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JEL Classification: D44, C92

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Anonymity deters collusion in hard-close auctions:

Experimental Evidence

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1. Introduction

Auction market design has become a popular topic in theoretical and experimental economics. The growing interest in the field is due to the increased significance of auction mechanism design in empirical government procurement, privatization programs and internet markets. To organize, for example, markets for spectrum licenses, gas leases or electricity the auction design must be carefully chosen to prevent undesired outcomes,¹ since these markets usually involve the sale of multiple units (worth several millions of dollars) to a small number of potential bidders. It has been argued that one of the most important challenges to the auction designer is to prevent (open or tacit) collusion among the bidders against the seller, since such agreements are likely to result in decreased revenue for the seller as well as in decreased efficiency (e.g., Klemperer 2002). Several circumstances that may favor collusion in multiple-unit auctions have been pointed out in the literature. For instance, if the auction design involves several stages, bidders may use the early stages to signal their willingness to cooperate with the other bidders.² Ascending auctions may offer the possibility of punishing uncooperative behavior immediately if bidders are simultaneously competing in more than one auction (Brusco and Lopomo 2002) or, in the case of repeated interaction (Kwasnica and Sherstyuk 2007), at a later stage.

This paper reports the results of a laboratory study designed to measure the losses of revenue and efficiency due to tacit collusion among bidders using a simultaneous, multi-unit hard-close auction. The bidders simultaneously participate in several single-unit auctions with heterogeneous objects. The hard-close auction is defined as a dynamic auction with a known number of bidding stages in which bidders can subsequently submit enhancing bids and the high bid is privately known by the high bidder. The auction considered here is a stylized discrete-time version of the ascending bid auction with a fixed ending time as used on eBay, the world's most successful e-commerce auction platform.³ This auction format suits the purposes of the present study for at least two reasons. Firstly, Klemperer (2002) conjectures

that auction formats which combine both ascending and sealed bid formats may have the necessary characteristics to discourage collusion. Since we use a repeated setting, we test the robustness of Klemperer's conjecture under quite adverse conditions. Nonetheless, the data collected in the reported *anonymity* treatment in which subjects interact repeatedly but anonymously seem to provide support for Klemperer's conjecture. Secondly and despite this conjecture there remains an apparent concern about collusion in empirical online markets. For instance, eBay enables sellers to choose an anonymous auction design involving covered bidder names, and even enforces an anonymous bidding format for more valuable items in order to obstruct collusion among customers.⁴ By means of our experimental data we examine how reasonable this concern is in a collusion-friendly environment. In particular, we address this issue in our *friends* treatment for which any group consists of real-world friends who jointly sign up for participation in the experiment.⁵ In the friends treatment, we find more evidence for collusion than in the anonymity treatment. However, only four of ten groups realized "conspicuous" supra-equilibrium payoffs. The data thus suggest that without communication, even among subjects who repeatedly interact with each other, coordination towards a collusive outcome is not easily established.

Our study is based on the independent private value model. Some experimental results have been advanced that suggest collusion may occur in such an environment. It has been shown that open collusion may be enabled through communication between subjects in the repeated first price auction under otherwise controlled laboratory conditions (Isaac et al. 1984, Isaac and Walker 1985). Tacit collusion has been observed in the ascending auction market. For instance, Kwasnica and Sherstyuk (2007) find that subjects develop tacit collusive strategies in repeated interaction even without explicit communication in two-bidder two-object markets but not in five-bidder five-object markets. Brown et al. (2006) elicit tacit collusion for a market with eight bidders and eight objects in ascending auctions when public information is given on the bidder's preference ordering. Through the public information on

the preference ordering, subjects are enabled to coordinate their demands and to achieve the collusive outcome with only few repetitions. In general, Sherstyuk (forthcoming) concludes on the basis of her survey, and in line with Klemperer's conjecture, that the auction format is crucial for collusion in experimental auctions. In particular, she suggests that the sealed bid auction is far less susceptible to tacit collusion than the ascending auction.

Since the hard-close auction involves a final sealed bid stage, the auction design studied here includes a feature that is arguably unfavorable for collusion.⁶ But the experimental design also involves favorable features for collusion including repeated interaction and a multiple simultaneous market structure where the number of bidders equals the number of auctions. Due to the finite number of repetitions, signaling and punishment are possible but incredible from the game theoretic perspective of rational agents. A collusive equilibrium cannot be sustained, even with only two bidders, due to the possibility of "sniping", because bidders cannot punish uncooperative last-stage bids submitted by the others. The standard backward induction argument leads to competitive bidding in each repetition. However, cooperation can be achieved in the laboratory in the repeated prisoner's dilemma game where standard theory also predicts competitive play in each repetition (e.g. Loos and Neugebauer 2007). Taking the collusion possibilities into account, the simultaneous multi-unit hard-close auction shares many similarities with the prisoner's dilemma concerning cooperative behavior.

The paper is structured as follows. In the following second section, the simultaneous, multi-unit hard-close auction is introduced and testable hypotheses are presented. The third section presents the experimental design. The results of this study are reported in the fourth section and the fifth section provides concluding remarks.

2. The simultaneous multiple-unit hard-close auction

The single-unit hard-close auction is a dynamic, discrete auction which proceeds in $T < \infty$ bidding stages (Füllbrunn and Sadrieh 2006). In each bidding stage $t \leq T$, every bidder $i = 1$,

2, .. , N may renew her bid of the previous stage $t-1$ or enhance it by raising it above the current price. The *high bidder* at stage t is the player who has submitted the highest bid by stage t . The *current price* at any stage t is equal to the second highest bid plus the smallest possible increment $\varepsilon \geq 0$ if the highest bid exceeds the second highest bid by more than ε , and it is equal to the highest bid otherwise. The bidders share common knowledge about the current price and about the high bidder, but the highest bid is not revealed unless highest bids tie. Ties are randomly broken to determine the high bidder. The auction terminates after stage T , and the high bidder wins the auction and pays the final current price. Since the private value model is considered here, in which each bidder's valuation for the object is privately and independently drawn from a commonly known distribution, the payoff for the buyer is the difference between her private value and the final current price. All other bidders' payoffs are zero. Therefore, the stage game in T is equivalent to a sealed bid auction in which each bidder has a (weakly) dominant strategy to bid her private value. Under the standard rationality assumption in non-cooperative game theory, all $T-1$ previous stages can be considered as '*cheap talk*' since bids should equal private values in stage T . In equilibrium, the bidder with the highest value wins the auction and pays a price equal to the second highest value plus ε given that this amount is not greater than his own value.

Given the empirical relevance of thin auction markets with identical participants, we study the bidding behavior of a small number of bidders who simultaneously compete in N single-unit auction markets. Each bidder has N identically and independently drawn values, one for each single-unit market. Even under these conditions which evidently open the floodgates to collusion as, for example, each bidder could specialize in bidding for the privately most valued unit, the strategy of bidding the value in the final auction stage remains the weakly dominant one in the hard-close auction. This prediction for the N -bidder N -object market is quite different from other auction formats as is the case in, for instance, the simultaneous English or soft-close auction format applied by Kwasnica and Sherstyuk (2007)

which facilitates a collusive outcome.⁷ While the soft-close auction, in the context of N single-object markets and N bidders, may be thought of as representing an indefinitely repeated game, due to its undetermined ending time, the simultaneous multi-unit hard close auction may be thought of as representing a finitely repeated prisoner's dilemma game (Füllbrunn 2007).

To illustrate this point, consider a simultaneous hard-close auction with two risk neutral bidders ($i = 1, 2$) who compete in two single-unit markets ($j = 1, 2$). The bidders' values for the two objects v_{ij} , are identically and independently drawn from a uniform distribution over the unit interval. Assuming the existence of a *collusive strategy* C in the sense of Brusco and Lopomo (2002); if $v_{i1} > v_{i2}$ player i bids in the first stage $b_{i1} = \varepsilon$ and $b_{i2} = 0$, and vice versa. If someone deviates from this bidding strategy or if $b_{1j} = b_{2j}$ in any market j , players submit $b_{ij} = v_{ij}$ in both markets at the latest in stage T . However, if bids are observed to be different for both players $b_{1j} \neq b_{2j}$, no further action is taken in the following stages. Assume also the existence of a *sniping strategy* S which mimics the collusive strategy but involves the submission of a bid equal to the value in stage T , $b_{ij} = v_{ij}$. Consider now the possible payoffs that may result in the game if players either play the collusive or the sniping strategy. Assume that $v_{11} > v_{12}$ and $v_{21} < v_{22}$, such that each player submits a bid only to the market $i = j$ in the first stage.⁸ According to this assumption, table 1 shows the payoff matrix of the resulting prisoner's dilemma game for the limit $\varepsilon \rightarrow 0$. If both players choose the collusive strategy C , each bidder receives a payoff that equals her highest value. If one bidder plays C and the other the sniping strategy S , the defecting player's payoff is the sum of her private values while the cooperating player receives nothing. If both play their strategy S , player 1 receives the following expected non-collusive payoff (equivalently, the payoff for player 2 is computed)

$$\pi_1(S, S) = \int_0^{v_{11}} (v_{11} - v_{21}) \times 2(1 - v_{21}) dv_{21} + \int_0^{v_{12}} (v_{12} - v_{22}) \times 2v_{22} dv_{22} . \quad (1)$$

The first integral in the equation represents the expected payoff from the first market for which player 1 has his higher value and player 2 has her lower value. The difference in the two values in this integral is thus multiplied by the probability that the first order value of the first player is greater than the second order value of the second player. The second integral represents the corresponding expected payoff for player 1 from the second market where he has his lower value and player 2 has her higher value.⁹

Table 1. Expected payoff matrix

		<u>Player 2</u>	
		<i>C</i>	<i>S</i>
<u>Player 1</u>	<i>C</i>	$v_{11}; v_{22}$	$0; v_{21} + v_{22}$
	<i>S</i>	$v_{11} + v_{12}; 0$	$(3v_{11}^2 - v_{11}^3 + v_{12}^3)/3; (3v_{22}^2 - v_{22}^3 + v_{21}^3)/3$

It is straight forward that *S* is the strictly dominant strategy, i.e., mutual sniping is the non-cooperative equilibrium outcome. As usual the result of the prisoner's dilemma extends to the finitely repeated game by the backward induction argument. Based on this reasoning, the testable benchmark hypothesis for this experiment is thus as follows.

Hypothesis 1. (defection)

The bidders submit non-cooperative equilibrium bids, i.e., bids equal values in each auction. The market allocation is efficient, i.e., the winner has the highest value and the price equals the second highest value plus ε .

In contrast to Hypothesis 1, theoretical (Kreps et al. 1982) and experimental results (Andreoni and Miller 1993) have suggested that if players face a small probability of being matched with

a tit-for-tat player, collusion in the finitely repeated prisoner's dilemma is possible. The tit-for-tat player starts the repeated game by playing C and thereafter copies the observed strategy of the other player. Under the condition of a threat of punishment, it is beneficial for the rational player to copy the behavior of the tit-for-tat player for almost all repetitions of the game. Therefore, mutual playing of the collusive strategy is also a reasonable strategy in the repeated game which results in a higher payoff for the bidder and a lower revenue for the seller. Hence, the testable alternative hypothesis is:

Hypothesis 2. (collusion)

Bidders collude and coordinate their bids so that prices are lower than in the non-cooperative equilibrium. Due to collusion, the auction winner does not necessarily have the highest value which implies that the market allocation is not always efficient.

Beside the described collusive strategy there are many other strategies to coordinate individual demand in the market. For instance, bidders can signal their valuation in the first stage by submitting a small but constant fraction of their value. Or the bidders can divide the markets among themselves so that each bidder wins in the same market every time. Another possibility is the use of side payments after the auction while having one active and $N-1$ passive bidders during the auction.

This paper reports the results of experiments with three bidders in three simultaneous markets, i.e., $N = 3$. As a matter of fact, the coordination difficulty increases with m . Based on the collusive strategy in the two-player two-market game, the mutual collusive outcome may be achieved in two out of four cases. Using the collusive strategy in the three-player three-market game, the mutual collusive outcome is reached only in six out of 27 cases. In general, the collusive strategy as described in the PD matrix yields a probability of the collusive outcome of $N! / N^N$. The possibility that subjects use the dominant sniping strategy S , i.e.

submit the equilibrium bid by the last stage in either of the games, and the subsequent punishment by the other players in the following rounds may decrease the likelihood of a collusive outcome further. In sum, the three-bidder scenario induces increased competition and exacerbates the coordination problem of the experimental subjects in comparison to the discussed two-player two-market PD game scenario.

3. Experimental Design

In this section details the experimental procedures and introduces to the two laboratory treatments, i.e. the *anonymity* treatment and the *friends* treatment. Both treatments involve a partner's setting, i.e., repeated interaction. The treatments differ with respect to the social ties of the experimental subjects. While the friends treatment involves groups of three subjects who jointly sign up for participation in the experiment, the anonymity treatment involves anonymously interacting subjects.

To us, the friends treatment seems appropriate to study collusion since problems of collusion have been suspected in empirical auction markets where the identities of the bidders (attendees or absentees) were known (Klemperer 2002). We presume that collusion is more likely if bidders know each other and will surely meet each other again after the auction. Recent experimental evidence evokes such a presumption as it has been shown that social ties affect pro-social behavior; e.g., Leider et al. (2006) reported that subjects are more generous when they are knowingly matched with their friends than when they are matched with strangers. Similar considerations may have led the internet auction house eBay to allow anonymous bidding only in auctions of more valuable items. Based on these considerations, we formulate the third testable hypothesis for our experimental study.

Hypothesis 3. (between-treatments comparison)

Collusion is more likely in the friends treatment than in the anonymity treatment.

Accordingly, prices and efficiency levels are likely to be higher and payoffs should be

lower under conditions of the anonymity treatment than under conditions of the friends treatment.

3.1. Experimental procedure

Experiments were computerized (Fischbacher 2007) and conducted at the Leibniz University of Hannover in January 2006. At the beginning of the experiment written instructions were read aloud and subjects' questions were answered.¹⁰

At the outset of the experiment, participants were randomly matched into groups of three bidders within which they were given the bidder-names yellow, red and blue, respectively. Thus they were identifiable both within and across periods of the experiment since all decisions could be traced back to the decision maker. Defectors, in particular, could be easily identified and a subject was able to inflict a (bilateral) punishment on a defector (in the sense of a tit-for-tat strategy). This feature should have facilitated a tacit collusion between group members given that they manage to coordinate their demands. However, tacit collusion was complicated due to the fact that no public information about preferences (as in Brown et al. 2006) was supplied, and no open collusion was possible since subjects were not able to talk to or see each other (as in Isaac and Walker 1985).

The three subjects within a group simultaneously competed with each other in three simultaneously run single-unit hard-close auctions labeled A, B, and C. A single *heterogeneous* object was sold in each such auction. At the beginning of the auction, each bidder was assigned an independent private value drawn from the uniform distribution over the interval [100.00 ; 200.00], which was rounded to the second decimal for each object A, B and C. Subjects' bids were limited to the interval [0.00 ; 200.00]. Thus, all bids included two decimals and subjects were able to overbid their value. The experiment involved 16 repetitions with the same three-subject groups.¹¹ Bids and values were expressed in the experimental currency unit ECU which was exchanged at a rate of 1 ECU = 0.02 Euro at the

end of the experiment. Since losses were possible, though unlikely, the subjects were given, instead of a show-up fee, an initial balance of 150 ECU. Subjects were truthfully instructed about all the features of the experimental design.

Each auction involved $T = 6$ stages and the *current stage* was posted on the computer-screen. For each stage, subjects submitted a non-negative maximum bid in each auction. The bid could not be reduced from one stage to the next, but could be maintained. In the first stage, after having received an independent private value for each object, subjects had to enter a bid for each object into the spaces on the computer screen and confirm these bids by a press on the button. In all later stages, the previous bid for an object was maintained by default, but could be enhanced by entering a new bid above the current prices. After each stage, subjects received common information for each auction including the current price, i.e. the minimum of the high bid and ‘the second-highest bid + 0.01 ECU’. All bids were identified with the submitter’s bidder name, and (as in the standard protocol in eBay auctions) all bids but the high bid were revealed in all stages. If in an auction the high bid was submitted by two or three bidders at the same stage, the high bidder was randomly selected. Otherwise, the high bidder would only change when the maximum bid of another bidder exceeded the maximum bid of the previous high bidder. At the end of the auction, i.e., after the sixth stage, the high bidder won the auction and paid the final current price resulting after the sixth stage. Information was then publicly disclosed including the auction winners’ bidder names and the prices paid. Each bidder was informed about her private profits. Profits were added to the cash balance of the subject, and the final cash balance after 16 repetitions was exchanged and paid out in Euro. From the instructions, it was common information for both treatments that subjects were going to be interacting in 16 repetitions of the simultaneous three-object hard-close auction. In total 48 subjects participated in one of the two sessions. According to our records, no subject had previously participated in an auction experiment.

3.2. Anonymity treatment

Subjects were recruited from among economics undergraduates. They arrived at the computer room and drew a covered number from a tray which indicated the cubicle where they were seated. Then they were randomly assigned to groups of three in which they interacted in 16 repetitions of the simultaneous hard-close auction. Subjects always interacted with the same *partners* but interactions were *anonymous*. While subjects did see each other at the entrance, no information was disclosed regarding the group composition at any time before, during or after the experiment. In total, 18 subjects participated in the anonymity treatment making up six independent groups. From each such independent group of three subjects we gathered the bids they submitted in the 48 ($= 16 \times 3$) single-unit hard-close auctions in which they participated. In total, there were 288 ($= 48 \times 6$) such auctions.

3.3. Friends treatment

For the friends treatment, groups of three subjects were recruited. They jointly signed up by writing their three names in the list. If a member of any group was missing upon arrival at the laboratory, the entire group could not participate in the experiment. Given full attendance, one group member drew a covered number, i.e., the identification of the group, from a tray. The number indicated the cubicles of the three subjects of the group. One member of the group, the “yellow” bidder, was seated in the first rows; the “red” bidder, was seated in the following rows; and the “blue” bidder, was seated in the last rows of the computer room. In fact, no communication was possible between subjects. Before the experimental instructions were read they did not know about their task; they did not even know that they were about to interact with another. When the instructions were read, subjects were identified with their group. Each subject was told her own bidder name and the bidder names of their friends; they had to stand up from their seats so that their friends could see them. Hence, the bidder names and personal identities were common information within each group. In total, 30 subjects

participated in the friends treatment making up 10 independent groups who submitted bids to a total of 480 single-unit hard-close auctions.

4. Experimental Results

Table 2 gives an overview of the basic market statistics. In accordance with the hypothesis 3, the bidders' average payoff is significantly lower under conditions of the anonymity treatment than under conditions of the friends treatment.¹² (Throughout our report, it should be noted, when reference is made to statistically significant results, the five per cent significance level has been adopted). The seller's surplus per auction, more accurately speaking the difference of the observed average revenue and the non-cooperative equilibrium revenue which would have resulted if subjects bid their value, is significantly lower for the friends treatment than for the anonymity treatment.¹³ The efficiency, measured as the frequency of single-unit auctions where the bidder with the highest value is awarded the object, is significantly higher under conditions of the anonymity treatment than under conditions of the friends treatment. This result also supports the hypothesis 3. Details are presented in the following sections.

Table 2. Descriptive Statistics

	Treatment condition	
	anonymity	friends
number of independent observations	6	10
number of single-unit auctions	288	480
Bidder's average profit per unit	8.31 ECU	19.56 ECU
seller's average surplus compared to equilibrium revenue	-3.74 ECU	-44 ECU
frequency of efficient auctions	86%	67%

4.1. Price and revenue

According to hypothesis 1, the price should be equal to the second highest value plus 0.01 ECU. Only few observations exactly match the point prediction of this hypothesis. Therefore, it was decided to treat those prices as equivalent to equilibrium prices, which fall into the one ECU neighborhood of the predicted price. Figure 1 shows for both treatments how often the

observed price is close to this prediction and how frequently it is farther off. In 58% of the auctions in the anonymity and in 30% of the friends treatment, the observed and the predicted price differ by less than one ECU. On the other hand, it is observed that the price falls short of the predicted price by more than 25 ECU in 5% of the auctions of the anonymity treatment and in 42% of the friends treatment. The pooled regression shows that there is no time trend in the price data for either treatment. The formal data analysis leads to the following result.

Result 1

- 1) Prices are not significantly below the non-cooperative equilibrium under conditions of the anonymity treatment.
- 2) Prices in conditions of the friends treatment are both lower than the non-cooperative equilibrium prediction and lower than for the anonymity treatment.

Support (result 1).

- 1) The average second highest value for the anonymity treatment is 150.25 ECU and the average price, 146.72 ECU, differs from this prediction by -3.74 ECU. The median difference between price and second highest value is 0.00 ECU. According to the one-tailed Wilcoxon signed ranks test, the null hypothesis which suggests no differences between the data and the theoretical prediction cannot be rejected.¹⁴ Thus, hypothesis 1 cannot be rejected in favor of hypothesis 2 for the anonymity treatment.
- 2) The average price in the friends treatment is 106.31 ECU, which deviates from the average second highest value by 43.82 ECU. The median difference between price and second highest value is 11.25 ECU indicating a skewed distribution of price deviations in the friends treatment. The one-tailed Wilcoxon signed ranks test rejects the null hypothesis in favor of the alternative hypothesis of below equilibrium prices for the friends treatment.¹⁵ Prices are 38% higher in the anonymity treatment than in the friends treatment. The seller in the case of the friends treatment receives only 71% of

the non-cooperative equilibrium revenue compared to a 98% share for the anonymity treatment. The one-tailed Mann-Whitney test confirms that the difference between the treatments is significant.¹⁶ Hence, according to these test results we must reject hypothesis 1 in favor of hypotheses 2 and 3 in case of the friends treatment.

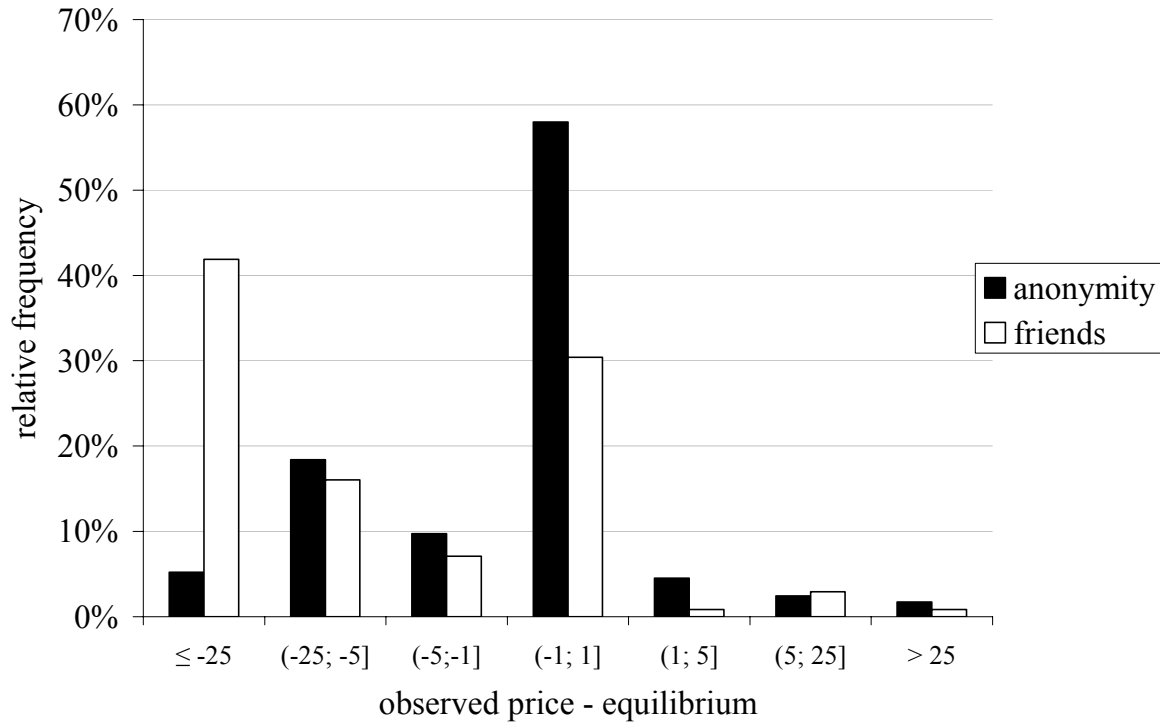


Figure 1. Relative frequency of price differences from the equilibrium

4.2. Efficiency

Figure 2 shows the relative frequency of efficient allocations over time. Efficient allocations are achieved with a relative frequency of 86% for the subjects of the anonymity treatment and 67% for the friends subjects. Based on the data, the following result can be stated:

Result 2.

- 1) The market allocation converges to efficiency under conditions of the anonymity treatment.
- 2) An efficient allocation is more likely in conditions of the anonymity treatment than in the friends treatment.

Support (result 2).

- 1) In the anonymity treatment, all units are efficiently allocated in the last repetition of the experiment (see figure 2). The relative frequency of efficient allocations increases significantly over time; the pooled regression on a time trend exhibits a slope that is significantly different from zero, the p-value is 0.001. With respect to the efficiency conjecture, the dynamics seem to favor hypothesis 1 over hypothesis 2 in the repeated setting of the anonymity treatment. The efficiency level for the friends treatment seems to increase over time too (pooled regression result, p-value = 0.032), but a closer look shows that this result is only due to the very low efficiency level in the first repetition. If the observation of the first repetition is discarded from the sample, the number of efficient allocations in the friends treatment remains quite steadily at 0.69.¹⁷
- 2) According to the one-tailed Mann-Whitney U-test, the hypothesis of equal efficiency levels in both treatments can be rejected. The exact p-value is 0.021. This result supports hypothesis 3.

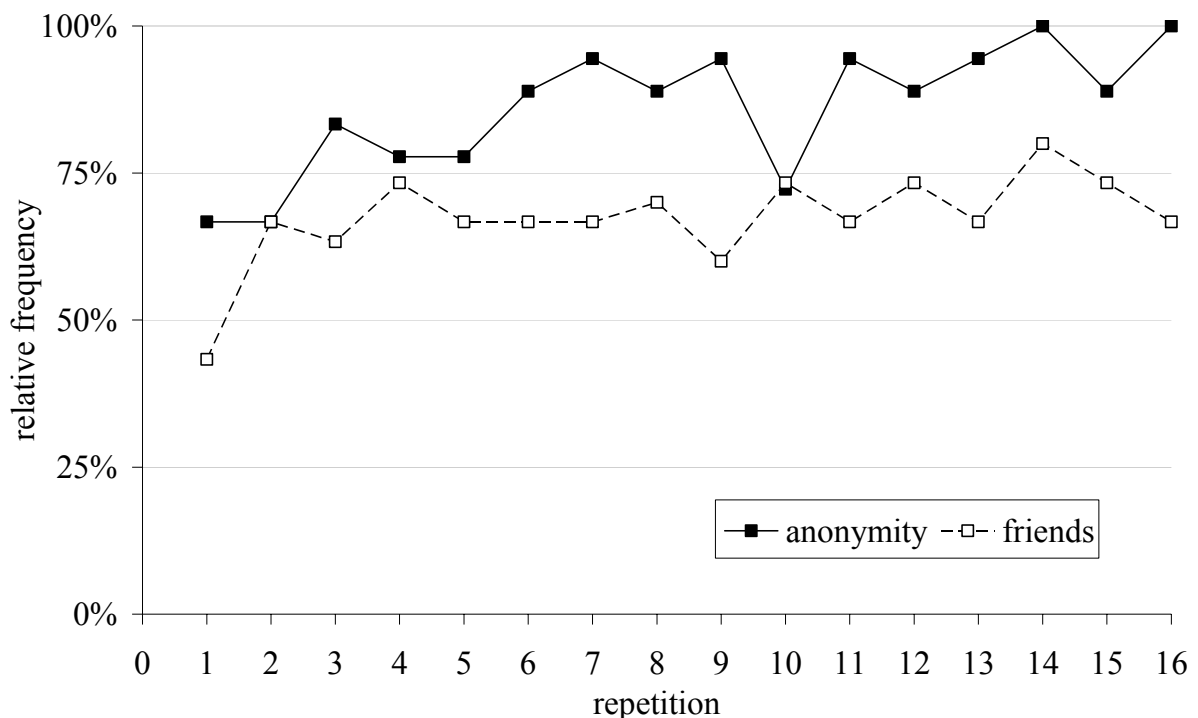


Figure 2. Relative frequency of efficient allocations over time

4.3. Bids

Many integer bids were observed, among which featured many prominent numbers (Albers and Albers 1983), although we had explicitly encouraged the usage of non-zero decimals. To study the predictions of the three hypotheses regarding last-stage bids, close-to-equilibrium bids are defined, in line with the procedure that was earlier applied to prices, as those bids that fall into the one ECU interval around the value. Since, due to the price enhancement rule in the auction, it frequently happens that the low-value bidder in a market cannot bid her value, we restrict the analysis of our research question to the bidders with the two highest values in an auction. The question asked was: do the bidders with the highest or the second highest values submit close-to-equilibrium bids?

Result 3.

In the anonymity treatment we observe a higher relative frequency of close-to-equilibrium bids and a lower frequency of bids below that level than in the friends treatment. With repetition, bids move closer to the predicted bid-to-value parity under conditions of anonymity.

Support (result 3).

Figure 3 shows how below-, above- and close-to-equilibrium bidding evolve over time. While the figure shows that in both treatments bidding above value plays a minor role, it also shows that close-to-equilibrium bidding is relatively more frequent in the anonymity treatment, and that bidding below value is more frequent in the friends treatment. Over time, the frequency of close-to-equilibrium bids increases while the frequency of below-value bidding decreases for the anonymity treatment.¹⁸ These observations reinforce the overall feeling that one gets with the anonymity treatment; that is that the dynamics move towards the non-cooperative equilibrium. In contrast to these dynamics, no significant changes are observed for the frequencies of

close-to-equilibrium bids and below-value bids of the friends treatment.¹⁹ This observation seems to suggest that hypothesis 2 may be supported by the data from the friends treatment. Therefore, while the between-treatments differences in the relative frequency of close-to-equilibrium bids are insignificant for the first eight repetitions, due to the dynamics within the treatments, they are significant for the last eight repetitions.²⁰ Evidently, the average bid-to-value ratio is also significantly lower in the friends treatment than in the anonymity treatment.²¹ Again these observations provide support for hypothesis 3.

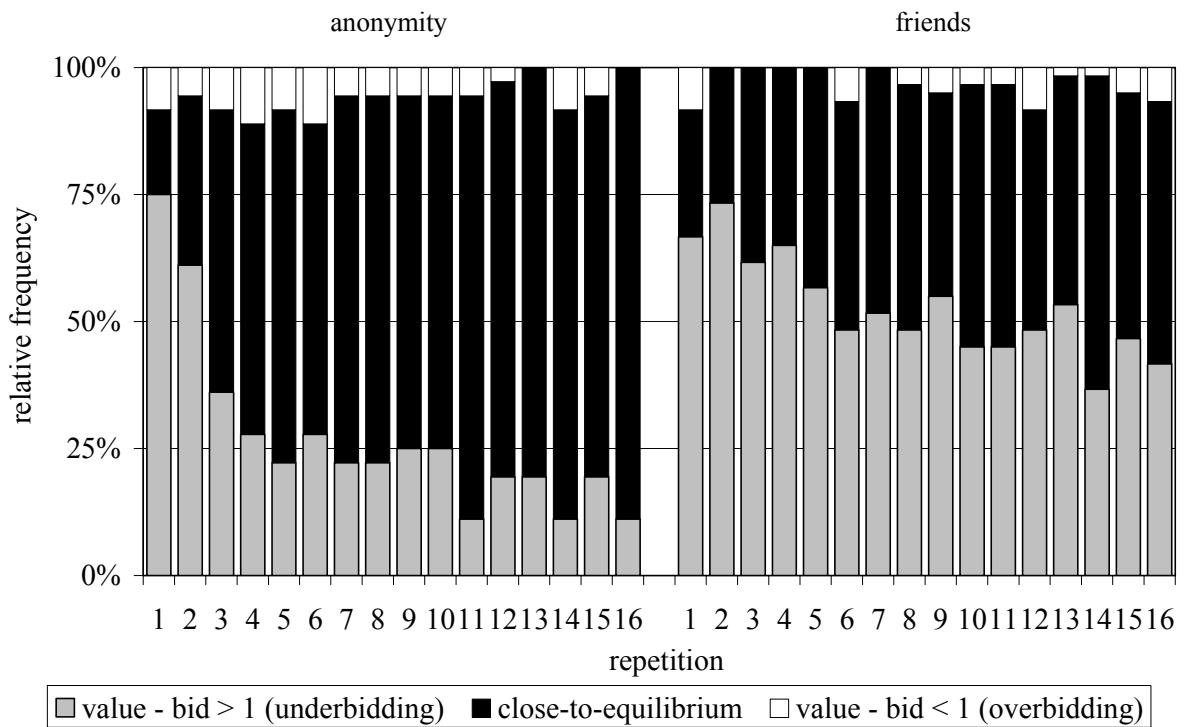


Figure 3. Relative frequency of close-to-equilibrium bids (highest and second highest value bidders only)

4.4. Dynamics

In the literature on online auctions (Ockenfels et al. 2006) it has been shown that subjects in real time hard-close auctions submit most bids at the very end of the auction. Figure 4 displays the bid-to-value ratio in each stage over time. We observe a substantial leap in the bid-to-value ratio between stages 5 and 6 in both treatments. Bidding behavior in both

treatments is in line with the recent literature, i.e. bidding low until the last stage and submitting a high bid in the last stage.

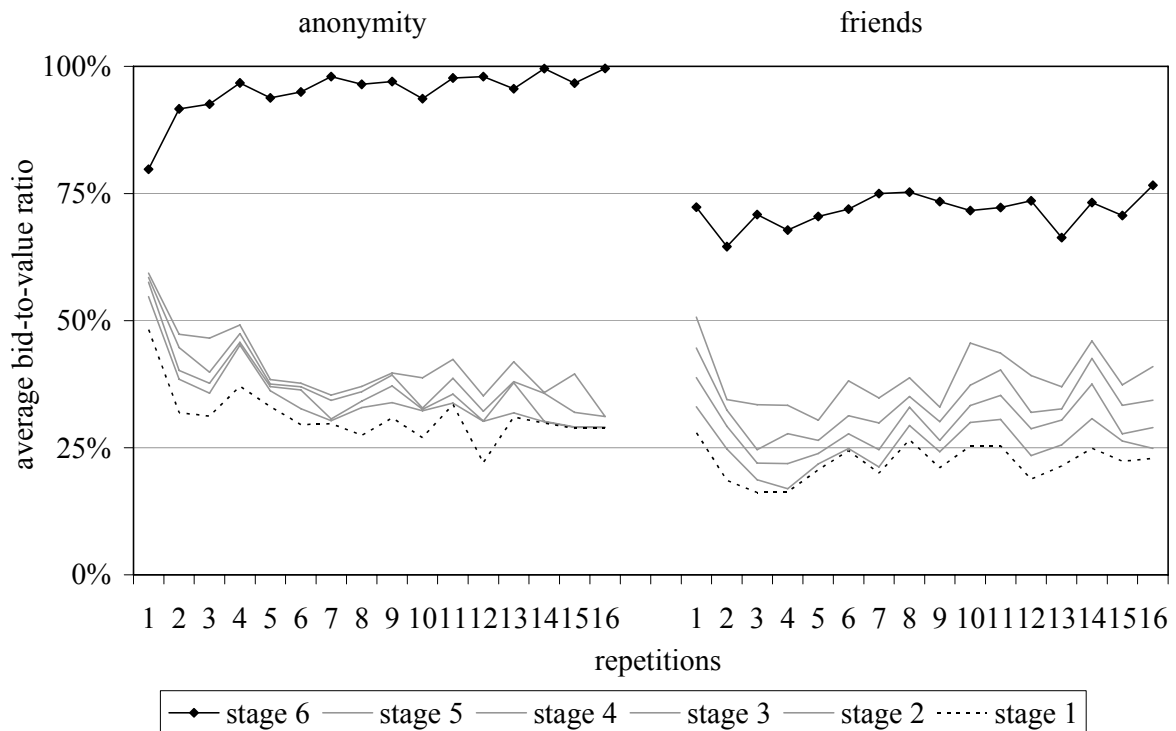


Figure 4. Average bid-to-value ratio between stages over time

4.5. Collusion pattern

The analysis of the data would be incomplete if one were the coordination pattern of the collusive groups in the experiment to be neglected. Since collusive group behavior was not observed for the anonymity treatment, we focus on the friends treatment in this section.

In four of the ten groups of the friends treatment, the results suggest that subjects tried to coordinate towards a collusive outcome. In the group with the highest average profit per unit, i.e., 46.33 ECU, one subject won all 48 auctions. In the first repetition she submitted a bid of 200 in each market and received a negative payoff in all markets. Afterwards the other (male) subjects submitted only zero bids in all repetitions and she (a female) won all auctions at a zero price. In the second group in which subjects earned an average profit of 34.75 ECU per unit, subjects alternated between bidding in all markets and not bidding in any market.

The coordination in that group was rather unsystematic so that we are unfortunately unable to identify the pattern that organized the collusion. However, the group managed in eight of the 16 repetitions to ensure that the alternating winning bidder nearly received a payoff equal to the sum of her three values. In six further repetitions, the alternating bidder won the auction in two auctions. In the third collusive group the average per unit payoff was 25.04 ECU. In this group, subjects attempted to apply the collusive strategy *C* which we described and discussed in section 2. In the first stage, they submitted a low bid to the market for which they held the highest value. Such behavior which agrees with strategy *C* could be observed in 48% of the auctions from different subjects. In the fourth group in which one subject earned an average of 29.52 ECU per unit we are again unable to specify the coordination mechanism, but we observe that the prices are very low in all repetitions. A mere 31% of the prices are above 100 ECU, i.e., the lowest possible value, 50% of the prices are in the range of 50 and 100 ECU and 19% are below 50 ECU. In all ten groups of the friends treatment and in some of the anonymity treatment, were subjects who signaled their valuation by bidding $v/100$ in the first stage. However these signals were apparently not understood by the others, and thus they did not help in achieving a higher group outcome.

It is clear that the collusion of the four reported groups has a substantial impact on the test results. Therefore, it would be worthwhile to redo the tests and compare the remaining six “non-collusive” groups of the friends treatment to the six groups of the anonymity treatment to see whether the stated results remain the same. Effectively, on the basis of this restricted sample of non-collusive groups only some support for hypothesis 3 vanishes. For instance, the payoff per unit is only insignificantly greater in the non-collusive groups of the friends treatment than in the anonymity treatment; the exact p-value of the one-tailed test is 0.075. Moreover, there is no significant difference between the non-conclusive groups of the friends treatment and the anonymity treatment concerning efficiency or below value bidding.

6. Concluding remarks

In this paper we have reported the experimental results of the three-bidder three-market hard-close auction in which subjects faced independent private values for each auctioned object. This experiment was designed to test the robustness of the hard-close auction against collusion. The results suggest that collusion is difficult to achieve in the hard-close auction even in the repeated setting where the punishment of defectors is possible and thus where intuition would make us expect collusion. In the data, some instances of signaling were observed and some intentions on the part of subjects to cooperate with each other in the early repetitions of the experiment were perceived. But ultimately tacit collusion does not succeed under the anonymity-treatment condition. Hence, evidence seems to have been found for Klemperer's conjecture that auctions that combine the ascending and the sealed-bid auction formats are less susceptible to collusion. For the anonymity treatment, the results are basically in line with the theoretical prediction, i.e. that the bidders submit equilibrium bids and the market allocation is efficient (hypothesis 1).

In conditions of the friends treatment, where the subjects share social ties outside of the laboratory, tacit collusion appears to be more successful. In our experiment, subjects gained an average of 21% surplus in payoff compared to the non-cooperative equilibrium prediction, thus lowering both the revenue of the seller and market efficiency (hypothesis 2). This observation seem to suggest that the market structure alone is not enough to inhibit collusion between people who know each other, and thus our findings seem to justify the anonymous bidding features enabled on eBay for more valuable goods. Under anonymous bidding, prices were 38% higher than for the friends treatment (hypothesis 3). It seems that anonymity in the hard-close auction helps to abolish tacit collusion in auctions.

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Instructions

Welcome to the experiment. Please turn off your cell phone now! Please take notice of the following instructions and raise your hand, if you do not fully understand them. Throughout the experiment, we ask you, to refrain from contact with the other participants. If you contact the others, we have to ask you to leave the experiment and you will lose any claim for remuneration. The purpose of the experiment is to study individual behaviour in the laboratory: It is important that you make your decisions independently of the others.

General Information

In the experiment, you are going to participate in auctions in which you must bid on fictitious items. For each fictitious item you may win, you are given a value in Eurocent. The respective value will be announced to you before the auction starts. If you win an item in an auction, you must pay the price at which the auction closes. Your profit for an auctioned item is the difference between your value and the price. For items, which you do not win in an auction, your profit is zero. All prices and values are stated in the experimental currency ECU. At the end of the experiment you will receive a payoff in Euro equal to the sum of your profits; an exchange rate of one ECU to two Eurocent will be applied. Additionally to the profits earned in the experiment you also receive a participation fee of 150 ECU credited to your balance at the beginning of the experiment.

How does an auction look like? You are about to participate in 16 auction rounds. In each auction round, three fictitious items are auctioned in three simultaneous auctions. For each item you are given a value between 100 and 200 ECU. The values for the three fictitious items are identically and identically drawn by the computer before the auction starts, i.e., each value in the given interval is equally likely. Your values are only known to you and unknown to the other bidders. To each auction the following rules apply: The bidder with the highest bid wins the auction and pays the price. In each round you are able to buy three items.

How to bid? An auction consists in six bidding stages. In each stage you can place a maximum bid. An automatic bidding system is bidding for you, i.e., all other bids are enhanced by 0.01 ECU up to your maximum bid. The maximum bids are unknown to the other bidders in any stage. From one stage to the next, you can either increase your maximum bid or maintain it, but you are not allowed to decrease it! Bids are stated in ECU up to two decimals. No bid may exceed 200 ECU.

Who wins the item? The high bidder in the last stage of the auction wins the item and pays a price. The price is equal to the second highest maximum bid plus an increment of 0.01 ECU. If there is more than one high bidder for an item, the price equals the highest maximum bid. In this case, the winner will be randomly determined among the high bidders.

What is your payoff? Items you win induce a payoff equal to the difference of value and price: $\text{value} - \text{price} = \text{payoff}$. Items you do not win induce a zero payoff.

Subjects in anonymity treatment read: Who are the other bidders? In all 16 auction rounds, you always encounter the same bidders in the markets. The true identity of the bidders will not be revealed to you at any time. However bidders are identified by a bidder name throughout the experiment. The bidder names of you and the other bidders in your market are blue, red and yellow. At the start of the experiment, each participant is randomly assigned one of these names.

Subjects in friends treatment read: Who are the other bidders? In all 16 auction rounds, you always encounter the same bidders in the markets. They are the two other participants with whom you have signed up for and come to the experiment. The bidders are identified by a bidder name throughout the

experiment. The bidder names of you and the other bidders in your market are blue, red and yellow. The participants seated in the first rows have the bidder name yellow, those in the following rows have the bidder name red and those in the last rows have the name blue.

What is your information? Your screen is divided into three equal sections. Each section shows an auction (item A, B and C). You will find the following information in each section: number of bids, bidding history, current high bid (top row), identities of the bidders, your maximum bid.

auction round		1 of 16 rounds		remaining time (sec) 26	
Number of bids for item A : 9		Number of bids for item B : 6		Number of bids for item C : 7	
red	$R_{A4}=B_{A3}$	red	$Y_{B2}+0.01$	yellow	$R_{C3}+0.01$
blue	B_{A3}	yellow	Y_{B2}	red	R_{C3}
red	R_{A3}	blue	B_{B2}		
yellow	Y_{A2}				
red	R_{A2}			red	R_{C2}
blue	B_{A2}			blue	B_{C2}
red	R_{A1}	red	R_{B1}	red	R_{C1}
blue	B_{A1}	yellow	Y_{B1}	yellow	Y_{C1}
yellow	Y_{A1}	blue	B_{B1}	blue	B_{C1}
Current high bid	$R_{A4}=B_{A3}$	Current high bid	$Y_{B2}+0.01$	Current high bid	$R_{C3}+0.01$
My value (100 - 200)	V_{BA}	My value (100 - 200)	V_{BB}	My value (100 - 200)	V_{BC}
my maximum bid	<input type="text" value="B<sub>A3</sub>"/>	my maximum bid	<input type="text" value="B<sub>B2</sub>"/>	my maximum bid	<input type="text" value="B<sub>C2</sub>"/>
Your bidder name : blue		balance : 300		stage 6: confirm all bids	

Example: A - high bidder is red and has submitted the same bid as blue, B - red is the high bidder, and due to the automatic bidding system s/he bids exactly 0.01 ECU more than yellow's maximum bid (yellow has submitted a maximum bid of Y_{B2} ECU), C - yellow is the high bidder and due to the automatic bidding system s/he bids exactly 0.01 ECU more than red (red has submitted a maximum bid of R_{C3} ECU made). This one is the last stage (see red bottom on the bottom left); thereafter, the auction will close.

How an auction closes? In the sixth stage you submit the final bids. Thereafter, the profit screen follows. The profit screen reveals your profit and the bids submitted in the each of the six stages (but not the maximum high bid). After the 16th auction round, the experiment finishes.

After the experiment, your payoff will be paid out to you in cash at your table. Fill in your receipt stating your payoff and your name and sign the receipt please!

Please leave the instructions on the table after the experiment has finished.

Good Luck!

Footnotes

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¹ Examples of design failures included the auction for Australian satellite television licenses (McMillan 1994) where bids could be withdrawn and the auction for Turkish telecom licenses where a monopoly market resulted from the auction (Klemperer 2002). As a matter of fact, these design failures induced immediate losses to public households and long-run losses to the domestic customers.

² In the German Spectrum Auction, Mannesmann used the design to signal T-Mobile a collusive bidding outcome which T-Mobile finally accepted (Grimm et al. 2003; Hoppe et al. 2006).

³ The discrete hard-close auction has also been used in some other recent experimental studies (Ariely et al. 2006, Füllbrunn and Sadrieh 2006). In contrast to these studies, we use a format in which all bids are certainly received by the seller. In electronic real world auctions, there exists the uncertainty that last-minute bids are not received due to bid transmission problems. We do not discuss these problems here (see Roth and Ockenfels 2002) as they are not part of the auction rules but rather a flaw in their implementation.

⁴ (http://pages.ebay.com/help/sell/manage_bidders_ov.html; 30.10.2007)

⁵ Recent experimental evidence has shown that social ties play a crucial role for cooperation in helping games (Leider et al. 2006) and public goods games (Haan et al. 2006). The cooperation in groups of friends is higher than in anonymous groups. We should expect that collusion among a group of friends is more frequent than in an anonymous group since post-experimental punishment possibilities exist.

⁶ Neugebauer (2007) shows that bidding above equilibrium results in experimental single-unit sealed-bid auction markets with three anonymous bidders. In contrast, markets with more than seven bidders tend to elicit bidding below equilibrium if no feedback is received on the competitors' bids.

⁷ The soft-close auction is a dynamic auction with a different termination rule. It terminates as soon as during the final x stages (or minutes) no further bids have been submitted.

Conversely, if a new bid has been submitted during the final x stages the auction is prolonged to another x stages. Ex-ante, the stopping time of the game is undetermined, thus the backward induction algorithm cannot be applied. If bidders simultaneously compete in N single-unit markets, a bid submitted in the final x stages prolongs bidding in all markets. Therefore, the threat of reversion to the non-collusive outcome is meaningful in the soft-close auction since the bidders can respond to last stage bids. Brusco and Lopomo (2002) consider such English auctions and derive a perfect Bayes-Nash equilibrium of the signalling game in a private value setting, where bidders split the markets among them. In the two-bidder two-market game, bidders only submit a lowest bid increment ε in the market with the higher object valuation. If bids are submitted in separated markets, bidding terminates and (in the limit where $\varepsilon \rightarrow 0$) the bidders receive the maximum buyer surplus in the according market.

⁸ The same payoffs result if market indices are reversed. In the other cases where both players submit a bid to the same market, mutual sniping is the equilibrium by definition of the collusive strategy.

⁹ See Füllbrunn (2007) for a detailed discussion.

¹⁰ The instructions are appended to the paper.

¹¹ In the experimental instructions, repetitions were called rounds and, on the computer-screen, the current repetition was indicated.

¹² The one-tailed Mann-Whitney U-test of the null-hypothesis that the payoff in the anonymity treatment is at least as great as in the friends treatment must be rejected in favor of the alternative that payoff is greater in the friends treatment. The exact p-value is 0.011.

¹³ The exact p-value of the one-tailed Mann-Whitney U-test is 0.009.

¹⁴ The exact p-value of the Wilcoxon test is 0.070. We also conducted the same test for the first eight repetitions and the last eight repetitions (i.e., repetitions nine to sixteen) in the experiment, to detect a possible trend. The corresponding p-values are 0.055 (first eight repetitions) and 0.213 (last eight repetitions).

¹⁵ The exact p-value is 0.003. Redoing the test for the first and second eight repetitions led to the following p-values; 0.003 (first half), 0.008 (second half).

¹⁶ The exact p-value is 0.008. For the first and second eight repetitions the p-values are 0.008 and 0.017.

¹⁷ The one-tailed Wilcoxon test yields the same result when we compare the first eight to the last eight repetitions. For the anonymity treatment, the group frequency of efficient auctions is significantly greater in the first than in the last eight repetitions; the exact p-value is 0.026. Conversely, for the friends treatment the p-value is 0.6075.

¹⁸ According to the two-tailed Wilcoxon test, the changes in the frequencies of the close-to-equilibrium bids and of the observed below-equilibrium bids is significant between the first and the last eight repetitions; the p-values are 0.0273 and 0.0277.

¹⁹ The two-tailed Wilcoxon test that compares the frequency of close-to-equilibrium bids and of below-equilibrium bids between the first and last eight repetitions cannot reject the null hypothesis that no change occurs; the p-values are 0.2402 and 0.2619.

²⁰ The corresponding p-values due to the one-tailed Mann-Whitney U-test of the close-to-equilibrium bids are: 0.0714 for the overall data, 0.1385 for the first eight repetitions, and 0.0362 for the last eight repetitions.

²¹ The one-tailed Mann-Whitney U-test results of the bid-to-value ratio are as follows. The p-value is 0.0048 for the overall data, 0.0170 for the first eight repetitions and 0.0126 for the last eight repetitions, respectively.