Collusion mechanisms in procurement auctions:

An experimental investigation

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Abstract:

Collusive agreements are often observed in procurement auctions. They are probably more easily achieved when competitors' costs are easily estimated. If, however, the individual costs of bidders are private information, effective ring formation is difficult to realize. We compare experimentally different coordination mechanisms in a first-price procurement auction in how they promote the prospects of collusive arrangements. One mechanism allows bidders to coordinate by means of unrestricted pre-play communication. The second one enables bidders to restrict their bidding range and the last one gives them the opportunity to implement mutual shareholding. According to our results first-price procurement is quite collusion-proof when allowing for the latter two coordination mechanisms whereas, on average, pre-play communication increases bidders' profits.

Keywords: competition, collusion, auction, bidding, public procurement

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1. Introduction

Collusion in procurement auctions, especially when they are organized by state authorities, is a criminal act in many countries.[1] Preventing ring formation requires understanding its functioning first. Our study tries to shed light on when and why collusive agreements in procurement auctions are likely to occur.

Sealed-bid first-price procurement auctions have been nearly universally used for the allocation of project contracts (see Gandenberger, 1961, for a survey of more than 500 years of public procurement practice in Germany and, e.g., Jofre-Bonet and Pesendorfer, 2000, 2003, De Silva, Dunne, and Kosmopoulou, 2002, for recent empirical research on first-price procurement), in spite of its non-incentive compatibility (Vickrey, 1961). The reason might be that, at least theoretically, collusive agreements can be stabilized more easily when relying on the second lowest bid-price rule rather than when relying on the lowest bid-price rule (see, e.g., Fehl and Güth, 1987, Güth and Peleg, 1996, Marshall and Marx, 2002). Moreover, as was argued by Milgrom (1987) and McAfee and McMillan (1992), the submission of sealed bids makes it more difficult to punish deviators immediately (compared to an oral auction) and tends to work against effective ring formation.

Employing the actually used auction rules, we want to investigate how immune they are against collusion and whether it is true that collusion can be further discouraged by preventing communication between bidders. Are, for instance, as expected by Keynes (1936), communication possibilities decisive?[2] More specifically, we will investigate three different coordination mechanisms in a procurement auction relying on the same iid (independently and identically distributed)-private cost distribution for all bidders and compare them to a control design, which does not provide an explicit opportunity for coordination. One coordination mechanism allows bidders to restrict their bids to an upper range of the bid interval, another to establish mutual shareholding. The third coordination mechanism employs pre-play communication via unrestricted email messages.

The paper is organized as follows: In section 2 we derive the theoretical solution for our sealed-bid first-price procurement auction design and introduce the restricted bidding and

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[1] This often might involve non-bidders, e.g. bureaucrats in the state authority, a problem from which we abstract since we do not want to study bribery (see e.g., Burguet and Che, 2004, Weber Abramo, 2003, Celentani and Ganuza, 2002 as well as, the experiment conducted by Büchner et al., 2005).

[2] That communication can considerably facilitate collusion has been observed in experiments on standard auctions (Isaac and Walker 1985; Kwasnica 2000; Philipps, Menkhaus, Coatney 2003) as well as in procurement-like market interactions (Davis and Wilson 2002).

mutual shareholding mechanisms more formally. Section 3 describes the experimental design and sections 4 and 5 present our main findings. The concluding section 6 shortly discusses the experimental results.

2. Theoretical analysis

The procurement auctions considered here are the competitive bidding analogue to the standard symmetric independent private values auction model (for surveys on this model see, e.g., McAfee and McMillan, 1987; Krishna, 2002; Holt, 1980, and Cohen and Loeb, 1990, analyze competitive bidding with private costs). In our design, each of two bidders $i = 1, 2$ submits a sealed bid.[3] The project contract is awarded to the bidder submitting the lowest bid at a price that equals this bid. The other bidder earns nothing. Let b_i denote the bid submitted by bidder i and c_i his private cost. Each player maximizes the expected value of the own profit

$$\pi_i = \begin{cases} b_i - c_i & \text{if the player obtains the project} \\ 0 & \text{otherwise} \end{cases}.$$

Assuming that bidders are risk neutral and that their private costs are randomly and independently drawn from a uniform distribution with support [50, 150], the symmetric equilibrium bid function assigning a bid $b_i(c_i)$ to all possible cost values c_i is given by

$$b_i(c_i) = 75 + \frac{1}{2}c_i \quad \text{for } i = 1, 2.$$

Accordingly, bidder ω, who submits the lower bid $b_\omega(c_\omega) \leq b_i(c_i)$ for $i \neq \omega$ (due to $c_\omega \leq c_i$ for $i \neq \omega$) wins the auction and earns $b_\omega(c_\omega) - c_\omega$.

Successful coordination aims at both bidders choosing $b_i(c_i)$ close to 150, the upper price limit of the buyer, and selecting ω, the bidder with the lower cost, as winner. One mechanism to achieve this is to restrict the bidding range by coordinating on a small, positive parameter $\varepsilon \in (0, 100)$ and to bid according to

$$b_i^\varepsilon(c_i) = 150 - \varepsilon\left(1 - \frac{c_i - 50}{100}\right) = 150 - \varepsilon + \frac{\varepsilon}{100}(c_i - 50) \quad \text{for } i = 1, 2$$

This allows to approximate $b_\omega(c_\omega) = 150$ for all $c_\omega \in [50, 150]$ by $\varepsilon \to 0$ and guarantees that the lower cost-bidder wins the auction.

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[3] In view of Olson (1971) the case of only two bidders seems to provide the best case scenario to observe ring formation where, however, Olson has disregarded private information, which renders ring formation far more difficult. Our findings reveal that with private information even the smallest groups (of two competitors) often fail to collude.

Another possibility is to introduce coordination by mutual shareholding where we, as in the experiment, require this to be symmetric to preserve the a priori symmetry of bidders. Let $s \in [0, ½)$ be the share by which any bidder i participates in the profits of the other bidder j ($\neq i$). The solution assumes that due to $0 \leq s < ½$ bidder i is solely responsible for $b_i(c_i)$ as the majority share holder of firm i. It is given by (see Appendix A)

$$b_i^s(c_i) = \frac{1-s}{2-3s} \cdot 150 + \frac{1-2s}{2-3s} c_i \quad \text{for } i = 1,2.$$

If $s \to ½$ the solution approaches cooperative behavior, i.e. $b_i^{½}(c_i) = 150$ for $i = 1,2$.

If $s = 0$ the solution approaches the theoretical benchmark, i.e. $b_i^0(c_i) = 75 + \frac{1}{2} c_i$ for $i = 1,2$.

How the bidders can actually implement an ε-restriction of their bids or symmetric mutual shareholding with share s will be described in the experimental protocol.

3. Experimental design

Before bid submission, each cost value c_i for $i = 1, 2$ is randomly and independently selected and revealed only to bidder i. To facilitate statistical analyses and to make data straightforwardly comparable, the same time series of cost values (c_1, c_2) is used in all treatments. Some additional sessions with varying time series of cost values are conducted in order to test the robustness of results against the specific cost series chosen.

After reading the instructions (see Appendix B) and asking privately for clarification, subjects play two training rounds of the auction against the computer. The bids submitted by the computer follow a predetermined algorithm that is the same for all subjects. In the (payoff-relevant) bidding phase the two bidders independently determine their behavior, where it depends on the type of treatment what they have to choose.

- In the *control treatment*, which does not provide any coordination mechanism, both bidders $i = 1, 2$ simply choose their bids $b_i(c_i)$.

- In the *communication treatment* the two bidders are given the opportunity to communicate with the help of an email program offered by the experiment software package Utah[4] which is used for the computerized experiment. Bidders can freely discuss bidding strategies or other issues, but were not allowed to provide any information that

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[4] For further details, please contact the author (Torsten Weiland).

could reveal their identity. After five minutes of communication, bids $b_i(c_i)$ are independently submitted.

- In the *restricted bidding range treatment*, the two bidders first choose a proposal ε_i with $0 \leq \varepsilon_i \leq 100$, where voluntary coordination commits them only to $\varepsilon = \max\{\varepsilon_1, \varepsilon_2\}$. After being informed about ε, both bidders can restrict themselves to bid according to

$$b_i^\varepsilon(c_i) = 150 - \varepsilon\left(1 - \frac{c_i - 50}{100}\right)$$, but do not need to do so.

- In the *mutual shareholding treatment*, the two bidders first choose a proposal t_i with $0 \leq t_i \leq 100$, where voluntary coordination commits them only to $t = \min\{t_1, t_2\}$. After being informed about t, both bidders determine their bids $b_i(c_i)$. The winner of the auction ω is then free to give the loser his share $s = \dfrac{t}{200}$ of the profit.

Assuming that promises to bid in the upper ε-range of [50, 150] or to share profits according to t are non-binding captures the criminal aspect of ring formation when public procurement is concerned. If a bidder deviates, his co-bidders cannot sue him legally. But experience proves that the binding character of collusive agreements is no *conditio sine qua non* for ring formation.

In total, 204 undergraduate students participated in the experiment. They were recruited from the University of Jena using ORSEE (Greiner, 2004). In all sessions, subjects played the first-price procurement auctions with different opponents. Pairs of bidders were randomly matched from a matching group consisting of four subjects with the publicly announced restriction that subjects would not meet the same partner in two consecutive auctions.[5] Subjects played several auctions of one treatment type, but were not informed about the specific number of auctions to be played.[6] At the end of each session five auctions were randomly selected and subjects were paid according to their profits made in these auctions. In addition, each subject received a show-up fee of €2.50. The average payoff was about €7.07, with a minimum of €2.50 and a maximum of €19.37. A session typically lasted for 70 to 80 minutes. Table 1 summarizes treatments, sample sizes, and the number of auctions played in each treatment.

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[5] In none of the treatments subjects were informed about the size of the matching group. Since in the treatment with communication it could have been less difficult for subjects to identify the matching protocol from the content of email messages, we have used matching groups consisting of eight subjects in this treatment and assured a perfect stranger re-matching.

[6] The number of auctions per session was chosen in a way that the duration of the experiment was the same for all treatments.

treatment	cost series	# of auctions	# of subjects	matching group size
control (CT)	same	22	32	4
restricted bids (RB)	same	8	32	4
mutual shareholding (MS)	same	12	32	4
	variable	8	28	4
communication (CO)	same	5	32	8
	variable	5	48	8

Table 1. Treatment types.

4.   Bidding data

We first compare the bids made in the control treatment with the equilibrium prediction (RNE) based on commonly known risk-neutrality. Out of a total of 704 observed bids, the majority of bids (76.5 percent) is below the equilibrium prediction. This finding is similar to the frequently observed bid shading (i.e., overbidding the equilibrium benchmark) in standard first-price auctions (see Kagel, 1995). Only 4.0 percent of bids are equal to the predicted bids and 19.5 percent of observed bids are higher.[7] Figure 1 illustrates the bids submitted in the 22 auctions sorted by subjects' cost values.
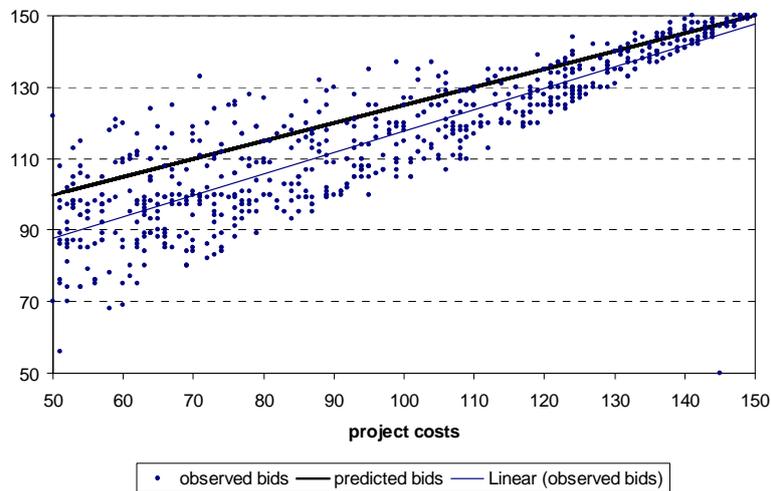
Figure 1.   Bids observed in the control treatment.

To test the null hypothesis that underbidding is as likely as overbidding, the 28 observations of RNE-bidding are counted as overbidding favoring the null. Using two-tailed Binomial

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[7] Appendix C, Table C.I provides more detailed bidding data.

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tests, we can reject this hypothesis for 21 of the 22 auctions in favor of underbidding ($p < 0.050$). The finding is further supported by a series of one-tailed one-sample t tests: In all auctions the difference between the subjects' average bids and the RNE prediction is significantly lower than zero ($p < 0.024$).

Observation 1 (*RNE*): Compared to the equilibrium benchmark (RNE) the dominant tendency is bid shading, i.e. bidders overbid their cost less than predicted.[8]

Giving subjects the opportunity to restrict their bids does not affect this observation. In none of the eight auctions played in RB we find a significant change of behavior ($p > 0.395$, exact two-tailed MWU test). Similar results are obtained for the mutual shareholding treatment; only in the first of the twelve auctions played in MS average bids are (weakly) significantly higher than the average bids submitted in the control treatment ($p = 0.098$ in one auction, $p > 0.204$ in eleven auctions, exact two-tailed MWU test).[9] As a consequence, in both treatments we observe a tendency for underbidding (RB: $p < 0.008$, MS: $p \leq 0.050$ for ten auctions, $p > 0.100$ for two auctions, two-tailed Binomial tests).

Pre-play communication via email messages has a significant effect on behavior, however. In three of the five auctions in CO subjects' average bids are (weakly) significantly higher than the average bids submitted in the control treatment ($p < 0.025$ for two auctions, $p < 0.050$ for one auction, $p > 0.050$ for two auctions, exact one-tailed MWU test). There is neither a tendency to overbid ($p > 0.214$) nor one to underbid ($p > 0.119$, except for one auction where $p = 0.050$, exact two-tailed Binomial test). Thus, pre-play communication induces a behavior which is, on average, in line with the RNE prediction. Our results are illustrated in Figure 2.

Observation 2 (*bids*): Neither the possibility to coordinate on "restricted bidding" nor the possibility for "profit sharing" significantly affects bidding behavior. Only pre-play communication induces higher bids which, however, resemble more the benchmark solution than reflect collusion as it is commonly understood.[10]

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[8] This behavior was also observed in the procurement auction experiment conducted by Brosig and Reiß (2003).

[9] Unless indicated otherwise, the analyses are based on data obtained in the sessions with the *same* series of cost values. Including sessions with other series of cost values (*variable*) yields similar results, which we report in footnotes.

[10] This observation is supported by the results of a linear mixed effects regression (see Table C.II in Appendix C) describing how bids submitted in the same and variable cost series treatments depend on treatment dummies, cost levels, and experience.
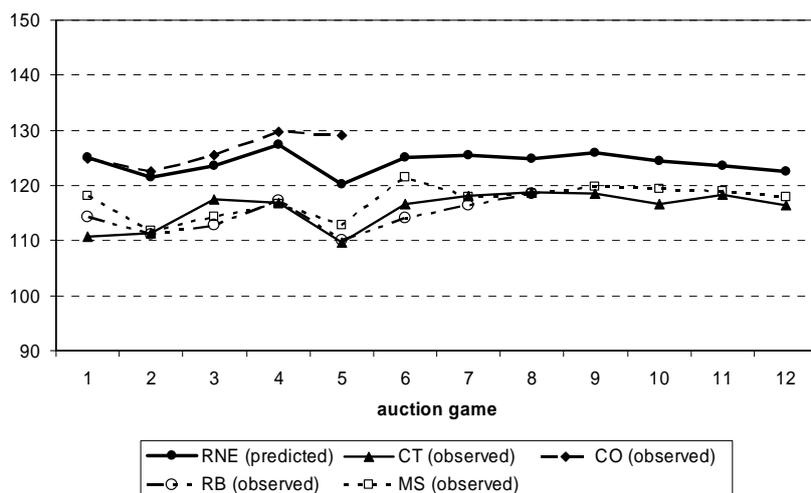
Figure 2.   Treatment comparison of average bids.

As a consequence of described bidding behavior, average profits realized in the control treatment are lower than those predicted by theory ($p < 0.015$ for twenty auctions, $p < 0.027$ for two auctions, one-tailed one-sample t test) and do not significantly differ from those realized in the restricted bidding and in the mutual shareholding treatment ($p > 0.122$ for all comparisons, exact two-tailed MWU test). Only pre-play communication leads to a (weakly) significant increase of average profits in two of the five auctions ($p = 0.029$ for one auction, $p = 0.014$ for one auction, $p > 0.485$ for three auctions, exact one-tailed MWU test).[11]

Investigating profit sharing in the treatment with mutual shareholding reveals that, at least in some auctions, the average amount given to the unsuccessful bidder is (weakly) significantly positive ($p = 0.019$ for one auction, $p < 0.048$ for three auctions, $p > 0.056$ for eight auctions, one-tailed one-sample t test) and the winners' profit realized after profit sharing is lower than their total profit ($p = 0.008$ for one auction, $p < 0.032$ for three auctions, $p > 0.062$ for eight auctions, exact one-tailed Wilcoxon test). The average profit realized by winners in this treatment does not differ significantly from the average profit in the control treatment, however ($p > 0.104$ for all twelve auctions, exact two-tailed MWU test).

Observation 3 (*profits*): The lower degree of bid shading in the communication treatment is reflected by somewhat higher profits in this treatment. Otherwise average profits of bidders do not react significantly to the treatment design.

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[11] Table C.III in Appendix C provides more detailed profit data. Since bids and realized profits are correlated, we observe the same pattern of treatment effects in a linear mixed effects regression on periodic profits as in the mixed effects model on submitted bids (see Table C.IV in Appendix C).

A procurement auction allocates a project efficiently if the bidder with the lowest cost value for this project is awarded the contract. Following this definition, we labeled the percentage of pairs in which the lower cost-bidder won the auction as *efficiency rate*. Table 2 illustrates the average efficiency rates observed in the first five rounds of each treatment.

auction	efficiency rate (in percent)			
	CT	RB	MS	CO
1	87.5	93.8	87.5	93.8
2	87.5	87.5	68.8	75.0
3	81.3	81.3	93.8	62.5
4	87.5	93.8	93.8	81.3
5	81.3	87.5	93.8	81.3
mean	85.0	88.8	87.5	78.8

Table 2.   Observed efficiency.

Due to the *a priori* symmetry of both bidders, the predicted efficiency rate is 100 percent, i.e. the bidder with the lower cost should always win the auction. In most of the auctions of the control treatment the observed efficiency rate is not significantly different from the predicted one ($p > 0.169$ for eighteen auctions, $p < 0.050$ for two auctions, $p < 0.100$ for two auctions, one-sample two-tailed t test). Implementing one of the coordination mechanisms does not change this result. Neither restricting the bidding range, nor mutual shareholding, nor pre-play communication between bidders does significantly affect the average efficiency rates compared to the control treatment ($p > 0.199$ for all comparisons, exact two-tailed MWU test).[12]

Observation 4 (efficiency): The partly differing degrees of bid shading do not imply significant effects on the efficiency of allocation. In the majority of auctions the contract is awarded to the bidder with the lower cost value.

5.   Coordination

This section illustrates in more detail why the three coordination mechanisms do or do not affect subjects' bids. The analysis particularly focuses on proposals made by subjects before bid submission and compares proposed with observed behavior.

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[12] Similar results apply when analyzing the *efficiency loss* (measured as the difference between the winner's and the lowest cost bidder's cost values). In none of the 22 auctions of the control treatment the efficiency loss is significantly higher than predicted (i.e., is significantly positive) and in only one auction of MS and CO, respectively, we observe a slightly higher efficiency loss than in CT ($p < 0.050$, exact one-tailed MWU test).

5.1 Profit sharing

In the treatment with mutual shareholding bidders $i = 1, 2$ are given the opportunity to choose a number t_i from the interval [0, 100]. While choosing $t_i = 0$ implies a proposed profit share of 100 percent for the winner and 0 percent for the loser, choosing $t_i = 100$ suggests to share the profit equally. On average, subjects propose to give about one third of the profit to the loser with most subjects proposing either 100 (36 percent) or 50 (16 percent).

Testing whether proposals t_i are correlated with cost values c_i reveals a weakly significant positive correlation in two of the twelve auctions (Spearman's $\rho = 0.667$, $p = 0.071$). This suggests the self-serving tendency that those with relatively high costs, i.e. those who are very likely to loose the auction, submit relatively high proposals.[13] Comparing average proposals made by winners with average proposals made by losers reveals no significant difference, however, except for one auction where $p = 0.035$ (exact two-tailed MWU test). Yet, in most auctions the average of selected proposals $t = \min \{t_1, t_2\}$ is not significantly different from the average of proposals chosen by the auction winner ($p > 0.124$ for seven auctions, $p = 0.063$ for one auction, $p < 0.032$ for four auctions, exact two-tailed Wilcoxon test; see Figure 3).
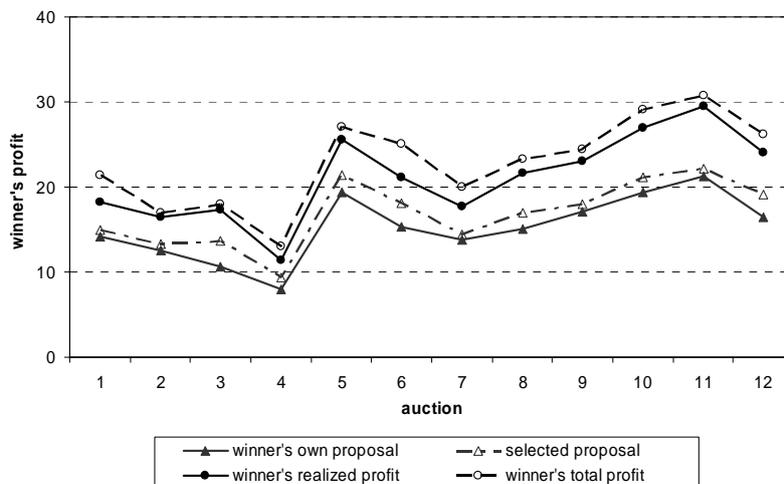
Figure 3.   Average proposals and profits related to winners.

According to the selected proposals t, winners should receive, on average, 73.6 percent of the total profit. Only 25.3 percent of winners share the profit as suggested by t, however.[14] The

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[13] This finding is further supported by the results of a linear mixed effects regression on proposals t_i (see Table C.V in Appendix C). The model shows that proposals and cost values are positively correlated. Yet, the large standard deviation of the residuals (*sigma*) indicates that the model features only limited predictive power.

[14] Calculating this percentage, we count the number of all winners whose realized profit deviate by no more than 1 from the proposed profit. The average percentage of winners choosing exactly the proposed profit is 4.7 and the average percentage of winner whose realized profit deviates by 5 or less is 62.1. Note, that we excluded two subjects, who received a negative profit and, therefore, could not share this profit.

majority of "deviators" keep more of the total profit than proposed.[15] As a result, the winners' profits realized after profit sharing are significantly higher than the profits suggested by t ($p < 0.021$, except for one auction where $p = 0.074$, exact one-tailed Wilcoxon test). Overall, realized profits deviate from proposed profits by 4.2 implying that winners receive, on average, 91.8 percent of the total profit while losers get 8.2 percent. Apparently, exchanging non-binding proposals of mutual shareholding is not an effective mechanism for coordinating bidder's behavior in first-price procurement auctions.

Observation 5 (*coordination in MS*): Cheap talk proposals of symmetric profit sharing are consistently used, but have little effect compared to the control treatment.

5.2 Restricted bidding

In the restricted bidding treatment the two bidders $i = 1,2$ are given the opportunity to choose a number ε_i from the interval [0, 100]. Choosing $\varepsilon_i = 0$ implies the proposal to bid 150, the highest possible bid, and choosing $\varepsilon_i = 100$ implies the proposal to submit a bid equal to the own cost value. In all eight auctions subjects, on average, propose an ε_i equal to 43.0. This observed average proposal does not significantly differ from $\varepsilon_i = 50$, which suggests to bid in line with the RNE prediction ($p > 0.296$ except for one auction where $p = 0.090$, two-tailed one-sample t test). Similar to the MS treatment, we analyze whether proposals ε_i are correlated with cost values c_i. In seven of the eight auctions we observe no significant correlation (Spearman's $\rho = 0.833$, $p = 0.010$ for one auction).[16] Comparing average proposals made by winners with average proposals made by losers reveals no significant difference, either ($p > 0.244$, exact two-tailed MWU test).

For each pair of bidders $\varepsilon = \max \{\varepsilon_1, \varepsilon_2\}$ is selected to guide subjects' behavior. Transforming proposals into bids considering actual cost values (see Figure 4) we find in all eight auctions that average bids suggested by ε ("selected proposed bid") are significantly lower than average bids suggested by ε_i ("own proposed bid"; $p < 0.018$), but do not significantly differ from average actual bids ($p > 0.460$, exact two-tailed Wilcoxon test). We conclude from these findings that restricting the bidding range is rather ineffective in coordinating bidding behavior. Moreover, although bids suggested by ε and actual bids are similar, we observe that, on aver-

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[15] Only 7 of the 142 deviators keep less than the amount suggested by the selected proposal. Four of them already proposed to keep a lower amount.

[16] Similar results are obtained when applying a linear mixed effects regression on proposals ε_i (see Table C.VI in Appendix C). Although the relation between proposals and cost values is weakly significant ($p = 0.066$), the large standard deviation ($\sigma_{SUBJECT}$) of the random effect of subjects on the intercept points out the likely inaccuracy of such predictions.

age, only 8.6 percent of subjects submit a bid in line with the selected proposal.[17] 50.4 percent of these deviators submit a bid that is lower than proposed and 49.6 percent submit a bid that is higher than proposed.[18]
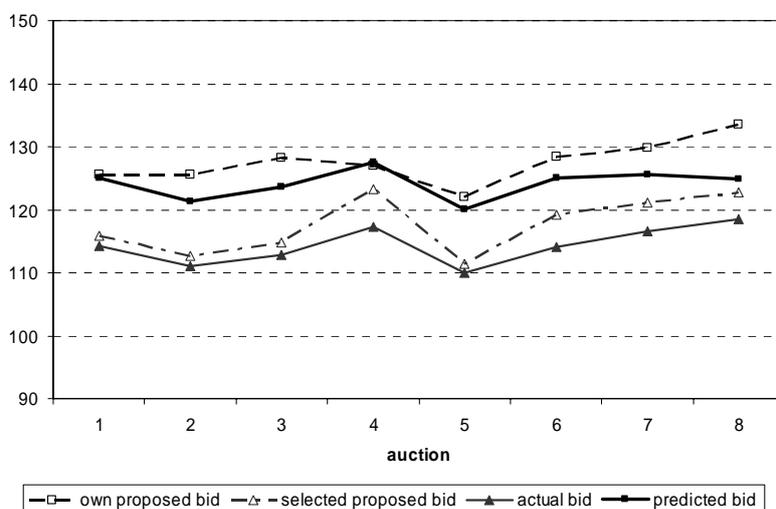
Figure 4.   Average proposed and realized bids.

Observation 6 (*coordination in RB*): Like profit sharing, restricting the bidding range is often suggested, but has no effect on resulting bids compared to the control treatment.

5.3   Pre-play communication

In order to shed more light on the observed effects of pre-play communication, we investigate the content of email messages sent in the *same* and *variable* cost treatments. In only 16.0 percent of pairs at least one subject states that the email exchange makes no sense. Most pairs (about 65.0 percent) start the discussion with a proposal regarding their bidding behavior (see Figure 5). About one third of all pairs also discuss a second proposal. Most first proposals suggest that both bidders should submit a bid equal to 150, the highest possible bid. About 22 percent of all pairs propose that the bidder with the higher cost value should bid 150 and the bidder with the lower cost value should bid 149. These two kinds of proposals are dominant also with regard to second proposals made in the five auctions. There are also some subjects who voluntarily offer to bid 150 arguing that their own profit margin is too low.

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[17] Calculating this percentage, we consider all bids deviating by no more than 1 from the selected proposed bids. The average percentage of subjects choosing exactly the bid suggested by ε is 2.0 and the average percentage of subjects whose submitted bid deviate by no more than 5 is 28.1.

[18] About 52.6 percent of "overbidders" proposed a bid which was higher than the one suggested by ε_i.
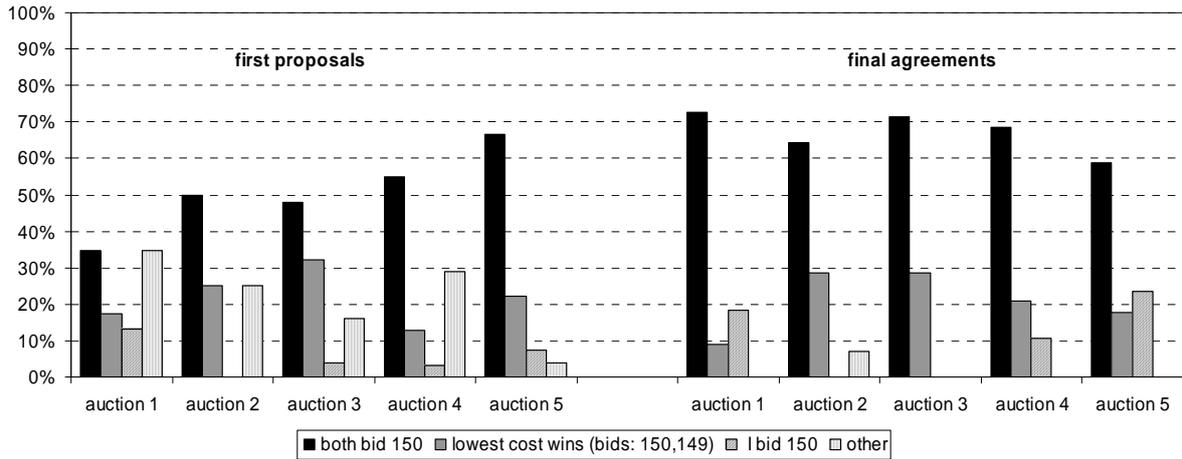
Figure 5.   Structure of first proposals and final agreements.

About 37.5 percent of all pairs reach a final agreement. Following the first proposals, most of the pairs agree that both players should bid 150 (67.1 percent) or agree that the one who stated the lower cost value should bid 149 and that the one who stated the higher cost value should bid 150 (21.0 percent).

About 55.2 percent of all subjects keep their agreement. Looking at the structure of realized agreements reveals that those who promise to bid either 149 or 150 are most successful in coordinating their behavior. About 65.8 percent of them keep their promise. Those who agree on bidding 150 realize this agreement in about 50.3 percent of all cases, and 41.7 percent of subjects who promise to bid 150 in any case keep this promise.

Since the proposal that the one with the lower project cost should win the auction requires that bidders talk about their cost, we also analyze the cost-related statements. In about 66.5 percent of all pairs subjects try to talk about their cost, i.e. at least one of the two bidders addresses this issue during the discussion. Most subjects (55.5 percent) state no cost value, however. 22.5 percent of subjects give a range for their cost and only 22.0 percent state an exact cost value. Of course, nobody could verify the statements. Interestingly, in all five auctions only 33.6 percent of subjects lie about their cost. That is, most of the subjects are honest. The number of lies does not depend on whether subjects give a range for their cost or whether they state an exact value (33.62 vs. 33.64 percent).

Observation 7 (*coordination in CO*): Many participants are aware of how to collude efficiently by bidding either 149 or 150 and revealing the cost value. Overall cheating about the cost value occurs in about one third of all cost statements.

6. Conclusions

Collusion in public procurement is one of the major causes why public authorities are rather inefficient. Although private cost information renders cooperation of potential bidders rather difficult, there is a lot of field evidence indicating successful ring formation. In our setup private costs are induced by appropriate chance moves. Surprisingly, cheap talk agreements to share profits or to restrict the bidding range do not enhance the bidders' profit. Rather it seems that Keynes' (1936) intuition was right: If bidders can freely communicate they manage to increase their profits significantly. Most notably, this is even true when communication is restricted to anonymous email messages.

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Appendix A. Linear benchmark solution in case of mutual and symmetric shareholding

For $i, j = 1, 2$ with $i \neq j$ the payoff expectation for the risk neutral bidder i with cost value $c_i \in [0, 1]$ is

$$E_i(b_i|c_i) = (1-s) \int_{b_i < f(c_j)} [b_i - c_i] dc_j + s \int_{b_i \geq f(c_j)} [f(c_j) - c_j] dc_j$$

where $f(.)$ is the linear symmetric and monotonic equilibrium bid function.

Let us rewrite $E_i(b_i|c_i)$ as

$$E_i(b_i|c_i) = (1-s)(b_i - c_i) \int_{f^{-1}(b_i) < c_j \leq 1} dc_j + s \int_{f^{-1}(b_i) \geq c_j \geq 0} [f(c_j) - c_j] dc_j$$

$$= (1-s)(b_i - c_i)\left[1 - f^{-1}(b_i)\right] + s\left[F(f^{-1}(b_i)) - F(0) - \frac{1}{2}(f^{-1}(b_i))^2\right]$$

where $F'(.) = f(.)$. For an interior best reply b_i to $f(.)$ the first order condition is

$$s\left[b_i \frac{d}{db_i} f^{-1}(b_i) - f^{-1}(b_i) \frac{d}{db_i} f^{-1}(b_i)\right] = (1-s)(b_i - c_i)\frac{d}{db_i} f^{-1}(b_i) - (1-s)\left[1 - f^{-1}(b_i)\right]$$

which can be simplified as follows:

$$\frac{d}{db_i} f^{-1}(b_i)\left[b_i - f^{-1}(b_i) - \frac{1-s}{s}(b_i - c_i)\right] = -\frac{1-s}{s}\left[1 - f^{-1}(b_i)\right]$$

$$\Leftrightarrow \frac{d}{db_i} f^{-1}(b_i) = -\frac{1-s}{s} \frac{1 - f^{-1}(b_i)}{b_i - f^{-1}(b_i) - \frac{1-s}{s}(b_i - c_i)}$$

$$\Leftrightarrow \frac{db_i}{df^{-1}(b_i)} = -\frac{s}{1-s} \frac{b_i - f^{-1}(b_i) - \frac{1-s}{s}(b_i - c_i)}{1 - f^{-1}(b_i)}.$$

Now substituting $b_i = f(c_i)$ and $c_i = f^{-1}(b_i)$ into the latter equation yields the ordinary differential equation

$$f'(c_i) = -\frac{s}{1-s} \frac{s - 1 + s}{s} \frac{f(c_i) - c_i}{1 - c_i} = \frac{1 - 2s}{1 - s} \frac{f(c_i) - c_i}{1 - c_i}.$$

For the linear and monotonic solution $f(c_i) = \alpha + \beta c_i$ with $\beta > 0$ we thus obtain

$$(1-s)\beta - (1-s)\beta c_i = (1-2s)\alpha + (1-2s)(\beta - 1)c_i.$$

Since the left and the right hand-side above have to coincide for all $c_i \in [0,1]$ this requires

$$(1-s)\beta = (1-2s)\alpha \quad \text{or} \quad \beta = \frac{1-2s}{1-s}\alpha$$

and

$$-(1-s)\beta = (1-2s)(\beta - 1)$$

or, after substituting for β,

$$-(1-2s)\alpha = (1-2s)\left[\frac{(1-2s)\alpha}{1-s} - 1\right]$$

and thus

$$a = \frac{1-s}{2-3s} \quad \text{and} \quad \beta = \frac{1-2s}{2-3s}.$$

Appendix B. Instructions (originally in German)

Welcome to this experiment!

<u>**Preliminary remarks**</u>

In the following, you will take part in an experimental study in the field of economics in which the decision behavior of individuals is investigated. During the experiment, you will participate in a series of auction games in which you can earn money. How much you eventually earn depends on your own and others' decisions (possible losses will be deducted from the show-up bonus of 2.50 Euro which you receive for participating in this experiment). At the end of the experiment, your accrued earnings will be converted into Euro at the rate of **1 ECU : 0.07 EURO** and disbursed to you in cash.

Please read the subsequent instructions carefully. About five minutes after you have received these instructions, we will come to your place to answer any remaining questions. Afterwards, you will receive a questionnaire which is used to ensure that you have fully understood the rules of this experiment. We will not start with the experiment until all participants have correctly answered all the listed questions.

In case that you have further questions in the course of the experiment, please indicate this by <u>raising your hand</u>. We will then come to your place and answer your questions.

<u>**Description of the auction:**</u>

In every period of the experiment, a generic "project" is auctioned off. The project is awarded to the bidder who states the lowest bid.

Bidders: In each auction there are exactly two bidders, i.e., you and another bidder. In each period, the other bidder with whom you will interact is randomly assigned to you from a group of participants. It is ensured that you will not interact with the same participant in two consecutive periods.

Costs: For every auction period and for every bidder, a cost value is independently and randomly assigned from the interval from 50 LD to 150 LD whereby each value in this range is equally likely. Before the start of an auction, you will be informed about your own cost value. Apart from this, you will not receive any further information.

Decision: In each auction period you have to decide on the bid that you want to submit for the project.

If your bid for the project is <u>less</u> than the bid of the other bidder, you are awarded the project and your auction profit is the difference between your bid and your cost. It is possible to realize a loss if your bid is less than your cost.

If your bid for the project is <u>greater</u> than the bid of the other bidder, you do not win the auction. In this case your profit equals zero, since you were not awarded the project and therefore did not incur any cost.

If your bid is <u>equal</u> to the bid of the other bidder, you are awarded the project with a probability of 50%.

<u>**Proposal stage:**</u>

In every auction and before determining his/her bid, each of the two bidders has the possibility to make the other bidder a suggestion concerning the distribution of the bids that are to be submitted. For this purpose, both bidders independently select an integer value from the range of 0 to 100. After each bidder has decided on a particular value, both bidders are informed about the larger of the two stated values. In the following, this value shall be denoted as N.

Given *N,* each bidder is free to set his/her own bid according to the following rule:

$$\text{Own bid} = 150 - N + (N/100) * (\text{own cost} - 50)$$

This means that if your cost amount to 50, your bid would be $150 - N$. If you were assigned the maximal cost of 150, you would always bid 150, irrespective of the value of N. This shows that it is possible to constrict the bidding interval by agreeing on a small value of N. The smaller is N, the larger is the least "accepted" bid and the larger is the potential profit of the bidders.

Please notice that every bidder is free to decide whether (s)he sets his/her bid according to the above-mentioned formula or not.

Proposal stage:

In every auction and before determining his/her bid, each of the two bidders has the possibility to make the other bidder a suggestion concerning the distribution of the yet unrealized auction profit between the two. For this purpose, both bidders independently select an integer value from the range of 0 to 100. After each bidder has decided on a particular value, both bidders are informed about the smaller of the two stated values. In the following, this value shall be denoted as N.

Given *N,* the winning bidder is free to divide the realized auction profit according to the following rule:

The winner of the auction obtains: $(200 - N)/200$ * (winner's bid – winner's cost).

The losing bidder obtains: $N/200$ * (winner's bid – winner's cost).

This means that the larger is N, the smaller is the difference between the payoff of the winning and the losing bidder.

Please bear in mind that every bidder is free to decide whether to split the realized auction profit according to the above-mentioned rule or not, after (s)he is informed that (s)he has won the auction.

Communication stage:

Before an auction is conducted the two bidders have the possibility to communicate with each other via electronic (chat) messages before they then independently decide on their bid.

Generally, the content of your communication is totally up to you. You are, however, not allowed to:

- provide personal information about yourself such as your age, address, gender [please always use gender-neutral terms, e.g., "bidder A", "bidder B"], field of studies [this also includes mentioning the names of professors, lectures or similar contents which allow to identify the other's field of studies] and the like, or to

- negotiate any form of side-payments.

In case that you do not respect these rules we will unfortunately have to exclude you from the experiment which means that you will not receive any payment at all in this experiment. The duration of the communication stage is limited to five minutes. You may, however, finish your conversation earlier as well.

Practice periods:

Before the actual experiment starts you will have the possibility to familiarize yourself with the decision problem and the use of the software in the course of two practice periods. Note that in both periods, the other bidders' decisions are simulated by the computer and are identical for all participants. All decisions that are made during the two practice periods are for training purposes only and will not affect your eventual payoff in the experiment.

Payment:

After you have finished the two practice periods, you will participate in a series of auctions of which five auctions will be randomly selected to determine your payoff in this experiment. Once all auctions have been finished, your earnings in the respective five periods will be summed up, converted according to the exchange rate of **1 ECU : 0.07 EURO**, and disbursed to you in cash.

PLEASE NOTE:

All participants in this experiment have received the identical set of instructions.

None of the participants will receive any information concerning the identity of any other participant.

Appendix C.

Table C.I: Bidding behavior – summary statistics

treatment	cost series	periods	deviation from RNE median	mean	sd
CT	same	1-5	-8.25	-10.29	14.89
	same	6-10	-5.50	-7.38	9.99
	same	11-15	-6.00	-6.02	8.34
	same	16-20	-4.50	-6.04	8.64
	same	21-22	-5.75	-6.55	8.06
BR	same	1-5	-9.25	-10.50	11.36
	same	6-8	-8.00	-8.81	9.70
MS	same	1-5	-8.75	-9.25	14.88
	same	6-10	-6.25	-5.94	12.25
	same	11-12	-3.75	-4.72	8.41
	variable	1-5	-7.25	-9.34	15.77
	variable	6-8	-7.00	-6.18	13.85
CO	same	1-5	0	1.25	19.22
	variable	1-5	-0.5	0.97	19.22

Table C.II: Linear mixed-effects model of submitted bids

covariate	coefficient	Std.Error	p-value
Intercept	54.524	1.899	< 0.001
RB	-10.280	3.003	< 0.001
MS	-2.828	2.486	0.256
CO	25.523	2.670	< 0.001
COST	0.591	0.015	< 0.001
COST:RB	0.102	0.029	< 0.001
COST:MS	0.055	0.022	0.014
COST:CO	-0.013	0.025	< 0.001
PERIOD	0.308	0.062	< 0.001
AIC: 15495 BIC: 15556		logL: -7736	
$\gamma_{subject} \sim N(0, 5.711)$		$\varepsilon \sim N(0, 11.804)$	

Table C.III: Profits – summary statistics

treatment	cost series	periods	period payoff median	mean	sd
CT	same	1-5	18.00	18.86	22.14
	same	6-10	20.00	22.02	11.38
	same	11-15	30.00	28.67	15.27
	same	16-20	24.00	25.34	13.11
	same	21-22	17.50	19.44	13.16
BR	same	1-5	15.50	19.06	12.51
	same	6-8	19.00	19.79	9.56
MS	same	1-5	14.00	15.86	12.60
	same	6-10	20.00	20.91	12.87
	same	11-12	27.00	26.78	11.45
	variable	1-5	10.50	13.79	11.84
	variable	6-8	20.00	20.48	11.27
CO	same	1-5	25.00	29.23	22.33
	variable	1-5	27.50	31.97	26.55

Table C.IV: Linear mixed-effects model of period profits[a]

covariate	coefficient	Std.Error	p-value
Intercept	51.428	2.186	< 0.001
RB	-0.546	1.509	0.718
MS	2.091	1.631	0.200
CO	14.443	1.581	< 0.001
COST	-0.418	0.018	< 0.001
PERIOD	0.531	0.097	< 0.001
AIC: 7959 BIC: 7998		logL: -3971	
$\gamma_{subject} \sim N(0, 6.262)$		$\varepsilon \sim N(0, 12.995)$	

[a] The model is based on observations of winning bidders, only. In MS, the winner's profit is defined as the sum of the winner's and loser's profit. Without this adjustment, the coefficient for the MS-dummy would be negatively biased.

Table C.V: Linear mixed-effects model of coordination parameter (MS)

covariate	coefficient	Std.Error	p-value
Intercept	54.771	3.699	< 0.001
COST	0.085	0.023	< 0.001
AIC: 9689	BIC: 9709	logL: -4840	
$\gamma_{subject} \sim N(0, 27.124)$		$\varepsilon \sim N(0, 21.223)$	

Table C.VI: Linear mixed-effects model of coordination parameter (RB)

covariate	coefficient	Std.Error	p-value
Intercept	50.248	7.193	< 0.001
COST	-0.077	0.042	0.066
AIC: 3223	BIC: 3238	logL: -1607	
$\gamma_{subject} \sim N(0, 32.640)$		$\varepsilon \sim N(0, 22.478)$	