total sidepayments/total (gross) earnings.

Concentrating on the case of players with value 20 who revealed their value truthfully and won with a bid of 2 we see that higher sidepayments are connected with efficient collusion as we would expect. The table also reflects a slight decline of average sidepayments over time, though not as sharp as the theory would predict.

5 Conclusion

In our repeated game experiment, players seemed to coordinate most often on the repetition of the stage game Nash equilibrium in undominated strategies. On the other hand, efficient collusion was more frequent than simple collusion, so that neither complexity nor payoff dominance alone explain the equilibrium selection by the players.

A possible explanation of the low frequency of collusion is that the gains from selecting an efficient but risky equilibrium involving complicated strategies were too small. A possible extension of the present study would be to increase the incentives to cooperate by implementing longer supergames and/or changing the parameters, or alternatively to enlarge the message space. One could also study the effects of simplifying the game even further by making the values public information.

References

Artale, A. (1997). *Rings in Auctions: An Experimental Approach.* Berlin: Springer Verlag.

Athey, S., and K. Bagwell. (1999). "Optimal Collusion under Private Information," forthcoming in *RAND Journal of Economics.*

Aumann, R. J. (1990). "Nash Equilibria Are Not Self-Enforcing," in *Economic Decision Making: Games, Econometrics and Optimisation* (ed. by J. J. Gabszewicz, J. F. Richard, and L. A. Wosley), 201-206. Amsterdam: Elsevier.

Brown Kruse, J., Cronshaw, M. B., and D. J. Schenk. (1993). "Theory and Experiments on Spatial Competition," *Economic Inquiry* 31, 139-165.

Brown Kruse, J., and D. J. Schenk. (2000). "Location, Cooperation and Communication: An Experimental Examination," *International Journal of Industrial Organization* 18, 59-80.

Cason, T. N. (1995). "Cheap Talk Price Signalling in Laboratory Markets," *Information Economics and Policy* 7, 183-204.

Cason, T. N., and F. U. Khan. (1999). "A Laboratory Study of Voluntary Public Goods Provision with Imperfect Monitoring and Communication," *Journal of Development Economics* 58, 533-552.

Charness, G. (2000). "Self-Serving Cheap Talk: A Test of Aumann's Conjecture," *Games and Economic Behavior* 33, 177-194.

Charness, G., and N. Garoupa. (2000). "Reputation, Honesty, and Efficiency with Insider Information: An Experiment," *Journal of Economics and Management Strategy* 9, 425-451.

Clark, K., and M. Sefton. (2001). "Repetition and Signalling: Experimental Evidence From Games with Efficient Equilibria," *Economics Letters* 70, 357-362.

Clark, K., Kay, S., and M. Sefton. (2001). "When are Nash Equilibria Self-Enforcing? An Experimental Analysis," *International Journal of Game Theory* 29, 495-515.

Duffy, J., and N. Feltovich. (2000). "Do Actions Speak Louder Than Words? An Experimental Comparison of Observation and Cheap Talk," forthcoming in *Games and Economic Behavior.*

Farrell, J. (1988). "Communication, Coordination and Nash Equilibrium," *Economics Letters* 27, 209-214.

Farrel, J., and M. Rabin. (1996). "Cheap Talk," *Journal of Economic Perspectives* 10, 103-118.

Forsythe, R., Lundholm, R., and T. Rietz. (1999). "Cheap Talk, Fraud, and Adverse Selection in Financial Markets: Some Experimental Evidence," *Review of Financial Studies* 12, 481-518.

Frohlich, N., and J. Oppenheimer. (1998). "Some Consequences of e-Mail vs. Face-to-Face Communication in Experiment," *Journal of Economic Behavior and Organization* 35, 389-403.

Isaac, R. M., and J. M. Walker. (1985). "Information and Conspiracy in Sealed Bid Auctions," *Journal of Economic Behavior and Organization* 6, 139-159.

Isaac, R. M., and J. M. Walker. (1988). "Communication and Free-Riding Behavior: the Voluntary Contributions Mechanism," *Economic Inquiry* 26, 99-126.

Kwasnica, T. (2000). "Collusion in Multiple Object Simultaneous Auctions: Theory and Experiments," *Journal of Economic Behavior and Organization* 42, 323-346.

McAfee, R. P., and J. McMillan. (1992). "Bidding Rings," *American Economic Review* 82, 579-599.

Palfrey, T. R., and H. Rosenthal. (1991). "Testing for Effects of Cheap Talk in Public Goods Game with Private Information," *Games and Economic Behavior* 3, 183-220.

Palfrey, T. R., and H. Rosenthal. (1994). "Repeated Play, Cooperation and Coordination: An Experimental Study," *Review of Economic Studies* 61, 545-565.

Wilson, R. K., and J. Sell. (1997). " 'Liar, Liar...', Cheap Talk and Reputation in Repeated Public Good Settings," *Journal of Conflict Resolution* 41, 695-717.

6 Appendix: Collusion in equilibrium

6.1 Collusive strategies

Efficient collusion

Suppose the stage game is repeated T times. The efficient collusion strategy has the following three phases:

Phase 1 (cooperative phase)

This phase lasts from period 1 to period $\bar{t} \in (1, T)$. During this phase players send truthful messages about their value ($m_i^t = v_i^t$ for all $t \in [1, \bar{t}]$) and collude efficiently (if $m_1^t = m_2^t$, both players bid r; otherwise the high-value player bids r and the low-value player stays out). Finally, the winner sends a sidepayment s.

Phase 2 (noncooperative phase)

This phase lasts from period $\bar{t} + 1$ till period T. During this phase players send arbitrary messages, bid according to the undominated Nash equilibrium of the stage game ($B_i^t(L) = r$ and $B_i^t(H) = L$) and send no sidepayments.

Phase 3 (punishment phase)

This phase is reached if at least one of the players deviates observably from strategy σ (that is, a player's bidding or sidepayments are not as prescribed). During this phase players send arbitrary messages, bid according to the dominated Nash equilibrium of the stage game ($B_i^t(L) = B_i^t(H) = L$) and send no sidepayments.

Simple collusion

This strategy differs from efficient collusion only in phase 1.

Phase 1 (cooperative phase)

Players bid r regardless of value.

We now turn to the question of under which conditions collusion is an equilibrium. Since players play equilibria of the stage game in phases 2 and 3, we only have to check whether the cooperative phase can be sustained.

6.2 Efficient collusion as an equilibrium strategy

The cooperative phase of this strategy consists of three elements: messages, bidding and sidepayments. We consider the incentives to deviate at each of the three moments in turn. It suffices to check that a deviation is not profitable at time $\bar{t}$, since this is the time at which punishment is smallest.

6.2.1 Incentives to tell the truth

Since the actual values of the players are never revealed, players may send untruthful messages without triggering any punishment. Thus, the value of s has to be set in such a way that players find it profitable to tell the truth.

If a player has value L and reports value L, he expects a payoff of $\frac{L-r}{2}$ if the other players says L and s if the other player says H. If on the other hand he reports H, he expects $L - r - s$ (if the other player reports L) or $\frac{1}{2}(L - r)$ (if the other player reports H). Thus, he will tell the truth if $p_L \frac{L-r}{2} + p_H s \geq (L - r - s)p_L + p_H \frac{L-r}{2}$ or $s \geq \frac{L-r}{2}$. Analogously, in order for a high value to be reported truthfully, $s \leq \frac{H-r}{2}$.

Thus, players have an incentive to tell the truth if

$$\frac{L-r}{2} \leq s \leq \frac{H-r}{2}. \tag{2}$$

6.2.2 Incentives to bid low

Players with a high value Consider the possibility of a deviation of the high type to bid L rather than r (this makes sense only when the opponent has announced a high value). If he does so, he wins the auction for sure and gets $H - L$. However, this deviation triggers the punishment phase and his expected payoff is only $p_H \frac{H-L}{2}$ in each subsequent period. If instead he bids r, he expects $\frac{H-r}{2}$ in this period and $(p_H p_L(H - L) + p_H^2 \frac{1}{2}(H - L) + p_L^2 \frac{1}{2}(L - r))$ in each of the remaining periods. Thus, in order for bidding r to be an equilibrium for a high-value player we need

$$H - L - \frac{H-r}{2} \leq (T - \bar{t})\ p_L \left[p_L \frac{1}{2}(L - r) + p_H \frac{1}{2}(H - L) \right]. \tag{3}$$

Players with a low value Given that sidepayments are at least $\frac{L-r}{2}$, the low value player has an incentive to stay out when prescribed. If he instead bids r, his expected payoff is no larger than the sidepayment and moreover he triggers the punishment phase.

6.2.3 Incentives to give sidepayments

Does the winner have an incentive to give sidepayment s? If instead he gives zero, his gain is s and his loss is as in the previous section. Thus, in order for the winner to have an incentive to give a sidepayment, we need

$$s \leq (T - \bar{t})\ p_L \left[p_L \frac{1}{2}(L - r) + p_H \frac{1}{2}(H - L) \right]. \tag{4}$$

Clearly, this inequality is more likely to be satisfied the lower the value of s. Notice also that incentives to give sidepayments do not depend on the value of the player.

There are also equilibria in which players achieve efficient collusion without sidepayments in the first rounds of the game: a low value player will have an incentive to stay out if by doing so he is more likely to win in future rounds (the increase in the probability of winning in future rounds is an implicit sidepayment, cf Athey and Bagwell, 1999). This type of collusion involves more complex and less profitable strategies than collusion with sidepayments; moreover, the risk of being exploited is higher: since the reward for staying out does not take place in the current round cheating is not immediately discovered. We did not observe this type of collusion in our experiment.

6.3 Simple collusion as an equilibrium strategy

For the low value player, bidding r is automatically an equilibrium since it is a weakly dominant strategy. For a high value player, inequality (3) should be satisfied.

6.4 Collusion as an equilibrium strategy in our experiment

For the parameters we used, equation (4) implies equation (3). If we take into account that in our experiment the stage game is repeated $T = 10$ times for sure and after this it is repeated with probability $\delta = \frac{1}{2}$ up to a total number of 15 rounds, we obtain the following inequality

$$s \leq p_L \left[p_L \frac{1}{2}(L - r) + p_H \frac{1}{2}(H - L) \right] \left[T - \bar{t} + \frac{\delta(1 - \delta^5)}{1 - \delta} \right].$$

Efficient collusion can then be sustained up to round 9 for the lowest possible value of the sidepayment ($\frac{L-r}{2} = 4$) and up to round 6 for the highest possible value of the sidepayment ($\frac{H-r}{2} = 9$). Thus, the most efficient equilibrium corresponds to the lowest value of the sidepayment.

As for simple collusion, we only have to check for incentives to bid low and thus we only need

$$H - L - \frac{H - r}{2} \leq p_L \left[p_L \frac{1}{2}(L - r) + p_H \frac{1}{2}(H - L) \right] \left[T - \bar{t} + \frac{\delta(1 - \delta^5)}{1 - \delta} \right].$$

For the parameters we use, this inequality is satisfied up to round 10 (after round 10, it can be checked that cooperation can be sustained up to round 14).

A combination of efficient collusion (played until round 9) and simple collusion (played until round 14) is clearly also an equilibrium.

We have assumed risk-neutral players. The presence of risk aversion does not change the equilibria of the one-shot game or the bounds on the sidepayments which ensure truthtelling, but it affects the incentives to bid low for high value types and the incentives to actually pay the sidepayment. Since the short run gain is sure and the punishment is only probabilistic, sustaining cooperation is more difficult with risk aversion.