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ARTICLE

Comparing the effectiveness of collusion devices in first-price procurement: an auction experiment

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Abstract Collusion in procurement auctions is illegal, but often observed. We compare experimentally three coordination mechanisms in how effectively they promote collusion in first-price procurement auctions. One mechanism aims at excluding competitive bids via bidding restrictions. The second one allows for promises on sharing the gains from collusion as in mutual shareholding. The third mechanism relies on unrestricted pre-play communication. Agreements made under the three mechanisms are non-binding. In the experiment, bidders interact with the same group of competitors only once as it is quite common in globalized (online) markets. We find that first-price procurement is quite collusion-proof regarding the first two mechanisms whereas pre-play communication, on average, increases profits. The communication protocols provide valuable insights about how to coordinate and implement non-binding collusion agreements in competitive one-shot interactions with private information.

Keywords First-price procurement auction · Collusion · Communication · Experiment

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1 Introduction

Before turning to the specific topic of how bidders can effectively collude in first-price procurement, let us embed our study in the broader context of what is sometimes called the "dark" side of human nature (e.g., Rustichini and Villeval 2014). While research on crime, corruption, and illegal collusion has a long tradition in economics (e.g., Becker 1968; the reviews provided by Bardhan 1997 or Martin 1988), not until the last years more attention is given also to other types of 'anti-social' behavior. Among others, field and laboratory research increasingly focused on behavioral patterns like lying and deception (e.g., Gneezy 2005, Fischbacher and Föllmi-Heusi 2013), sabotage (e.g., Harbring and Irlenbusch 2008; Chowdhury and Gürtler 2015), or internet fraud (e.g., Bajari and Hortacsu 2004; Bolton et al. 2013). Similarly, behavioral explanations like spite or nastiness became more common in economic research (e.g., Cason et al. 2002; Andreoni et al. 2007; Abbink and Sadrieh 2009). Possibly, the increased attention to the "dark" side of human nature is a reaction to the success of propagating social preference concepts which rather point to the "bright" side (see, e.g., Cooper and Kagel 2013, for a review). Of course, neither side is claimed to be the only one and recent literature increasingly points to both sides of human nature (Fehr et al. 2013; Thöni 2014).

In the field, there have always been attempts to limit anti-social behavior like compliance rules and antitrust regulations. Our study provides insights important for the design of antitrust regulation, specifically for limiting collusion in first-price procurement and its detrimental effects. In procurement auctions, e.g., those organized by state authorities, collusion (often referred to as ring formation) is a criminal act in many countries. Due to the illegal nature of ring formation, many collusive agreements are non-binding, i.e., not legally enforceable. Preventing ring formation requires understanding its functioning first. How do bidders coordinate on an agreement to collude and how are actual bids influenced by such attempts? We try to answer this question in a stylized setup without any risk of detection and sanctioning. This setup allows to explore how bidders can reach coordination on non-binding collusive agreements. By identifying how coordination is realized in first-price procurement auctions, our study provides the basis for developing effective means to detect and sanction collusion in this environment.[1]

First-price sealed-bid procurement auctions have been frequently used for the allocation of project contracts (see Gandenberger 1961, for a survey of more than 500 years of public procurement practice in German-language regions and, e.g., Jofre-Bonet and Pesendorfer 2000, 2003; De Silva et al. 2002, for empirical research on first-price procurement), in spite of their property of not being incentive

[1] As such, our set-up is in line with the more general view in the economics of crime literature (e.g., Eide et al. 2006) that prevention, detection, and sanctioning should be based on understanding the motives, practices, and the success chances of those who possibly consider and attempt to gain from illegal behavior.

compatible (Vickrey 1961).[2] The main reason might be that, at least theoretically, collusive agreements are more stable when relying on second-price rather than first-price procurement (see, e.g., Fehl and Güth 1987; Güth and Peleg 1996; Marshall and Marx 2007; for other reasons see, e.g., Rothkopf et al. 1990). Moreover, as argued by Milgrom (1987) and McAfee and McMillan (1992), sealed bids make it more difficult to punish deviators immediately (compared to an oral auction) and tend to work against effective ring formation (see also Robinson 1985).

Despite these properties, there is empirical evidence for collusive agreements also in first-price sealed-bid procurement (see, e.g., Pesendorfer 2002, who investigates bid-rigging in the school milk market in Florida and Texas during the 1980s or the examples provided by Kovacic et al. 2006). Collusion in auctions is not only studied in the field, but also in the laboratory (see Kagel and Levin 2011, for a survey). Laboratory experiments allow to better control different aspects of the decision environment like privacy of information or affiliation of individual evaluations and to induce common(ly known) priors in non-incentive compatible auctions (the latter of which is difficult to observe in the field). Experimental research on ring formation in procurement auctions seems to be particularly useful since illegal collusive agreements are difficult to detect and, therefore, to study in the field.[3] But how can bidders implement non-enforceable arrangements in private-value auctions, specifically when they are not aware of other bidders' cost levels?

Employing the frequently used first-price sealed-bid auction rule, we want to test under controlled laboratory conditions how immune it is against three common collusion mechanisms. To capture the aforementioned criminal aspect of collusion in public procurement, our experimentally investigated collusion mechanisms are non-binding, i.e., they can be implemented only in a cheap talk way. To what extent can collusion be reduced by preventing communication between bidders? And are, as expected by Smith (1776), communication possibilities decisive?

Genesove and Mullin (2001), who focus on the role of private discussions in the US sugar-refining cartel between 1927 and 1936, conclude from their findings that communication is a key element of collusion. Previous laboratory research on standard auctions supports the supposition that communication between bidders can facilitate collusion. These experimental studies implemented both single-unit designs (e.g., Isaac and Walker 1985; Hu et al. 2011) and multi-unit designs (Goswami et al. 1996; Kwasnica 2000, Phillips et al. 2003; Sherstyuk and Dulatre 2008; Li and Plott 2009; Sefton and Zhang 2013).[4] As these experiments focus on collusion in environments in which bidders repeatedly interact with each other and/or bid for multiple items, collusive agreements relying on bid rotation (i.e., winning bidders alternate over time or over objects) or on linear bid reductions (i.e., bidders submit bids which are linear transformations of their actual evaluations) are

2 For laboratory research on first-price procurement auctions see, e.g., Brosig and Reiß (2007), Büchner et al. (2008), Brosig-Koch and Heinrich (2014), Hoppe et al. (2013), and Aycinena et al. (2014).

3 Unregistered and therefore illegal employment of labor is one such example where one tries to estimate the size of an iceberg when only observing its top (see, e.g., Schneider and Enste 2013).

4 See also the survey provided by Kwasnica and Sherstyuk (2013).

frequently observed.[5] But how do these results translate to procurement auctions in which bidders compete for one project and do not repeatedly interact with the same group of competitors? This question has gained more importance with the globalization of procurement. In the European Union we experience that foreign bidders often compete with incumbent ones in rather unpredictable ways (see, e.g., Martin et al. 1999, who study intra-EU competition in public procurement). Moreover, an increasing number of procurement auctions is run online and with geographically distant strangers (see, e.g., Cutcheon and Stuart 2000; MacLeod 2007). In this study, we test whether collusive agreements can be effective in first-price procurement auctions even if bidders interact with the same group of competitors only once. As repeated interaction tends to enforce cooperation,[6] our study provides a lower bound for the extent of collusion that can be expected in first-price procurement.

We focus on three common coordination mechanisms, which all are non-binding or based on "cheap talk". The three different collusion mechanisms in a procurement auction with private information about individual costs are compared with a control design, which does not provide an explicit opportunity for coordination. In one collusion mechanism bidders can try to restrict their bids to an upper range of the bid interval, another gives them the opportunity to promise mutual shareholding. The third coordination mechanism allows for unrestricted pre-play communication via email messages. We choose these three mechanisms to compare institutional cheap talk devices which allow for simultaneous and, thus, independent bidding (irrespective of the collusion mechanism and irrespective of whether one feels obliged by cheap talk or not). Whereas profit sharing and bid restrictions are rather obvious, but pre-structured collusion devices, free communication is often claimed to be particularly successful in reducing market competition (see Keynes 1936).

Theoretically, in independent private-value first-price auctions the three types of collusive agreements should be not effective (i.e., they cannot raise payoffs above the non-cooperative bidding level) as long as they are non-binding and interactions are one-shot (see McAfee and McMillan 1992; Lopomo et al. 2011). Nevertheless, there are a number of experimental studies demonstrating that non-binding agreements are still effective in one-shot games in which individual payoffs are not aligned (see, e.g., Sally 1995, or Chaudhuri 2011, for overviews). The experimental evidence is quite robust, but it is mainly based on social dilemma games, which typically abstract away from private information. Does it suffice to induce private information to render voluntary cooperation rather unlikely, even when a common prior is experimentally induced? Until now, there is no study investigating whether the observed effects of non-binding agreements translate to

[5] To our knowledge, only Hu et al. (2011) test the effectiveness of collusion in a single-unit design with repeated one-shot interactions. In their study, communication is restricted to voting on cooperation, however. If all six bidders voted to cooperate, cooperation was binding for all six bidders.

[6] That future contact allows stabilizing cooperation without commitment power has been theoretically established by Folk Theorems (see, e.g., Aumann and Shapley 1994) and confirmed experimentally even when the requirements of Folk Theorems (infinitely many interaction periods or multiplicity of equilibria in the base game) are not met (see, e.g., Selten and Stoecker 1986; Axelrod 1984).

common coordination mechanisms in one-shot independent private-value auctions. With this study we want to close this gap of research.

The paper is organized as follows: In Sect. 2 we derive the theoretical solution for our sealed-bid first-price procurement auction and introduce the restricted bidding and mutual shareholding mechanisms more formally. Section 3 describes the experimental design and Sects. 4 and 5 present our main findings. Section 6 concludes.

2 Theoretical analysis

The procurement auctions considered here are the competitive bidding analog to the standard symmetric independent private value auction model (e.g., Holt 1980; Cohen and Loeb 1990). In our design, each of two bidders $i = 1, 2$ submits a sealed bid.[7] The project contract is awarded to the bidder submitting the lowest bid at a price that equals this bid.[8] The other bidder earns nothing. In case of a tie, an unbiased random draw determines the winner among the two bidders. Let b_i denote the bid submitted by bidder i and c_i his private cost. Each player maximizes his own expected profit

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

If bidders are (commonly known to be) risk neutral and if 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 $b_\omega(c_\omega) - c_\omega$. Symmetry, of course, only applies to the a priori expectations of other's costs. When bidding, the two contestants will most likely face different costs and expect them to be different.[9]

7 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.

8 The property ruling out any arbitrary (dis)favoring of bidders is envy freeness according to bids in the sense of $p(b)\text{-}b_\omega \geq 0 \geq p(b) - b_i$ for $i \neq \omega$, where $p(b)$ denotes the price paid to the winner ω as determined by the bid vector $b = (b_1, b_2)$. This implies $b_\omega \leq p(b) \leq b_i$ for $i \neq \omega$. Asking additionally for equal payoffs according to bids, i.e. $p(b) - b_\omega = 0$, further implies $p(b) = b_\omega$. Thus, envy freeness and equal payoffs according to bids together characterize the rules of lowest bid = price procurement auctions as analyzed here. To characterize axiomatically the second (-lowest bid) price rule one only has to substitute "equal payoffs according to bids" by "incentive compatibility" (Vickrey 1961).

9 The equality axiom used in the previous footnote only guarantees equal payoffs according to bids, but not according to true costs which are idiosyncratic and privately known and, thus, mostly not objectively, i.e., interpersonally, verifiable.

Successful coordination aims at both bidders choosing $b_i(c_i)$ close to 150, the upper price limit of the buyer, and at selecting ω, the bidder with the lower cost, as winner. Assuming that bidders can trust each other's promise (this pattern might be explained by guilt aversion or a preference for promise-keeping per se; e.g., Charness and Dufwenberg 2006; Vanberg 2008), one way 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[10]

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

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.

Another possibility is to coordinate by mutually trusted 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 $(\neq i)$. Due to $0 \leq s < ½$ bidder i remains solely responsible for $b_i(c_i)$ as the majority share holder of firm i. The solution is given by (see Appendix 1)[11]

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

For $s \to ½$ the solution approaches cooperative behavior with $b_i^{1/2}(c_i) = 150$ for $i = 1, 2$. If $s = 0$ it approaches the competitive benchmark, i.e., $b_i^0(c_i) = 75 + \frac{1}{2}c_i$ for $i = 1, 2$.

The two benchmark solutions for collusion are derived under the assumption that the bidders are bound by their agreement. However, as such ring formation is illegal, these binding agreements are not legally enforceable. In the experiment we therefore allow the subjects to agree on collusive behavior, but exclude such agreements to become binding. 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. This procedure was implemented in each of the several auctions played by subjects in our experiment (i.e., in each of these auctions each bidder i was informed about the individual cost

[10] To equilibrate such collusive bidding, mutual trustworthiness must be sufficiently strong, e.g., in the sense of regret exceeding the gain of winning the auction at the highest possible price of 150.

[11] Again, this requires sufficiently strong trustworthiness to be an equilibrium, specifically of keeping one's promise to share one's profit in case of winning.

value c_i before submitting a bid b_i).[12] To facilitate statistical analyses and to make data straightforwardly comparable, the same time series of randomly and independently selected cost values (c_1, c_2) was used in all treatments.[13]

After reading the instructions (see Appendix 2) and asking privately for clarification, subjects play two training rounds of the auction against the computer. The idea was to familiarize participants with the task of bidding in first-price sealed-bid procurement auctions without an opportunity to coordinate behavior. 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 simply choose their individual bid b_i based on the realized individual cost value c_i in the usual fashion of auction experiments (see Kagel and Levin 2011).

In the following three treatments, the second stage is designed in a similar way as the control treatment, i.e., whatever subject arranges in the first stage (see below) does not constrain their bidding decisions made in the second stage. The different treatments imply different cognitive demands[14] ranging from having to focus on how to arrange voluntary cooperation to numerical choices of how to limit competition by restricting the bidding range or suggesting profit sharing.

- In the *communication treatment* the two bidders are given the opportunity to exchange text messages with the help of an email program offered by the experiment software package Utah,[15] which is used for the computerized experiment. Bidders can freely discuss bidding strategies, their costs, or other issues, but are not allowed to provide any information that could reveal their identity or to agree on side payments. Lying was not forbidden by our instructions. After 5 min of communication, bidders independently submit their individual bid b_i based on the realized individual cost value c_i (without being bound to what they have promised to do).[16]

[12] Revealing individual cost values before bid submission is quite common in experimental research (see Kagel and Levin 2011, for a review of auction experiments). The idea is to learn more about bidding behavior by letting subjects repeatedly respond to *realized* cost values instead of by eliciting bid functions which assign a specific bid for any cost value that could be *possibly realized* (which is an alternative method to study bidding behavior).

[13] Some additional sessions with varying time series of cost values were conducted in order to test the robustness of results against the specific cost series chosen. We observed no obvious bias.

[14] This is why we refrained from the usual practice of trial rounds and/or control questionnaire before the experiment.

[15] For further details, please contact the authors.

[16] Note that, in contrast to the restricted bidding range treatment and the mutual shareholding treatment, no hint was given on how to collude when not being informed about the other bidder's cost value.

- In the *restricted bidding range treatment*, the two bidders $i = 1, 2$ 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 that bidders are informed about ε only (implying that the bidder with the lower proposal knows the exact value of both proposals whereas the other one only knows that her proposal was the highest proposal). Both bidders can then restrict themselves to submit an individual bid based on their realized individual cost value c_i 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 (implying that the bidder with the higher proposal knows the exact value of both proposals whereas the other one only knows that her proposal was the lowest proposal), both bidders determine their individual bid b_i based on the realized individual cost value c_i. The winner of the auction ω can then give the loser his share $s = t/200$ of the profit, but is free to neglect what t recommends him to do.

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 in public procurement. 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.

Communication obviously allows the two competitors to develop some form of solidarity by email chats what in turn might induce them to bid less aggressively. On the other hand coordinating on ε or s is much more focused on *how* to collude what could imply strong demand effects for collusion. Both ideas, coordinating on ε or s, still allow for private values to matter for who wins what,[17] but let bidders control for what they jointly earn. Since all coordination devices are cheap talk the default hypothesis is of course to observe no treatment effects at all.

In total, 204 undergraduate students participated in the experiment. They were recruited from the University of Jena using ORSEE (Greiner 2004).[18] 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.[19] We implemented

17 Actually, such variability seems attractive when being monitored by antitrust authorities. In case of complete information such variability would require coordinating on alternating in winnings.

18 Undergraduate students who registered in ORSEE to participate in laboratory experiments at the University of Jena were invited via automatically generated e-mails and registered for a specific session. We can thus say that subjects were randomly allocated to the experimental treatments. Moreover, subjects were not informed about the content of the experimental conditions unless they participated in a session.

19 In none of the treatments subjects were informed about the size of the matching group to discourage even further their anyhow unlikely reputation concerns (in very stochastic environments like our setup, where cost levels change a lot, small matching groups usually suffice to discourage repeated interaction effects). 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.

Table 1 Treatment types

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

matching groups to guarantee statistically independent observations (as no participant of one matching group ever competes with somebody in another matching group). Subjects played several auctions of one treatment type, but were not informed about the specific number of auctions to be played. At the end of each session five auctions were randomly selected and subjects were paid according to their profits made in these auctions. The number of auctions per session was chosen in a way that the duration of the experiment was the same for all treatments (what further justifies paying not all, but five random auctions across treatments). Of course the number of endogenously determined auctions may not suffice for behavior to converge but should clearly reveal the learning direction for the three treatments. 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 min. Table 1 includes treatments, sample sizes, and the number of auctions played in each treatment.

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 %) are 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 and Levin 2011). From a neoclassical point of view, the dominance of overbidding the benchmark prediction can be explained by assuming some form of risk aversion. This explanation was debated among experimental economists, however. More basically, it seems doubtful that participants engage in counterfactual considerations as assumed by Bayesian equilibrium analysis (see Kagel and Levin 2011, for a discussion; for an evolutionary justification of RNE-bid functions denying such considerations see Güth and Pezanis-Christou 2015). Only 4.0 % of bids are equal to the predicted bids and 19.5 % of observed bids are higher.[20] Figure 1 illustrates the bids submitted in the 22 auctions sorted by subjects' cost values.

[20] Appendix 3, Table 6 provides more detailed bidding data.

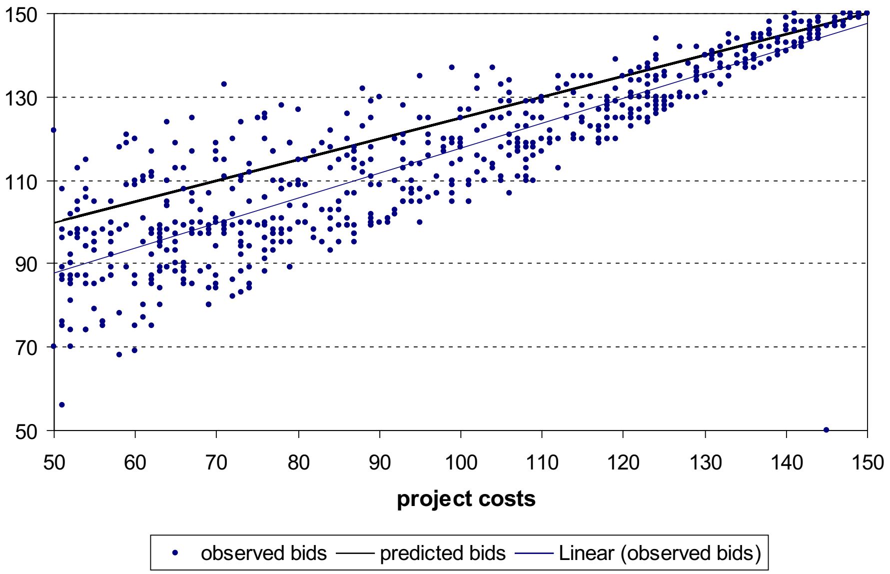

Fig. 1 Bids observed in the control treatment

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 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 ($p < 0.024$).

Result 1 (RNE): Compared to the equilibrium benchmark (RNE) the dominant tendency is bid shading, i.e., bidders overbid their cost value less than predicted.[21]

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).[22] 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).

[21] This behaviour was also observed in the procurement auction experiment run by Brosig and Reiß (2007).

[22] Unless indicated otherwise, the analyses are based on data obtained in the sessions with the same series of cost values. Regressions including sessions with other series of cost values (variable) yield similar results which is also reported in the paper.

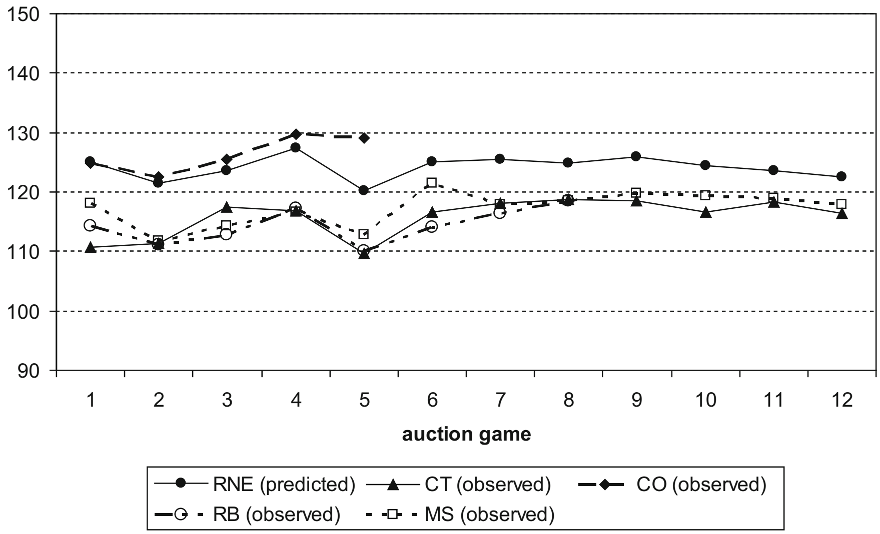

Fig. 2 Treatment comparison of average bids

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 Fig. 2.

We additionally run a linear mixed-effect regression describing how bids depend on treatment dummies, cost levels (COST), and experience (PERIOD). This regression also includes sessions with variable cost series. The results are included in Table 2. In line with our previous analyses, only in CO submitted bids are significantly higher than in CT. For RB we even observe significantly lower bids than in CT.

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).[23] Since bids and realized profits are correlated, we observe a similar pattern of treatment effects in a

[23] Table 7 in Appendix 3 provides more detailed profit data.

Table 2 Linear mixed-effects model of submitted bids

Independent variable	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
$\gamma_{\text{subject}} \sim N(0, 5.711)$		$\varepsilon \sim N(0, 11.804)$	

linear mixed-effects regression on periodic profits observed in the same and variable cost series treatments as in the mixed-effects model on submitted bids (see Table 8 in Appendix 3).

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 average 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).

Result 2: Neither the opportunity to coordinate on "restricted bidding" nor the opportunity for "profit sharing" significantly increases submitted bids. Only pre-play communication induces higher bids which, however, resemble more the benchmark solution than reflect collusion as it is commonly understood. 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.

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 3 illustrates the average efficiency rates observed in the first five rounds of each treatment.

Due to the a priori symmetry of both bidders, the predicted efficiency rate is 100 %, 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 collusion mechanisms does not change this result. Neither restricting the bidding range, nor mutual shareholding, nor pre-play communication between

Table 3 Observed efficiency

Auction	Efficiency rate (%)			
	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

bidders does significantly affect the average efficiency rates compared to the control treatment ($p > 0.199$ for all comparisons, exact two-tailed MWU test).[24]

> Result 3 (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 Collusion

This section illustrates in more detail the way in which the three collusion 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.

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 % for the winner and 0 % 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 %) or 50 (16 %).

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 lose the auction, submit relatively high proposals. This finding is further supported by the results of a linear mixed-effects regression on proposals t_{i} (see Table 4) which also includes sessions with other series of cost values (variable). The model shows that proposals and cost

[24] 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).

Table 4 Linear mixed-effects model of coordination parameter (MS)

Independent variable	Coefficient	Std. error	*p* value
Intercept	54.771	3.699	<0.001
COST	0.085	0.023	<0.001
$\gamma_{subject} \sim N(0, 27.124)$		$\varepsilon \sim N(0, 21.223)$	

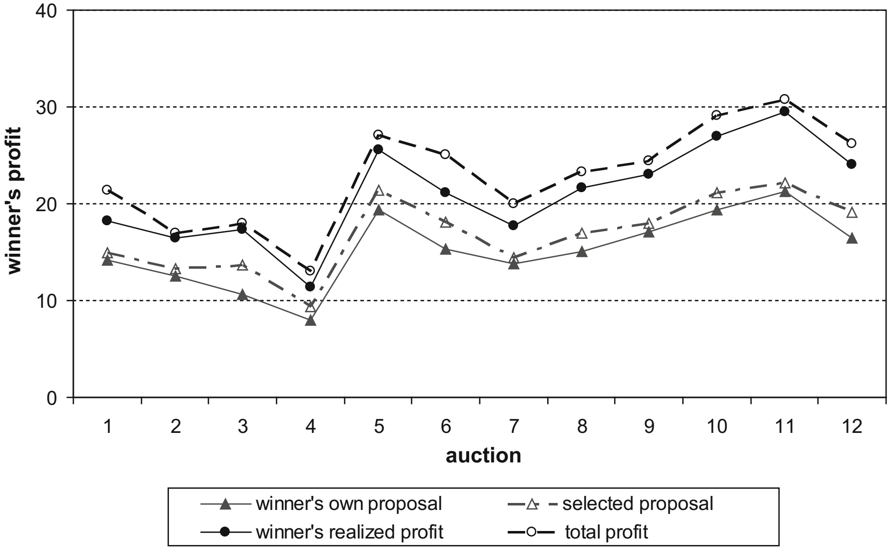

Fig. 3 Average proposals and profits

values (COST) are positively correlated. Yet, the large standard deviation of the residuals (sigma) indicates only limited predictive power.

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): 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 Fig. 3).

According to the selected proposals *t*, winners should receive, on average, 73.6 % of the total profit. Only 25.3 % of winners share the profit as suggested by *t*, however.[25] The majority of "deviators" keeps more of the total profit than

[25] Calculating this percentage, we count the number of all winners whose realized profits 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 winners 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.

proposed.[26] 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 % of the total profit while losers get 8.2 %. Apparently, exchanging non-binding proposals of mutual shareholding is not an effective mechanism for coordinating bidding behavior in first-price procurement auctions.

> Result 4 (Collusion 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 $\varepsilon_{\mathrm{i}} = 100$ 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). Similar results are obtained when applying a linear mixed-effects regression on proposals ε_i observed in both same and variable cost series treatments (see Table 5). Although the relation between proposals and cost values is weakly significant ($p = 0.066$), the large standard deviation ($\sigma_{\mathrm{SUBJECT}}$) of the random effect of subjects on the intercept points out the likely inaccuracy of such predictions.

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 Fig. 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 average, only 8.6 % of subjects submit a bid in line with the selected proposal.[27]

[26] 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.

[27] 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.

Table 5 Linear mixed-effects model of coordination parameter (RB)

Independent variable	Coefficient	Std. error	p value
Intercept	50.248	7.193	<0.001
COST	−0.077	0.042	0.066
$\gamma_{\text{subject}} \sim N(0, 32.640)$		$\varepsilon \sim N(0, 22.478)$	

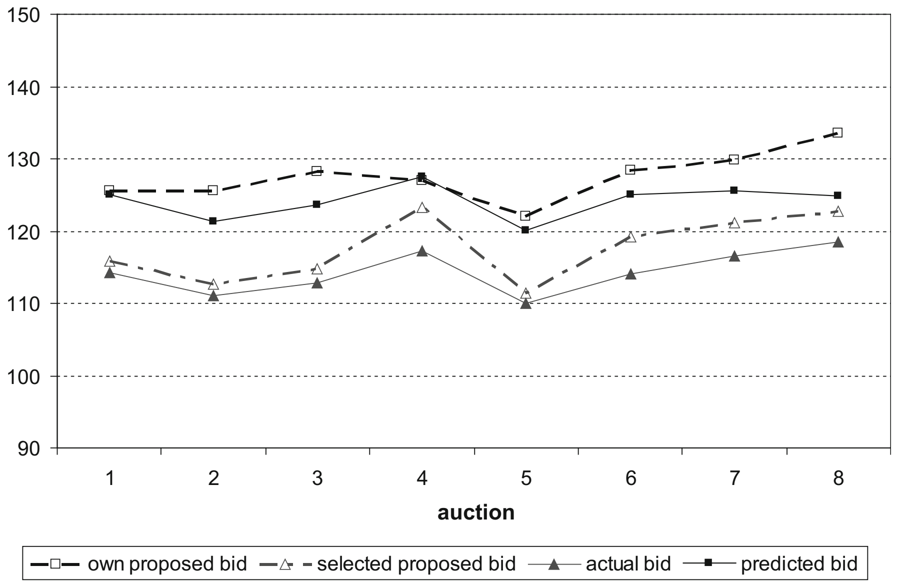

Fig. 4 Average proposed and realized bids

50.4 % of these deviators submit a bid that is lower than proposed and 49.6 % submit a bid that is higher than proposed.[28]

> Result 5 (Collusion 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

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 % of pairs at least one subject states that the email exchange makes no sense. Most pairs (about 65.0 %) start the discussion with a proposal regarding their bidding behavior (see Fig. 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

[28] About 52.6 % of "overbidders" chose a bid which was higher than the one suggested by the own ε_i.

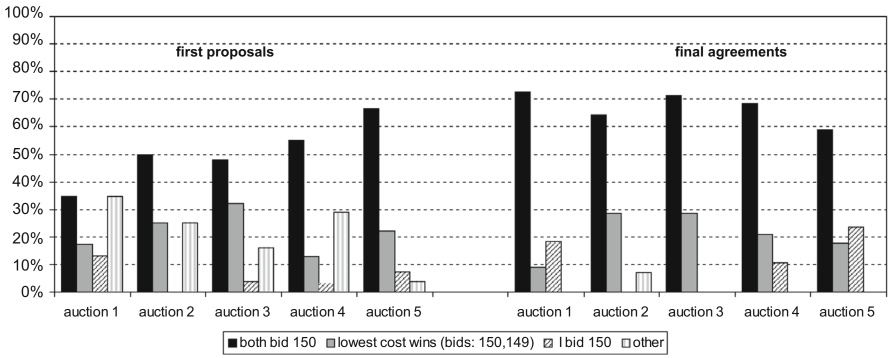

Fig. 5 Structure of first proposals and final agreements

possible bid. About 22 % 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.

About 37.5 % of all pairs reach a final agreement. Following the first proposals, most of the pairs agree that both players should bid 150 (67.1 %) 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 %).

About 55.2 % 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 % of them keep their promise. Those who agree on bidding 150 realize this agreement in about 50.3 % of all cases, and 41.7 % 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 % 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 %) state no cost value, however. 22.5 % of subjects give a range for their cost and only 22.0 % state an exact cost value. Of course, nobody could verify the statements. Interestingly, in all five auctions only 33.6 % of subjects lie about their cost. That is, most of the subjects who make a statement 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 %).

Result 6 (Collusion 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

This study focuses on the effectiveness of non-binding agreements in one-shot procurement auctions with independent private costs. We observe that cheap talk agreements to share profits or to restrict the bidding range do not enhance the bidders' profits. Rather it seems that Keynes' (1936) intuition was right: If bidders can freely communicate—while having breakfast—they will manage to cooperate. Most notably, this even holds when communication is restricted to anonymous email messages. This confirms the key role of communication for establishing and maintaining voluntary collusion (see also Genesove and Mullin. 2001).[29]

A more detailed investigation of communication protocols reveals that most bidders try to coordinate on bidding the highest possible value (i.e., 149 or 150) and, in more than half of the cases, keep their agreements. That subjects tend to stick to their promises has been reported also in other studies analyzing the content of unrestricted communication (see, e.g., Vanberg 2008, who tests two possible explanations for observed promise-keeping), though most of this research focuses on less competitive environments. Existing theory has rather little to say about the observed effects of communication in collusion. Besides stressing the need to model this effect (see the contributions made by Ellingsen and Johannesson 2004; Charness and Dufwenberg 2006; Chen et al. 2008; Kartik 2009), what implications can be drawn for the design of procurement auctions?

Our study suggests that even in auctions which seem less prone to collusion, communication channels that allow bidders to freely exchange messages with each other have to be carefully controlled. An elaborate design attempting this has also to consider recent empirical findings of communication effects between buyers and bidders in e-procurement. For example, Heinrich (2011) reports that not only positive feedback ratings, but also sending messages are quite effective in increasing a bidder's probability of winning.

Nevertheless, although anonymous messages increase bidders' profits significantly, they have a quite limited effect on competition in our stochastic decision environment with private information: bidders' profits are far lower than what can be maximally gained by voluntary cooperation. Private information renders voluntary cooperation very difficult since bidders can "free ride" by pretending lower than actual costs. Accordingly, the robust evidence of voluntary cooperation based on social dilemma games with complete information, suggests a very biased intuition of how likely attempts to limit competition succeed.

[29] Another idea would have been to investigate mechanisms that combine restricted bidding or mutual shareholding with free-form pre-play communication like "restricted bidding range negotiation after communication" or "mutual shareholding negotiation after communication". This combination might help to establish anticompetitive behavior since it provides a clear hint on what to communicate about when trying to restrict bidding competition. It, thus, focuses the cheap talk exchange on how far one wants to restrict competition. Furthermore, it seems natural that one can freely communicate when being able to "restrict bidding" or to arrange "mutual shareholding". Since our focus is on isolating the effects of the three mechanisms, we implemented them in separate treatments, however.

Our study appeals to both, the literature on the "dark" side of human nature and that of the economics of crime. While former research explores anti-social behavior in a more general sense, the latter, by definition, is restricted to illegal practices. We focus on illegal practices in the sense that whatever the competing bidders have agreed to do is cheap talk, i.e., non-binding. But since in our stylized scenario there is no antitrust regulation, using one of the three coordination devices is not illegal, i.e., it cannot be detected and sanctioned. As such our study provides the basis for further research on which antitrust regulation is required specifically for each practice. Nevertheless, our results already foreshadow a likely conclusion for this antitrust regulation: since at least in on–off lab interactions first-price procurement with private cost information renders some practices rather unsuccessful, we should try to maintain as far as possible

- the on–off aspect by ensuring free entry and exit (e.g., by removing the barriers of auction entry and exit which are often justified to protect "home" industry),
- private cost information, e.g., by enforcing detecting and sanctioning any information exchange of competing bidders, and
- the anonymity of the actually involved bidders to render chat conversations of bidders before competing with each other less likely.

The latter seems important since, without anonymity, pre-play chat conversation, as experimentally implemented, can hardly be avoided in the modern world with all sorts of electronic communication devices.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Appendix 1: 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

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

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

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

$$E_i(b_i|c_i) = (1-s)(b_i - c_i)\int\limits_{f^{-1}(b_i)<c_j\leq 1} \mathrm{d}c_j + s\int\limits_{f^{-1}(b_i)\geq c_j\geq 0}\left[f(c_j) - c_j\right]\mathrm{d}c_j$$

$$= (1-s)(b_i - c_i)\left[1 - f^{-1}(b_i)\right] + s\left[F\left(f^{-1}(b_i)\right)\right]\int\limits_{f^{-1}(b_i)<c_j\leq 1} \mathrm{d}c_j$$

$$+ s\int\limits_{f^{-1}(b_i)\geq c_j\geq 0}\left[f(c_j) - c_j\right]\mathrm{d}c_j,$$

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

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

which can be simplified as follows:

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

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

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

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

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

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,

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

Appendix 2: Instructions (translated from German)

Welcome to this experiment!

Preliminary remarks

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 5 min 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 raising your hand. We will then come to your place and answer your questions.

Description of the auction

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 less 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 greater 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 equal to the bid of the other bidder, you are awarded the project with a probability of 50 %.

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 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 amounts 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:

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

$$\text{The losing bidder obtains: } N/200 \; * \; (\text{winner's bid} - \text{winner's cost})$$

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 5 min. 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 3

See Tables 6, 7, and 8.

Table 6 Submitted bids—summary statistics

Treatment	Cost series	Periods	Deviation from RNE		
			Median	Mean	Std. dev.
CT	Same	1–5	−8.25	−10.29	14.89
	Same	6–10	−5.50	−7.38	9.99
	Same	11–15	−6.00	−6.00	8.34
	Same	16–20	−4.50	−6.04	8.64
	Same	21–22	−5.75	−6.55	8.06
RB	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 7 Period profits—summary statistics

Treatment	Cost series	Periods	Period profit		
			Median	Mean	Std. dev.
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
RB	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 8 Linear mixed-effects model of period profits

Independent variable	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
$\gamma_{subject} \sim N(0, 6.262)$		$\varepsilon \sim N(0, 12.995)$	

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

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