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Anonymity deters collusion in hard-close auctions:

Experimental evidence

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Abstract:

This paper studies whether collusion occurs in three-bidder three-object second-price hard-close auctions. The anonymity treatment which involves repeated interaction with anonymous other bidders is compared with the friends treatment which involves repeated interaction within groups of friends who know each other. The paper reports no collusion in the anonymity treatment but some collusion in the friends treatment.

Keywords: multi unit auctions, collusion, experimental economics

JEL No: D44, C92

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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 of spectrum licenses, gas leases or electricity the auction design must carefully be chosen to prevent undesired outcomes,[1] since these markets usually involve the sale of multiple units (worth several millions of dollar) to a small number of potential bidders. Therefore, 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 and decreased efficiency (e.g., Klemperer 2002). Several circumstances that may be favorable for collusion in the multiple-unit auction 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 to punish uncooperative behavior immediately if bidders simultaneously compete in more than one auction (Brusco and Lopomo 2002) or at a later time in the case of repeated interaction (Kwasnica and Sherstyuk 2007).

In this study, we report results of a laboratory study designed to measure the losses of revenue and efficiency due to 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

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[1] Examples for 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 the 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).

number of bidding stages in which bidders can subsequently submit enhancing bids and the high bid is privately known by the high bidder. The considered auction is a stylized discrete-time version of the ascending bid auction with a fixed ending time used on eBay, the world's most successful e-commerce auction platform.[3] This auction format is appealing for our purpose at least for two reasons. First, Klemperer (2002) argues that auction formats which combine ascending and sealed bid formats may have the needed characteristics to discourage collusion. Since we use a repeated setting, we test the robustness of this conjecture under quite adverse conditions. Nonetheless, the data of our "anonymity" treatment in which subjects interact repeatedly but anonymously seem to provide support for Klemperer's conjecture. Second, despite this conjecture there is an apparent concern about collusion in empirical online markets; eBay enables sellers to choose an anonymous auction design involving covered bidder-names and even enforces the anonymous bidding format for more valuable items 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 on a collusive outcome is not easily established.

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[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 (Roth and Ockenfels 2002). These problems are not part of the auction rules but rather a flaw of 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 plays 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. Thus, we should expect that the likelihood of collusion in the auction in a group of friends is greater than in an anonymous group.

Our study is based on the 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 small markets (2 bidders, 2 objects) but not in large markets (5 bidders). Brown et al. (2006) elicit tacit collusion for a market with eight bidders and eight items in the ascending auction when public information is given on the preference ordering of values in the auction. Through the public preference order, subjects are enabled to coordinate their demands and to achieve the collusive outcome with only few repetitions. In line with Klemperer's conjecture, Sherstyuk (forthcoming) concludes on the basis of her survey that the auction format is crucial for collusion in experimental auctions; the sealed bid auction seems far less susceptible to collusion than the ascending auction.

Since the hard-close auction involves a final sealed bid stage, our auction design includes a feature that is arguably unfavourable to collusion. But the experimental design also involves favourable features for collusion including repeated interaction and multiple simultaneous market structure where the number of bidders equals the number of auctions. Due to the finite number of repetitions, signalling and punishment is possible but incredible from the game theoretic perspective of rational agents. A collusive equilibrium cannot be sustained even with two bidders due to the "sniping" possibility, i.e. bidders cannot punish uncooperative last-stage bids of 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 to the prisoner's dilemma concerning cooperative behavior.

The paper is structured as follows. In the following second section, we introduce the simultaneous, multi-unit hard-close auction and present testable hypotheses. The third section presents the experimental design. The results of our 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 submitted the highest bid in the market 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 have common knowledge about the current price and about the high bidder, but not about the highest bid as it is not revealed unless there is a tie of highest bids. 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 we consider the private value model, in which each bidder's valuation for the object is privately and independently drawn from a commonly known distribution, the payoff of 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 $m > 1$ bidders who simultaneously compete in $m > 1$ parallel single-unit auction markets. Each bidder has m identically and independently drawn values, one for each single-unit market. Even under these conditions which evidently open the floodgates to collusion as, e.g., each bidder could specialize on bidding for the privately most valued unit, the strategy of bidding the value in the final auction stage remains to be the weakly dominant one in the hard-close auction. This prediction for the m markets and m bidders case is quite different from other auction formats as, for instance, the simultaneous English or soft-close auction format applied by Kwasnica and Sherstyuk (2007) which facilitates a collusive outcome.[6] While the soft-close auction, in the context of m markets and m bidders, may be thought of representing an indefinitely repeated game, due to its undetermined ending time, the simultaneous multi-unit hard close auction may be thought of 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. Assume 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

[6] The soft-close auction is also 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 compete in m simultaneous markets, a bid submitted in the final x stages prolongs bidding in all single-unit markets. Therefore, the thread 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 "signaling" equilibrium in a private value setting, where bidders split the markets among them. In the two-bidders two-markets 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.

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.[7] Table 1 shows the payoff matrix of the resulting asymmetric prisoner's dilemma game for the limit $\varepsilon \to 0$. 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)

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

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.[8]

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[7] The same payoffs result if market indices are reversed. In the other cases, where both players submit a bid to the same market, the equilibrium outcome will result by definition of the collusive strategy and bidders expect the mutual sniping payoff as defined in equation (1).

[8] See Füllbrunn (2007) for a detailed discussion.

Table 1. Expected payoff matrix

		Player 2	
		C	S
Player 1	C	$v_{11}; v_{22}$	$0; v_{21} + v_{22}$
	S	$v_{11} + v_{12}; 0$	$\frac{1}{3}(3v_{11}^2 - v_{11}^3 + v_{12}^3); \frac{1}{3}(3v_{22}^2 - v_{22}^3 + v_{21}^3)$

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 our experiment is thus as follows.

Hypothesis 1. (defection)

The bidders submit equilibrium bids in all markets. 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 to the rational player to copy the behavior of the tit-for-tat player for almost all repetitions of the game. Therefore, mutual play of the collusive strategy is also a reasonable strategy in the repeated game which results in 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 equilibrium. Due to collusion, the auction winner has not necessarily 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 the individual demand in the market. For instance, bidders can signal their valuation in the first stage by submitting a small constant fraction of their value. Or the bidders can divide the markets among each other 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 m-1 passive bidders during the auction.

In the paper, we report the results of experiments with three bidders in three parallel markets, i.e., $m = 3$. 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, and so on. In general, the collusive strategy yields a probability of the collusive outcome of $m! / m^m$. The possibility that subjects use the dominant sniping strategy S, i.e. submit the equilibrium bid at the latest in 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 an increased competition and exacerbates the coordination problem of experimental subjects.

3. Experimental Design

In this section, we detail the experimental procedures and introduce to the two treatments, i.e. anonymity and friends. The differences between the treatments are the social ties between the subjects. In the laboratory both treatments involve a partner's setting, i.e., repeated interaction. 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.

We regard the friends treatment as empirically relevant. In auction markets where problems of collusion may accrue, the identities of the bidders (attendees or absentees) are quite important as they are usually not restricted to the auction market. It is likely that collusion in the auction is more relevant if bidders know each other and surely meet each other again after the auction. Recent experimental evidence has shown that subjects are more generous when they play a dictator game with their friends (e.g, Leider et al 2006). This issue may be the reason for the fact that the Internet auction house eBay enables sellers to withhold the bidders' identities in auctions. Based on this evidence, we formulate a third testable hypothesis.

<u>Hypothesis 3</u>. (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 in the anonymity treatment than in the friends treatment.

3.1. Experimental procedure

Experiments were conducted computerized (Fischbacher 2007) at the Leibniz University of Hannover in January 2006. At the beginning of the experiment written instructions were read aloud and arising questions were answered.[9] Subjects were given the bidder-names yellow, red and blue at the outset of the experiment. Thus they were identifiable within the experiment at any time and all decisions could be traced back to the decision maker. In particular, defectors could be easily identified and a subject was able to inflict a (bilateral)

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[9] The instructions are appended to the paper.

punishment on a defector (in the sense of a tit-for-tat strategy). This feature should help tacit collusion to evolve given that subjects manage to coordinate their demands. However, we have no public information about preferences or other focal points to facilitate tacit coordination (as in Brown et al. 2006) and no open collusion was enabled since subjects were not allowed to talk to or see each other (as in Isaac and Walker 1985).

Three subjects simultaneously competed with each other in three simultaneously run single-unit hard-close auctions labeled A, B, and C, in each of which a single heterogeneous object was sold. 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 subjects.[10] Bids and values were expressed in the experimental currency unit ECU which was exchanged 1 ECU = 0.02 Euro at the end of the experiment. Since losses were possible, though unlikely, subjects were given their show-up fee as an initial balance of 1.50 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. In each stage, subjects submitted a non-negative maximum bid in each market. 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

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

of the high bid and 'the second-highest bid + 0.01 ECU'. All bids were identified with the bidder-name of the submitter, and (as in the standard protocol in eBay auctions) all bids but the high bid were revealed in all stages. If the high bid was equal to the second highest bid, and both were submitted at the same stage, the high bidder was randomly selected. Otherwise, the high bidder in an auction would change only if the maximum bid of the other bidder would exceed her maximum bid. At the end of the auction, the high bidder wins the auction and pays the current price resulting after the sixth stage. All subjects received information about the auction winners, prices, and realized private profits. Profits were added to the cash balance of the subject.

3.2. Anonymity Treatment

Subjects were recruited among economic 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 interacted with always the same partners but interactions were anonymous. Subjects did see the other subjects at the entrance, but the identity of their partners in the experiment was not revealed to them at any time during or after the experiment. In total, 18 subjects participated in the anonymity treatment implying six independent groups who bid on 48 single-unit hard-close auctions per group, totaling 288 single-unit auctions. Subjects had not participated in any auction experiment before.

3.3. Friends Treatment

For the friends treatment, groups of three subjects were recruited. The three subjects came together to the laboratory. If one person in a group was missing, the group could not participate in the experiment. One subject of the group 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 subject of the group, the "yellow" bidder, was seated in the first rows; the "red" one, was seated in the following rows; and the "blue" one, 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 the group. Each subject was told the 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 implying 10 independent groups who submitted bids to a total of 480 single-unit hard-close auctions. They had not participated in an auction experiment before.

4. Experimental Results

Table 2 gives an overview over the basic market statistics. In accordance with hypothesis 3, the bidders' average payoff is significantly lower in the anonymity treatment than in the friends treatment;[11] throughout we apply a significance level of five percent. The seller's surplus per auction, more accurately speaking, the difference of the observed average revenue and the revenue that would have been achieved if subjects had bid their value is significantly lower for the friends than in the anonymity treatment.[12] The efficiency, measured as the frequency of single-unit auctions where the bidder with the highest value is awarded the object, is significantly higher in the anonymity treatment than in the friends treatment. Details are presented in the following sections.

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[11] 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.

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

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. Prices and revenue

According to the hypothesis 1, the price should be equal to the second highest value plus 0.01 ECU. Figure 1 shows how often the observed price is close to this benchmark prediction and how frequently it deviates in each treatment. In 58% [30%] of all auctions in the anonymity [friends] treatment, we observe a price in the range between -1 and +1 ECU around the equilibrium. In the anonymity [friends] treatment, 5% [42%] of the prices are more than 25 ECU below the equilibrium. The formal data analysis leads us to the following result. (The pooled regression shows that there is no trend in the price data for either treatment.)

Result 1

1) Prices are not significantly below the equilibrium in the anonymity treatment.
2) Prices in the friends treatment are both, lower than the equilibrium and lower than in the anonymity treatment.

Support (result 1).

1) The average second highest value in 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.[13] Thus, hypothesis 1 cannot be rejected in favor of hypothesis 2 for the anonymity treatment.

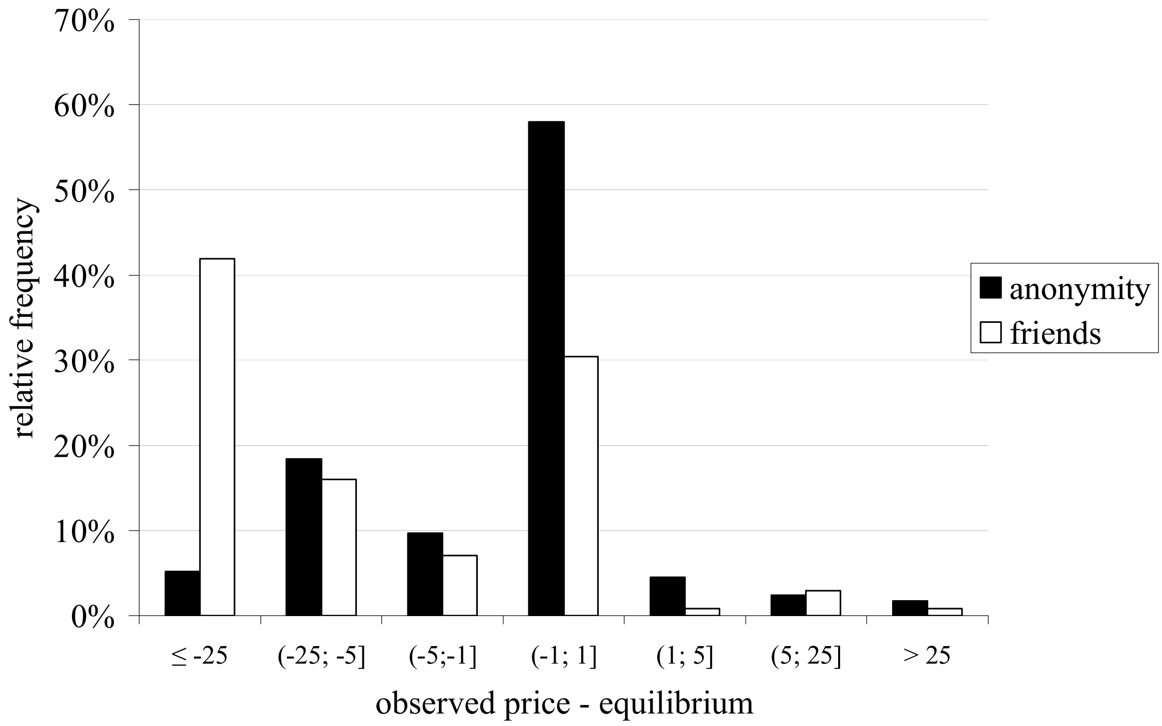

Figure 1. Relative frequency of price differences from the equilibrium

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 seller in the friends treatment receives only 71% of the equilibrium revenue, whereas the share is 98% in the anonymity treatment). 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 for the friends treatment.[14] Prices are 38% higher in the

[13] 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., the repetitions nine to sixteen) in the experiment, to indicate a possible trend. The corresponding p-values are 0.055 (first eight repetitions) and 0.213 (last eight repetitions).

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

anonymity treatment than in the friends treatment. According to the one-tailed Mann-Whitney test the difference is significant.[15] Hence, according to these results we must reject hypothesis 1 in favor of hypotheses 2 and 3 for the friends treatment.

4.2. Efficiency

Figure 2 shows the relative frequency of efficient allocations over time. Efficient allocations are achieved with a relative frequency of 86% and 67% in the anonymity treatment and in the friends treatment, respectively. Based on our data, we state the following result.

Result 2.

1) The market allocation converges to efficiency in the anonymity treatment.
2) An efficient allocation is more likely in 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 in 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

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

discarded from the sample, the number of efficient allocations in the friends treatment is quite steadily about 0.69.[16]

2) According to the one-tailed Mann-Whitney U-test, the hypothesis of equal efficiency between treatments can be rejected. The exact p-value is 0.021. This result supports hypothesis 3.

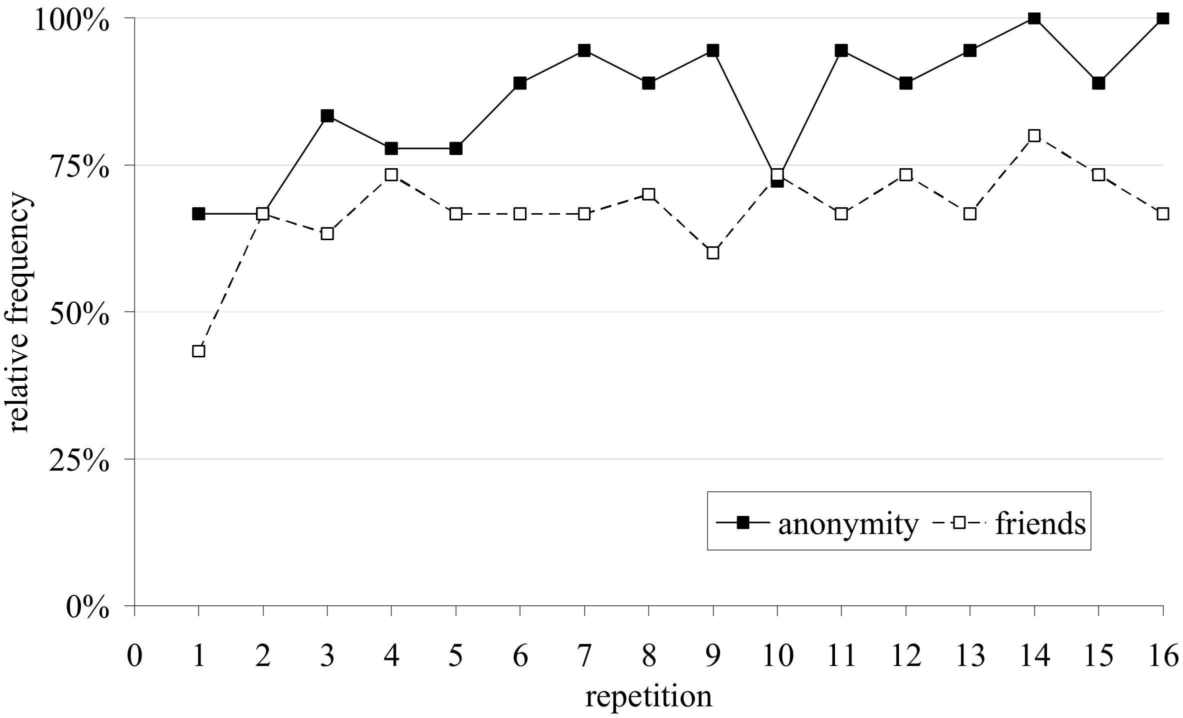

Figure 2. Relative frequency of efficient allocations over time

4.3. Finally Submitted Bids

Hypothesis 1 states that bids should equal value in the end. However, many bids are not equal to the value as the bidders disregard the decimals of the value or even round the bid to the next prominent number (Albers and Albers 1983). To plot equilibrium bids in an intuitive way, we thus use a less demanding approach by defining close-to-equilibrium bids in the

[16] 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.

interval [-1, 1] 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 reformulate the research question as follows. Do the bidders with the high or the second highest value submit close-to-equilibrium bids?

Result 3.

In the anonymity treatment we observe more close-to-equilibrium bids and a lower frequency of underbidding than in the friends treatment as well as a movement towards the equilibrium over time.

Support (result 3).

Figure 3 shows how under-, over- and close-to-equilibrium bidding evolve over time for these bidders. While the figure shows that in both treatments overbidding plays a minor role it also shows that close-to-equilibrium bidding is more important for the anonymity treatment and underbidding is more important for the friends treatment. Over time, the frequency of close-to-equilibrium bids increases while the frequency of underbidding decreases in the anonymity treatment.[17] These observations reinforce the overall feeling that one gets with the anonymity treatment, that is, that the dynamics move towards the equilibrium. In contrast to these dynamics, no significant changes for the frequencies of close-to-equilibrium bids and underbidding are observed in the friends treatment.[18] This observation seems to suggest that hypothesis 2 may be supported by the data from the friends treatment. Therefore, while close-to-equilibrium bids are not so different between treatments for the first eight repetitions, due to the dynamics of the treatments, they are significantly different for the last eight

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

[18] The two-tailed Wilcoxon test that compares the frequency of close-to-equilibrium bids and of underbidding 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.

repetitions.[19] Evidently, the average bid-to-value ratio is also significantly lower in the friends treatment than in the anonymity treatment.[20] Again these observations provide support for hypothesis 3.

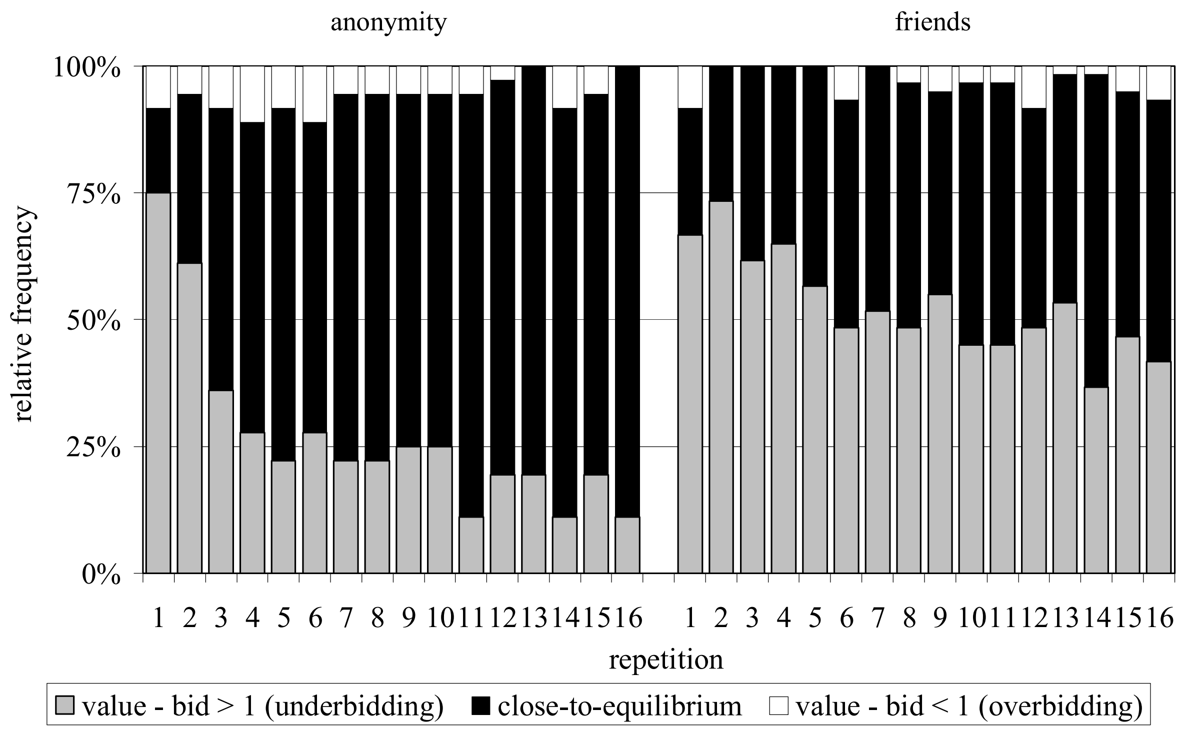

Figure 3. Relative frequency of close-to-equilibrium bids (highest and second highest value bidders only)

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 stage 5 and 6 in both treatments. Bidding behavior in both

[19] 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.

[20] 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.

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

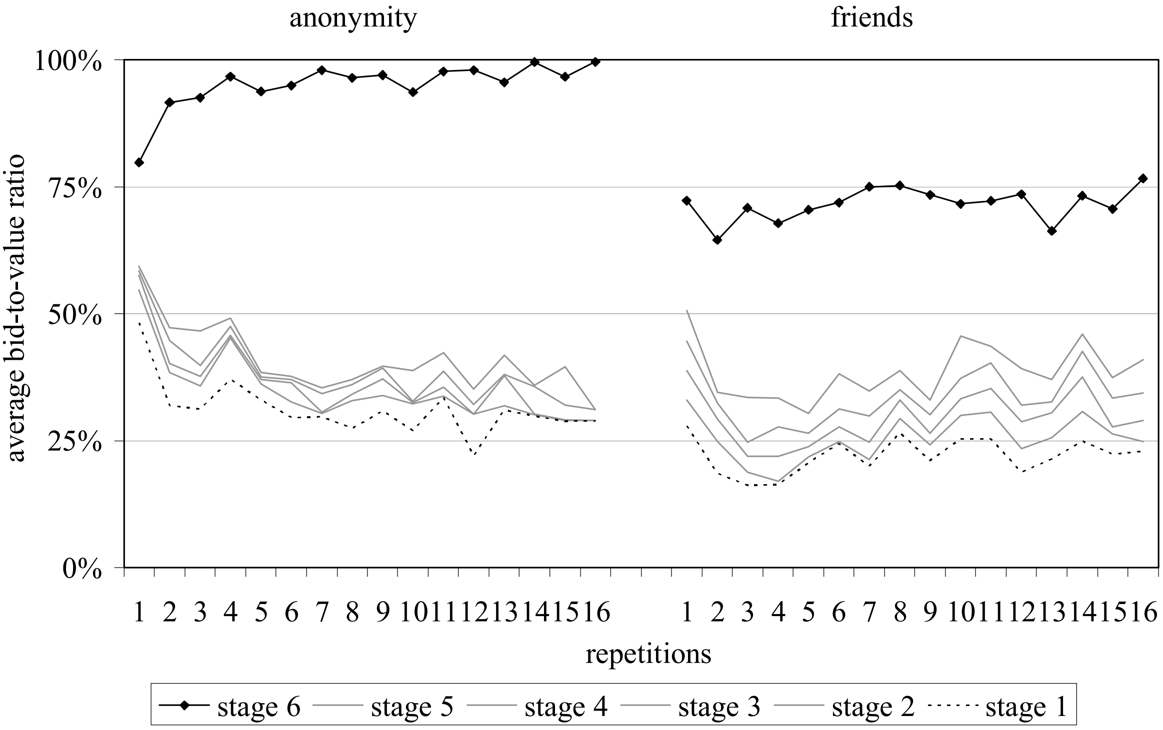

Figure 4. Average bid-to-value ratio between stages over time

4.5. Coordination

The analysis of the data would be incomplete if one would neglect the coordination pattern of the collusive groups in our experiment. Since we do not observe cooperative group behavior 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 on a collusive outcome. In the group with 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 subjects submitted only zero bids in all repetitions and she won all auctions at a zero price. In the second group in which subjects earned an average profit of 34.75 ECU per unit, they alternated between bidding in all markets and not bidding in any market. The coordination in this group was rather unsystematic so that we are unfortunately not able to identify the pattern that organized the collusion. However, the group managed in eight of the 16 repetitions that the alternating winning bidder nearly received a payoff equal to the sum of her three values. In six further auctions, the alternating bidder won the auction in two markets. 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 a 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. Merely 31% of the prices are above 100 ECU, 50% of the prices lie in the range between 50 and 100 ECU and 19% are below 50. In all ten groups of the friends treatment and in some of the anonymity treatment, subjects exist who signal their valuation by bidding $v/100$ in the first stage. However these signals have apparently not been 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 is 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, 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 0.0748. Moreover, there is no significant difference between the non-conclusive groups and the anonymity treatment concerning efficiency or underbidding.

6. Concluding remarks

In this paper we have reported the experimental results of the hard-close auction simultaneously run in parallel single-unit markets. We designed this experiment to test the robustness of the hard-close auction against collusion. Our results suggest that collusion is difficult to be obtained in the hard-close auction even in the repeated setting where the punishment of defectors is possible and we would intuitively expect collusion. In the data, we observe some instances of signalling and perceive some intentions of subjects to cooperate with another in the early repetitions of the experiment, but finally tacit collusion does not seem to succeed where anonymity prevails. Hence, we have found evidence for Klemperer's conjecture that auctions that combine the ascending and the sealed-bid auction are less susceptible for collusion. In the anonymity treatment condition, the results are basically in line with the theoretical prediction, i.e. the bidders submit equilibrium bids and the market allocation is efficient (hypothesis 1).

Under the friends treatment condition, in which 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 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. Under anonymous bidding, prices were 38% higher than in 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.

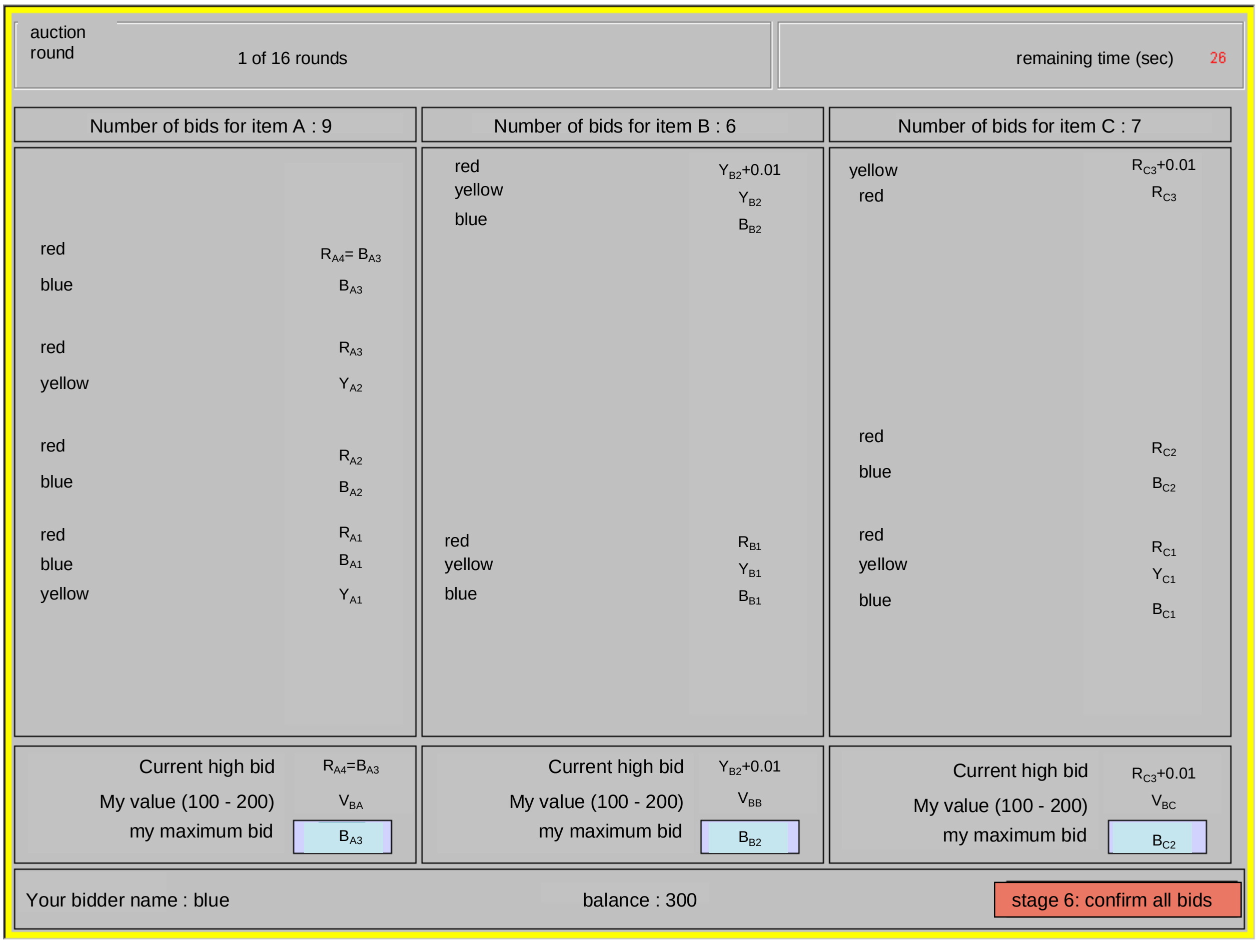
Who wins the item? The high bidder in the last stage of the auction wins the item and pays a price. The price is equal to the second highest maximum bid plus an increment of 0.01 ECU. If there is more than one high bidder for an item, the price equals the highest maximum bid. In this case, the winner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



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!