Auctions with Speculators: An Experimental Study*

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Abstract

We run experiments on second price auctions with resale opportunities, where a speculator (zero-value bidder) is commonly known to exist. Garratt and Tröger (2006) show that there is a continuum of speculative equilibria, apart from the standard bid-your-value one, in which the speculator gets the good in the first stage auction with a positive probability. She pays a price of zero and resells it to the private-value bidder in the second stage. In the most extreme equilibrium, the private-value bidder always bids zero and the speculator always obtains the good. We find that bidders often follow a speculative equilibrium, however, when they do, they tend to split the rents more equally than predicted by theory. When the speculative equilibrium is not observed, the presence of the speculator leads to more aggressive bidding by private-value bidders that results in increased revenue for the seller. An increase in the number of bidders makes speculation harder, but does not eliminate it.

Keywords: Auctions, resale, experiment, speculators. JEL classification: D44, C90

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1 Introduction

We study experimentally the behavior of a speculator who has absolutely no value for the good at sale, but nevertheless hopes to purchase the good and resell it for a profit. This speculator's hopes of profit do not rest on informational advantages regarding future supply or demand characteristics. Rather they depend on the ability of the speculator to *influence* market participants to play an alternative equilibrium in which private-value bidders concede the initial auction and take their chances in the resale market.

Our experiments are based on the theoretical model of Garratt and Tröger (2006) about speculation in standard auctions with resale. Single item auctions present especially fertile ground to study what is arguably the most basic form of speculation. There is a well structured, but not overly complex, set of rules regarding what bidders can do and bidding behavior is very well understood, both theoretically and experimentally. Resale in auctions is also increasingly well understood (see the theoretical work of Haile 2000, 2001, 2004; Garratt and Tröger, 2006; Calzolari and Pavan, 2006; Hafalir and Krishna, 2008; Garratt, Tröger and Zheng, 2009 and the experimental work of Lange et al., 2004; Georganas, 2011; Georganas and Kagel, 2011; Jabs-Saral, 2012; Pagnozzi and Saral, 2017).

In this paper we start by outlining the theory related to auctions with a speculator and one private-value bidder. This scenario involves two distinct classes of equilibrium: one in which the speculator wins with positive probability and one in which she does not. We test four hypotheses that relate to the distinct types of equilibrium behavior. Hypotheses 1 and 2 relate to bidding behavior in the initial auction. In the initial auction we see strong evidence of behavior that is consistent with the speculative equilibrium, by both the speculator and the private-value bidder. Hypothesis 3 and 4 relate to behavior in the resale auction. Hypothesis 3 relates to the existence of punishing beliefs that are required to enforce the speculative equilibrium, while hypothesis 4 tests whether speculators who win at equilibrium bids make take-it-or-leave resale offers that are consistent with equilibrium. Hypothesis 3 is confirmed, but hypothesis 4 is rejected because speculators tend to share more of the surplus they obtain from winning the initial auction than the theory predicts.

The theory presented in Garratt and Tröger (2006) applies when there are multiple private-value bidders. We also report results from an additional treatment in which we increase the number of private-value bidders from one to two. Each of the four hypothesis from the single private-value-bidder case still holds in the treatments two private-value bidders, with slight modifications. The results are qualitatively similar, in the sense that speculative behavior still emerges in non-trivial frequencies, but the frequencies are lower than in the one private-value-bidder case.

Introducing a second private-value bidder allows us to make a meaningful examination of the impact of a speculator on seller revenue. Theory outlined in Garratt and Tröger (2006) suggests that the impact of speculators is ambiguous and depends on equilibrium selection within the class of speculative equilibrium. We argue in this paper that subjects are most likely to coordinate on speculative equilibria in which no type of private-value bidder value bids, and hence the prediction is that seller revenue should fall. This is the focus of our Hypothesis 5. In fact, we find that subjects sometimes play speculative strategies that lead to lower revenue for the seller, but other times the presence of the speculator causes private-value bidders to bid more aggressively than they otherwise would and there is a resulting increase in seller revenue. Overall, we find instances of the latter outnumber instances of the former and the expected effect on seller revenue of adding speculators is to increase seller revenue. Hence Hypothesis 5 is rejected.

There is a very rich literature on standard auctions without resale, both in theory and the lab (see Milgrom and Weber, 1982; Kagel, 1995; Kagel and Levin, 2015). There are also numerous experimental studies on auctions with resale. Georganas (2003) and (2011) looks at symmetric English auctions where resale opportunities arise out of small deviations from equilibrium bidding. Lange et al. (2011) study symmetric FPSB auctions where resale results from bidder uncertainty regarding the value of the item. There is some work in asymmetric auctions too. Goeree and Offerman (2004) test auctions with asymmetric bidders, without resale. Georganas and Kagel (2011) study asymmetric auctions with resale where the weak bidder can, but does not have to, bid like a speculator. The explicit presence of the speculator in our study, however, leads, to the new equilibria described above that are qualitatively different from the previous papers. We find evidence that these equilibria, while not usually followed in their entirety, lead to behavior in the lab that has not been seen previously (e.g. strong bidders constantly bidding close to zero).

Section 2 describes the value-bidding and speculative equilibria of the game and formally presents the hypotheses. Section 3 covers the experimental design and procedures. Results are reported in Section 4.[1] Section 5 summarizes the findings.

2 Model and Predictions

The experiments use auction environments that are special cases of those considered in Garratt and Tröger (2006). Private values were drawn from a uniform distribution and we set the discount rate equal 1. The no-discounting case is allowed by the theory of Garratt and Tröger and is simpler for the subjects. Moreover, without discounting, we can use an argument related to the size of the equilibrium best-response set of the speculator to select among the continuum of equilibria that are possible according to the theory.

2.1 One private-value bidder, one speculator

Two risk-neutral bidders are interested in purchasing a single indivisible private good. The private-value bidder, whom we denote by bidder 1, has the random use value $\tilde{\theta}_1$ for the good, which is distributed uniformly over the interval $[0, 100]$. The speculator, also referred to as bidder s, has the commonly known use value $\theta_s = 0$. We call bidder s a *speculator* because her only incentive to purchase the good in the initial auction is the hope that she can resell it at a higher price.[2]

[1]For the purposes of comparison, results from an additional treatment with one private-value bidder, a speculator and fixed matching, are reported in the Appendix. Fixed matching makes it easier for matched groups to coordinate on strategic equilibrium outcomes and we see more instances of both the value-bidding and speculative equilibrium in the later rounds of the experiment.

[2]Our notational convention is to number the private-value bidders and refer to the sole zero-value bidder as bidder s. This will make more sense later on when we consider multiple private-value bidders.

We consider a two-period interaction. Before period 1, the private-value bidder privately learns the realization of his use value, $\tilde{\theta}_1 = \theta_1$. In period 1, the good is offered via a sealed-bid, second-price auction without a reserve price. The highest bidder becomes the new owner of the good (ties are settled via a coin toss). The period-1 winner either consumes the good in period 1 or makes a take-it-or-leave-it offer in period 2; if he/she fails to resell the good, then he/she consumes it in period 2. There is no discounting of period-2 payoffs.

The auction price becomes public information, but the winner's bid remains private. These bid revelation assumptions make the the two-bidder second-price auction strategically equivalent to an English auction.

We will say that the speculator *plays an active role* if she wins the auction in period 1 with positive probability.

2.1.1 Non-cooperative equilibria

Garratt and Troger (2006) construct and discuss a continuum of pure-strategy perfect Bayesian equilibria for second-price auctions with resale where the speculator plays an active role; see Garratt and Troger (2006a, Definition 2 and Proposition 2). For every $\theta^* \in [0, 100]$, the second-price auction with resale has a perfect Bayesian equilibrium where the private-value bidder bids according to the bid function

$$b_1 = \beta_1(\theta_1) \quad = \quad \begin{cases} 0 & \text{if } \theta_1 \in [0, \theta^*), \\ \theta_1 & \text{if } \theta_1 \in [\theta^*, 100] \end{cases} \tag{1}$$

and the speculator bids $b_s = \frac{\theta^*}{2}$. For all $b_1 \in [0, 100]$, the speculator's take-it-or-leave-it resale offer is at price

$$T(b_1) \quad = \quad \begin{cases} \frac{\theta^*}{2} & \text{if } b_1 = 0, \\ t = \frac{\theta^*}{2}(1+\lambda) & \text{if } b_1 \in (0, \theta^*), \\ b_1 & \text{if } b_1 \in [\theta^*, 100], \end{cases} \tag{2}$$

where λ ($0 < \lambda \leq 1$) is a parameter that captures a range of off-path beliefs that support the equilibrium strategies. This is a slight generalization of the resale price function presented in Proposition 2 of Garratt and Troger (2006). In that formulation, the speculator's resale price function is based on the off-path belief that a private-value bidder that deviates to a bid in $(0, \theta^*)$ has value θ^* with probability 1. In fact, as mentioned in footnote 16 of Garratt and Troger (2006), such extreme punishing beliefs are not required. The only requirement is that the speculator needs to have beliefs that "punish" strictly positive losing bids by the private-value bidder to dissuade him from making them. Our formulation reflects the minimal requirement that off-path beliefs lead to a resale price greater than $T(0)$.

Several properties of the equilibria were emphasized in Garratt and Troger (2006). First, equilibria where the speculator plays an active role ($\theta^* > 0$) coexist with an equilibrium where both the private-value bidder and the speculators bid their use values so that no active resale market arises ($\theta^* = 0$). Second, speculation is profitable in any equilibrium with $\theta^* > 0$ because the speculator wins at price 0 and sells at a positive price. Third, the final allocation is inefficient with positive probability in any equilibrium with $\theta^* > 0$. The inefficiency arises because the losing private-value bidder types pool at the same bid, which implies that the private-value bidder retains some private information when he enters the resale market. This means there is always a chance that the speculator will set a resale price that is too high and end up keeping the good for which she has zero value. Fourth, unlike the case of the second-price auction without resale, neither the private-value bidder's nor the speculator's equilibrium strategy is weakly dominated.[3]

The equilibrium payoffs of the bidders depend upon equilibrium selection, with the speculator favoring higher θ^* and the private-value bidder favoring lower θ^*. Let $\Pi_i(\theta^*)$ denote the expected payoff of bidder $i \in \{1, s\}$ under the equilibrium threshold θ^*. Then

$$\Pi_1(\theta^*) = \begin{cases} 0 & \text{if } \theta_1 \in [0, \frac{\theta^*}{2}), \\ \theta_1 - \frac{\theta^*}{2} & \text{if } \theta_1 \in (\frac{\theta^*}{2}, 100] \end{cases} \tag{3}$$

and

$$\Pi_s(\theta^*) = \theta^* \left[\frac{\theta^*}{2} \frac{\theta^*}{2} \right] = \frac{(\theta^*)^3}{4} \tag{4}$$

[3]This contrasts the second-price auction without resale which has a continuum of equilibria parameterized by θ^* where the private-value bidder uses a bid function β_1 satisfying (1) and the speculator submits the bid θ^*, but the equilibria with $\theta^* > 0$ are in weakly dominated strategies. See Blume and Heidhues (2004).

In principle, any of the equilibria could emerge, however the value-bidding equilibrium corresponding to $\theta^* = 0$ and the speculative equilibrium with $\theta^* = 100$ seem the most natural, since, under random matching, there is no way for bidders to coordinate on a particular θ^* between 0 and 100. The speculative equilibrium with $\theta^* = 77.0917$ gives equal expected payoffs and hence might also be focal, but it is hard to believe subjects would recognize this, or that they would have a preference for ex ante instead of ex post equality. We also note that the speculative equilibrium with $\theta^* = 100$ is the only one that is robust to deviations by the speculator within her best-response set. No matter what value of $\theta^* < 100$ the bidders might be contemplating, any bid $b_s > \frac{\theta^*}{2}$ is in the best response set for the speculator. However, such a deviation is part of a speculative equilibrium with the private-value bidder strategy described in equation 1 and beliefs and resale strategy described in equations X and Y only in the case of $\theta^* = 100$.

Hypothesis 1 *The speculator will either bid 0 or bid an amount greater than or equal to 50.*

Hypothesis 2 *The private-value bidder will either bid 0 or value bid.*

Hypothesis 3 (Punishing Beliefs) *Non-zero losing period 1 bids by the private-value bidder will result in resale offers above 50.*

Resale offers above 50 are punishing in the sense that a private-value bidder would be better off losing to the speculator with a bid of 0 than any positive bid. Hypothesis 3 applies specifically to the case where subjects are coordinating on the speculative equilibrium with $\theta^* = 100$, which we have argued is the most plausible case. We note, however, that under any speculative equilibrium (i.e., for any $\theta^* \in (0, 100]$), punishing resale offers should always be larger than $\theta^*/2$. Under the generous interpretation that any winning speculative bid b_s corresponds to an attempt to play a speculative equilibrium with $\theta^* = 2b_s$, a punishing resale offer must be larger than $\theta^*/2$. This implies that a requirement for resale behavior to be consistent with some speculative equilibrium, is that resale offers will be above a private-value bidder's losing bid.

Finally, if the speculator wins at a price of zero, then she should believe that the private-value bidder is playing the speculative equilibrium and the speculator's posterior belief about the private-value bidder's value is the same as her prior belief. Hence, the speculator should charge a resale price equal to $\theta^*/2$. Contemplating a speculative equilibrium with $\theta^* = 100$ we state the following

Hypothesis 4 (Equilibrium Resale Offer) *Period 1 bids of zero by the private-value bidder will result in resale offers of 50.*

Hypotheses 1 and 2 relate to period-1 equilibrium behavior. They do not depend on the bidders having common expectations as to which equilibrium will be played. Hypotheses 3 and 4 relate to period-2 equilibrium behavior and, as such, are predicated on some belief about the period-1 equilibrium play of the other bidder.

2.2 Two private-value bidders, one speculator

As a robustness check, our experimental plan included sessions with multiple private-value bidders. The intended purpose was to examine whether behavior consistent with the speculative equilibrium, that we might observe in the case of one private-value bidder, also emerges when there is competition among private-value bidders. In addition, it allows us to investigate the impact of speculation on seller revenue.

As before, we consider a 2-period interaction. In period 1, the good is offered via a sealed-bid second-price auction without a reserve price to two private-value bidders (bidders 1 and 2) and a speculator (bidder s). The highest bidder becomes the new owner of the good and offers it for resale in stage 2. As in Garratt and Troger (2006) we focus on equilbria in which the private-value bidders play symmetric strategies. Hence, we will be looking to see whether subjects play the value-bidding equilibrium or whether they play the multi-private-value bidder version of the equilibrium described in Section 2.1.1 with an active speculator.[4]

[4] Haile (1999) and Garratt and Troger (2006) show that value bidding is still an equilibrium for the model with multiple private-value bidders, although it no longer involves dominant strategies.

The stage-one speculative equilibrium bidding strategies of the private-value bidders are the same as in case with one private-value bidder, and are described by equation (1). Also as before, the speculator's bid is chosen so that a private-value bidder with type $\theta^* > 0$ is indifferent between overbidding the speculator and waiting for the resale market. If a private-value bidder with type θ^* waits for the resale market, then he either pays the reserve price set by the speculator or he pays the other private-value bidder's bid, which in equilibrium is equal to his value. The optimal reserve price set by the speculator in the resale market does not depend on the number of bidders (Myerson, 1981) and is equal to $\frac{\theta^*}{2}$, as in the one-private-value-bidder case. The expected value of the other private-value bidder's value, conditional on it being between $\frac{\theta^*}{2}$ and θ^*, is $\frac{3\theta^*}{4}$. Since private values are uniformly distributed, the probability that the other private-value bidder's bid is between $\frac{\theta^*}{2}$ and θ^* is .5. Hence the expected payment of a private-value bidder with value θ in the resale market is $.5\frac{\theta^*}{2} + .5\frac{3\theta^*}{4} = \frac{5\theta^*}{8}$. Therefore, the stage-one speculative equilibrium bid of the speculator is $b_s = \frac{5\theta^*}{8}$.[5]

As in the case of a single private-value bidder we formulate our hypotheses based on the assumption that to the extent that bidders and the speculator attempt to play the speculative equilibrium, they will focus on the speculative equilibrium corresponding to $\theta^* = 100$. This assumption is, in fact, more crucial in this setting since three bidders are expected to coordinate on a single choice of θ^*. The main implication is that under Hypothesis 1 the speculator will either bid 0 or an amount greater than 62.5. Hypotheses 2 through 4 remain unchanged, with the qualifier that 50 now becomes the reserve price set by the speculator in the resale market rather than a take-it-or-leave-it offer.

Finally, according to the theory outlined in Section 5 of Garratt and Tröger (2006a) the introduction of a second private-value bidder has an ambiguous effect on seller revenue. In particular, it depends upon equilibrium selection. The expected revenue for the seller is larger than the revenue of the value-bidding equilibrium if subjects coordinate on an equilibrium with θ^* close to 0, and smaller if θ^* is close to 100. The reason is that seller revenue in a speculative equilibrium only differs from the value-bidding equilibrium if at least one of the

[5] See Proposition 4 of Garratt and Tröger (2006b) for a full characterization of the equilibrium.

private value draws is below θ^*. But even then there are two possibilities. One is that both private values are below θ^*, in which case both private-value bidders bid zero, and so revenue decreases relative to a two private-value bidder auction with no speculator. The other is that one private value is above θ^* and the other is below. In this case revenue for the seller can increase, because the seller collects the speculator's bid, which can be higher than the losing private-value bidder's value. For low values of θ^* the latter case becomes much more likely than the former. Hence, speculative equilibria based on low θ^* increase seller revenue. As we discussed earlier, it is difficult to imagine how subjects will coordinate on equilibrium with values of θ^* strictly less than 100. As such, we anticipate that speculation would reduce seller revenue to levels below theoretical predictions in the two-private-value-bidder case.

We do not expect seller revenue to always be zero in auctions with two private-value bidders, as there may be many instances were both subjects are not attempting to play a speculative equilibrium. However, to the extent that speculative behavior emerges in some auctions, we can expect that seller revenue will be less, on average, than the theory of value bidding predicts. We are mindful of the fact that there is an experimental literature examining revenue in second price auctions in environments very similar to ours, but without speculators. See for example Kagel and Levin (1993) and Georganas, Levin and McGee (2017). These studies find the revenue in second price auctions is often higher than theory predicts as a result of a tendency for subjects to overbid. We nevertheless formulate a hypothesis that does not allow subjects to play dominated bidding strategies.

Hypothesis 5 *Average seller revenue in the auction with two private-value bidders and one speculator will be lower than that predicted by the value-bidding equilibrium.*

3 Experimental Design and Procedures

In order to test the hypotheses stated in Section 3, we ran six sessions of the treatment with one private-value bidder and one speculator and four sessions of the treatment in which the auctions had two private-value bidders and one speculator. The number of one and two private-value bidder sessions with a speculator differs because we did not have the same number of subjects in each session. We also ran six sessions of a treatment with one private-value bidder and one speculator, and nine sessions of the treatment with two private-value bidders and one speculator, under fixed matching. In the fixed matching treatments, subjects played with the same partner throughout the experiment. The minimum number of subjects in a session was 6 and the maximum was 18. In total, across all sessions, we had participation from 352 subjects.

Each session began with instructions distributed to subjects, which were read aloud by the experimenter. A short quiz followed covering payoff calculations as well as general auction procedures.[6] All sessions began with two unpaid periods followed by 40 auctions for cash. The experiment lasted for about two hours (depending on the treatment).

New valuations were drawn randomly at the start of each auction period. Bidder valuations were integer draws from their respective distributions, with speculators always having a value of zero. Subjects were randomly allocated a role at the beginning of the session and kept that role throughout the experiment.[7]

In resale auctions, sellers had to put the item up for sale, but were advised that if they did not want to sell they could set $r = 101$. In the two-private-value bidder case, if both private-value bidders decided they were willing to pay the reserve price, a new second price auction would happen, where the bids had to be weakly higher than the reserve.

Feedback after the final stage consisted of bidders' net profits, both players' bids and their corresponding valuations, along with their type (the instructions assigned them a type, A or B, according to whether they would act as speculators or not), with information from past periods available on subjects' computer screens.

[6] Instructions are available in the web appendix.

[7] The role of the speculator was unpleasant and a few subjects in this role indeed asked the experimenter about their options in case they left. We kept this design though, because an alternating roles design could lead to reciprocity concerns. We believe the setup is not unrealistic; speculators are indeed people who for some reason have a zero value for most, if not all auctions they participate in. We also think experimenter demand is not a big issue, since subjects were risking relatively large amounts when speculating. Speculators complaining about the payoffs were instructed that they did not *have* to bid positive amounts and that their initial endowment was actually not negligible in actual money.

Subjects received an initial capital balance of 100 experimental currency units (ECUs). The exchange rate was 16 ECUs per pound. Five periods were randomly chosen at the end of the experiment for payment, additional to the initial endowment. There was no show up fee. Bankrupt bidders, of which there were often one or two in each session, were dismissed with a cash payment of 5 pounds (around \$7). Profits in the auctions, excluding bankrupt subjects, averaged around \$15.4 across all sessions. The minimum payoff was around \$1 and the maximum payoff was \$38.5.

Subjects were recruited from the undergraduate student population at Royal Holloway, University of London. Software was developed using zTree (Fishbacher, 2007).

4 Experimental Results

4.1 One private-value bidder, one speculator

Table 1 provides summary statistics on bidding behavior related to hypotheses 1 and 2, based on all sessions with one private-value bidder and one speculator in the treatment with random matching. We break the results up into four consecutive 10-period blocks to reveal any changes in subject behavior over the course of the session. There is support for hypotheses 1 and 2 in that subjects often attempt to play either the value-bidding equilibrium or the speculative equilibrium. Speculator bids are below 5 ECUs 9.12% of the time, which is consistent with the value-bidding equilibrium, and equal to or above 50 ECUs 58.04% of the time, which conforms with the speculative equilibrium.[8] A Kolmogorov-Smirnov test for uniformity of the speculator bids is rejected with a p-value<0.001.[9] Private-value bidder

[8]As this is a lab experiment with real players, we allow for a margin of error of 5 ECUs for parts of hypotheses that require bids to be equal to a specific number.

[9]The tests here are done using each bid in each period as an independent observation. Tests taking averages per session are conservative (because we have just a few sessions), while tests assuming each bid is independent are likely to overstate significance, so we report both, when possible. In this case, the KS test could not be done with session averages, since all averages would be very similar in value and would not reflect the actual distributions.

bids are within 5 ECUs of value 34.32% of the time and below 5 ECUs 14.53% of the time.[10] Exact value bidding happened in 19.2% of the cases. These numbers show that speculators played value-bidding or speculative equilibrium strategies 67.16% of the time and private-value bidders played one of these equilibrium strategies 48.76% of the time. There is more conformity to the speculative equilibrium by speculators than by private-value bidders.

		Speculator	Private-Value Bidder	
Rounds	$b < 5$	$b \geq 50$	$b < 5$	$\lvert b - V \rvert < 5$
1-10	7.84	60.54	7.57	33.51
11-20	10.27	59.46	11.62	32.97
21-30	7.84	56.76	18.65	34.86
31-40	10.54	55.4	20.27	35.95
All	9.12	58.04	14.53	34.32

Table I: Percentages of bids of speculators and private-value bidders meeting different thresholds in different round blocks for the treatment with 1 private-value bidder, 1 speculator and random matching. V denotes private-bidder value.

Hypotheses 1 and 2 relate to equilibrium strategies. Instances where subjects coordinate on the same equilibrium are less frequent. We declare that a pair of period 1 strategies is consistent with the value-bidding equilibrium if the private-value bidders bid is within 5 ECUs of their value and the speculators bid is less than 5 ECUs. Likewise, we declare a pair of period 1 bids to be consistent with the speculative equilibrium if the private-value bidders bid is less than 5 ECUs and the speculator's bid is greater than 50. We classify period-1

[10]Kagel and Levin (1993) conducted experimental second-price auctions with 5 and 10 bidders using private values that ranged from 0 to 28.3. Value bidding in that paper is defined as bids within 5 cents of value, corresponding to roughly 0.18 units in our experiment. Given bids were integers in our experiment, we computed the fraction of bids within one unit. The percentage of value bidding, thus calculated, is 25.2% in our experiment (all periods). The relevant comparison group, however, from our experiment, is bidders who were not following the speculative equilibrium. Conditional on not bidding below 5 units, we find that 30% of our bidders value bid, the same percentage as in Kagel and Levin.

strategy pairs as being consistent with the value-bidding equilibrium 6.4% of the time and consistent with the speculative equilibrium 8.2% of the time.

The left panel of Figure 1 plots the private-value bidders' bids for all sessions with 1 private-value bidder and random matching. We provide the case of 2 private-value bidders in the right panel, to be discussed later, for the sake of comparison. An interesting aspect is the large number of bids at the maximum value of 100.[11] Bidding 100 is part of an equilibrium bid profile in which the speculator bids 0. While such a bid is weakly dominated by a value bid, it may have been selected by subjects seeking to eliminate any potential for profitable speculation by the speculator. In fact, any bid by a private-value bidder that is above his value is part of an equilibrium involving a weakly dominated strategy in which the speculator bids 0. We did not anticipate that bidders would play weakly dominated strategies when we formulated our hypotheses. In part, this is because such strategies are indistinguishable from the kind of over-bidding that is commonly observed in experiments in pure private-value contexts; see, for example, Kagel and Levin (1993). Including bids equal to or above the private-value line in our classification of equilibrium bids for the private-value bidder increases our estimate of equilibrium play (both value-bidding and speculative) for private-value bidders from 48.85% in Table 1 to 60.07%.

4.1.1 Take-it-or-leave-it resale offers

In cases where the speculator won the first-stage auction at a positive price, Hypothesis 3 predicts that the speculator will offer the item for resale at a price above 50. As evident from the left panel of Figure 2, this hypothesis is clearly rejected. Building on our discussion following the statement of Hypothesis 3, we do, however, still interpret the experimental data as being broadly in line with speculative behavior in the sense that resale offers are strictly above the first-stage auction price in 93.3% of the cases where the speculator won the initial auction (Wilcoxon test p-value < 0.01).[12] The reason this is suggestive of speculative

[11] Maximum-value bids equal to 100 ECUs represent 9.7% of the bids shown in Figure 1.

[12] To test using averages per session we look at the average difference of resale offer minus auction price by session we get that in all 6 independent sessions this was indeed positive. A Wilcoxon test yields a p-value

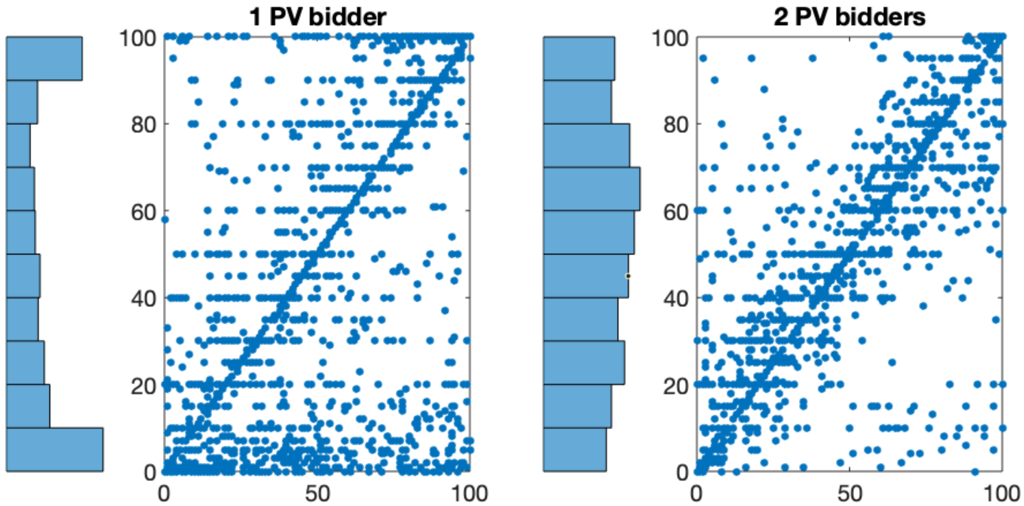

Figure 1: Private-value bidder values vs bids in the treatment with 1 private-value bidder (left panel) and with 2 private-value bidders (right panel). On the left of every scatterplot we plot the marginal distributions of the bids.

behavior is that such a strategy would never make sense if there was a perception of value bidding in the initial auction.

In cases where the private-value bidder bids zero (or near zero) in the first stage, the speculator can credibly believe a speculative equilibrium is being chosen. In this case, the speculator's resale offer should, according to the theory with $\theta^* = 100$, be equal to 50. We find that in these cases, winning speculators made a mean resale offer of 39.86 (Wilcoxon test that the mean is different from 50 has a p-value< 0.01 assuming bids are independent, and < 0.05 averaging by session). In fact, in cases where the speculator wins at a price near zero (below 5 ECUs) the resale offer is below the monopoly price of 50 in 77.18% of the cases. We therefore conclude that Hypothesis 4 is rejected.

4.2 Two private-value bidders, one speculator

Hypotheses 1-4 still apply to these auctions, with the minor modifications discussed in Section 2.2. We continue to find support for Hypotheses 1 and 2, however the data indicates that speculators are less effective at imposing their will on two private-value bidders. Table

of 0.03 (note this is the lowest possible p-value given this sample, for this test).

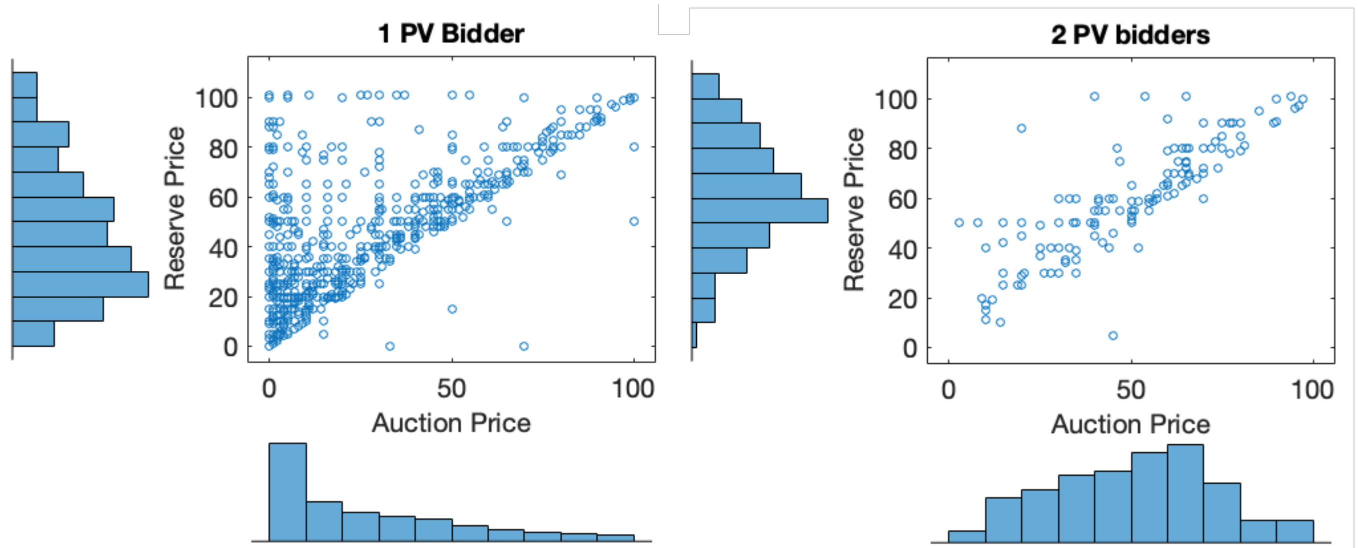

Figure 2: Reserve prices vs first-stage auction prices, given speculator won, under random matching. Left panel: 1 private-value bidder. Right panel: 2 private-value bidders. On the left of each scatterplot we show the marginal distribution of the reserve prices, below the scatterplot is the marginal distribution of auction prices.

II mirrors the presentation of data from Table I for this treatment, and shows the changes in observed percentages relative to the one private-value bidder treatment. More speculators appear to be playing the value-bidding equilibrium and few speculators are attempting to play the speculative equilibrium. Likewise, the percentage of private-value bidders that bid below 5 is lower than in the one-private-value-bidder case. As in the one-private-value-bidder case there is substantially more conformity to the speculative equilibrium by speculators than by private-value bidders.

Overall, looking at period-1 strategy triplets, we classify them as being consistent with the value-bidding equilibrium 9.1% of the time and consistent with the speculative equilibrium 0.2% of the time. Note that coordination is mechanically harder in this case, since there are three players.

Looking at the right panel of Figure 1, we see far fewer bids of 100 by the private-value bidders when there are two of them. This makes sense since, in the presence of a second private-value bidder, it is no longer the case that bidding 100 is payoff equivalent to value bidding, given that the speculator bids 0.

Rounds	Speculator $b < 5$	Δ	$b \geq 62.50$	Δ	Private-Value Bidder $b < 5$	Δ	$\lvert b - V \rvert < 5$	Δ
1-10	2.66	-5/18	32	-28.54	2.66	-4.91	33	-0.51
11-20	14	3.73	22.67	36.79	4	-7.62	45	12.03
21-30	30	22.16	18.67	-38.09	3.33	-15.32	41.33	6.47
31-40	21.33	10.79	18	-37.4	4.66	-15.61	45.66	9.71
All	17	7.88	22.83	-35.21	3.67	-10.86	41.25	7.2

Table II: Percentages of bids of speculators and private-value bidders meeting different thresholds in different round blocks for the treatment with 2 private-value bidders, 1 speculator, and random matching. V denotes private-bidder value. The Δs denote percentages in the two private-value case minus the percentages in the one private-value case.

4.2.1 Resale auctions

In the case of two private-value bidders, Hypothesis 3 can be reinterpreted in terms of the reserve price chosen by the speculator when she wins the initial auction at a non-zero price. In this instance, we are looking for evidence that the speculator demonstrates some form of punishing beliefs by posting a reserve price that is higher than 50.[13] Looking at the right panel of Figure 2, we observe that reserve prices are below 50 in 37.8% of the cases where the speculator won at a positive price. This again leads us to reject Hypothesis 3, as stated for the case of $\theta^* = 100$, despite there being stronger support than in the 1 private-value bidder case.[14] Hypothesis 4 cannot be properly evaluated, because there was just one case where the initial auction price is less than 5 ECUs (the reserve price was below 50 in that

[13] The theory presented in Garratt and Troger (2006b) for the case of $n \geq 2$ private-value bidders assumes bidders that bid a non zero amount in the initial auction have private values equal to θ^*. As in the case of the single private-value bidder auction we allow for weaker forms of punishing beliefs in our empirical test. Specifically, the belief that the speculator will set a reserve greater than 50 in response to positive bids in the initial auction is enough to make this deviation suboptimal.

[14] There is even some sparse evidence of speculators choosing a reserve of 50 across a variety of period-1 losing bids.

case).

4.2.2 Learning

Subjects observe outcomes and from past auctions and hence can learn what strategies seem to work best on average against the population of opponents. In our setting, in particular, subjects playing the role of private-value bidders need to assess what type of speculator they are likely to be facing. Is it one that attempts to play the speculative equilibria by bidding aggressively or one that plays passively by bidding zero? In principle, they could adjust their strategic play based on their observed outcomes within the session. Likewise, subjects playing the role of speculator might reassess the likelihood of a successful speculative attempt and change their behavior.

Figure 3 shows average overbidding (bids minus private values) for speculators and private-value bidders in the one private-value bidder (solid lines) and two private-value bidder (dashed lines) cases. Looking at these series, we see evidence of moderate learning behavior that seems quite intuitive. In the one-private-value-bidder case, speculators persist in attempting to play the speculative equilibria at a constant rate (frequencies of speculator bids great than or equal to 50 in all 10 period blocks are statistically indistinguishable) and there is evidence that more private-value bidders acquiesce over time. This is evident in the series in Figure 3 and the percentages of bids by private-value bidders that are less than 5, increases across the 4 blocks of rounds in Table I (Wilcoxon test, p-value < 0.001 comparing blocks 1 and 2 to 4, while 3 to 4 is not significant, using session averages, the comparison of blocks 1 to 4 yields p=0.0625, and 2 to 4 yields p=0.125). In contrast, in the two-private-value-bidder sessions, the private-value bidders behavior remains relatively constant throughout the sessions and the percentages of speculators that attempt to enforce the speculative equilibria declines over time (Wilcoxon test, p-value < 0.05 between blocks 2 and 4, while the comparison between 2 and 3 is not significant. By session all comparisons are insignificant, although since this is a within-subjects comparison there are not truly independent samples.). This is consistent with our expectation that speculative behavior is

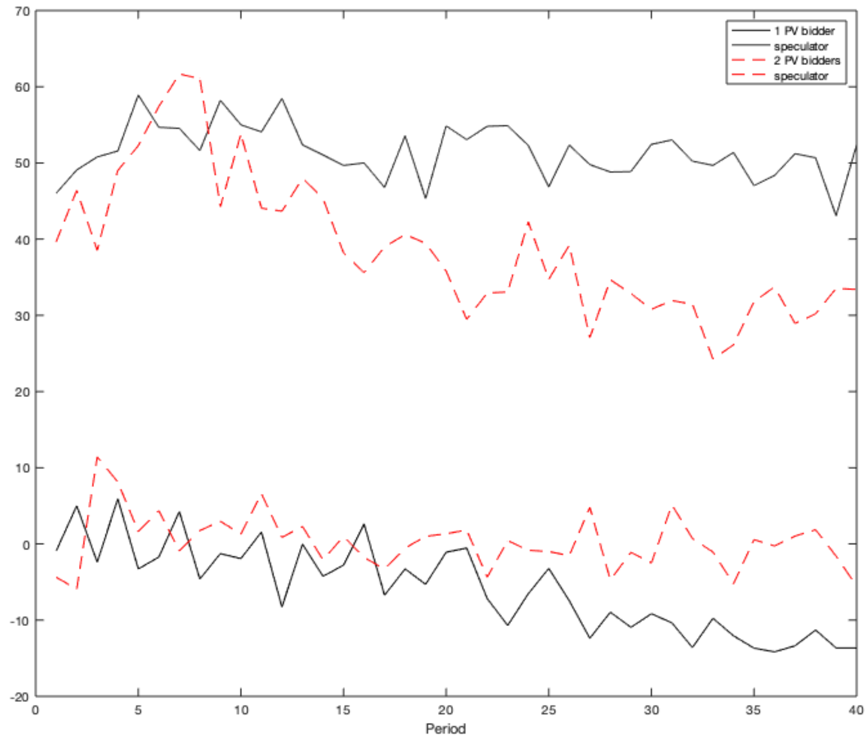

Figure 3: Overbidding (bid minus private value) over time in the treatments with random matching. Solid lines show the 1 private-value bidder case (speculator overbid is the upper line and private-value bidder overbid is the lower line). Dashed lines show the 2 private-value bidder case (speculator overbid is the upper dashed line and average overbid across the two private-value bidders is the lower dashed line).

hard to implement in auctions with more private-value bidders.[15]

[15]In fact, with two PV bidders speculation was relatively costly. After successful resale, 4.23% of the speculators in 1 PV and 14.58% lost money, The average profit was 13.03 and 6.8 units respectively. The average profit of all speculators who win in Stage 1, not conditioning on resale, was -14.22 and -32.03. Bidders choosing bids that actually cost them has already been seen in Kagel and Levin, 1993. In the present case there is the added incentive that speculators are trying to push PV bidders to a different equilibrium, that can be highly profitable.

Rounds	1-10	11-20	21-30	31-40	All
Observed	50.5	46.39	43.8	38.6	44.82
Value-bidding	33.2	32.5	34.3	30.9	32.7

Table III: Average revenue with 2 private-value bidders and 1 speculator under random matching.

4.2.3 Seller revenue

Our theory of the two bidder private-value auction with a speculator predicts that seller revenue should be lower (actually zero) in auctions where the bidders attempt to play a speculative equilibrium based on $\theta^* = 100$. In instances where subjects attempt to play a value-bidding equilibrium, the presence of the speculator has no effect on revenue. Overall, the prediction, which is expressed in Hypothesis 5, is that on average seller revenue should be lower in our treatments with two private-value bidders and a speculator than the theory of value-bidding predicts.

Table III shows average seller revenue in our two-private-value-bidder sessions broken down by 10 period blocks. The theoretical average revenue amounts under value bidding, based on the actually drawn values, are also shown. We see that average revenue has a tendency to fall across blocks. However, revenue is higher than the value bidding prediction (Wilcoxon test p-value< 0.001) leading us to reject Hypothesis 5.[16] While the occurrence of speculative behavior in many auctions, that we documented above, depresses some bids, there was a tendency for some low value bidders to overbid leading to the observed result. Similar behavior was observed in experiments conducted by Georganas (2011) involving two-private-value-bidder auctions with resale and no speculator. Low value bidders exhibit substantial dispersion in their bids (some of them behaving like speculators and overbidding substantially) and high value bidders concentrate their bids close to their use values.

[16]Taking averages by session, the difference between revenues and values is indeed positive in all four sessions. The p-value is 0.125, limited by the low number of independent sessions.

5 Conclusion

We ran experimental auctions with resale opportunities in the (commonly known) presence of speculators. In the auction environments we consider, a value-bidding equilibrium exists, but so do speculative equilbria in which private-value bidders pool their bids at 0 and allow a speculator to win the auction and earn positive profits by reselling the item. Theory does not predict which of these equilibria will emerge. However, it is useful to obtain some idea as to how likely it is for bidders to play strategies consistent with a speculative equilibrium, as such behavior changes revenue predictions and leads to inefficiency.[17]

We find that subjects frequently play strategies consistent with either a value-bidding or speculative equilibrium, confirming Hypotheses 1 and 2. Evidence in support of Hypotheses 3 and 4, which apply to period-2 behavior by the speculator, was much weaker. Speculators who won the period 1 auction did not typically respond to off-equilibrium path behavior by the private-value bidders in a way that matched the particular speculative equilibrium we anticipated. However, behavior was broadly consistent with a speculative motive, in the sense that successful speculators almost always acted in period 2 as if the private-value bidders bid below their values in period 1. In addition, subjects participating in the role of speculator did not generally play strategies which maximized their share of the surplus following successful speculative attempts. Rather, we found that speculators offered lower resale offers, in effect sharing their expected surplus with the private-value bidders.

Theory predicts that the presence of an active speculator may reduce seller revenue in 2 private-value bidder auctions. This happens when aggressive bidding by the speculator leads to a departure from value bidding by the private-value bidders who instead bid 0. Since speculators are not always successful in achieving a speculative equilibrium, the revenues we observe come from a mixture of equilibrium (both value-bidding and speculative) and non-equilibrium play. Under non equilibrium play where speculators are bidding aggressively

[17]Speculative equilibria are inefficient because the bids of private-value bidders do not reveal their private values and hence the optimal resale strategy by the speculator can result in the good not being allocated to any private-value bidder.

and private-value bidders are value bidding or even over-bidding, seller revenue can be quite high. In fact, our finding was that average revenue across treatments was considerably higher than theory predicts in the absence of speculators. Thus we strongly rejected Hypothesis 5.

We did not formulate a specific hypothesis related to efficiency. This is because speculation unequivocally reduces efficiency and hence the only issue is the extent to which this occurs. Since speculators were more likely to influence the auction outcome in the one-private-value bidder case, these auctions were less likely to have efficient outcomes than the two-private-value bidder auctions. We found that the good was optimally allocated in 74% of the two-private-value auctions compared to 62% for one-private-value bidder auctions.

Limited liability can be an issue in second-price auction experiments because subjects sometimes lose money by over-bidding. This issue is particularly relevant in our set-up, since failed attempts at playing the speculative equilibrium can lead to losses for the speculator. A potential concern is that subjects, finding themselves close to bankruptcy, might bid more aggressively, since they cannot leave the lab with negative payoffs, meaning that the downside of aggressive speculation is smaller than in the theoretical model. There are multiple features of our experimental design that were intended to mitigate the concern that speculative behavior was encouraged by limited liability. First, the endowment we chose was large and the payment scheme was such, that speculators needed to make substantial losses several times before the possibility of limited liability becoming likely. We randomly chose five periods to count for the final payoff. In the typical treatment a speculator expects a period's payoffs to count only with probability 1/8. This player could win against a value-bidding private-value bidder eight times, completely fail in the resale market, and still expect a cumulative payoff up to that point of 100-8/8*50=50 ECUs. This player still has full liability for any bid up to 50, and plenty to lose when bidding even higher.

Suppose, however, that players are extremely risk averse or that some paranoid bias is at play, such that they treat every auction payoff as an actual one. Even in that case, many players make positive payoffs during the experiment, which brings this (notional) endowment high enough for full liability. Indeed, looking at players who have had many chances to win an auction, i.e. between periods 25 and 30 inclusive, those who have notionally made 50 units on top of the initial endowment (which brings them clearly into full liability territory) have an average bid of 53.6 against a mean bid of 45.9 for those who have a notional endowment below 150 units. Mean bids for periods 31 and later are 55.9 vs 45.1 respectively. Note the causality here is unclear, since it could be that these subjects are not more aggressive because they have made money, but that they have made money because they are aggressive. In general, speculators have a notional endowment of more than 100 units before 68% of the auctions, and 66.5% in period 10 and afterwards.

Our results are potentially important for mechanism designers and regulators. In settings that resemble the ones we have tested, second-price auctions with independent values and a small number of bidders, the presence of speculators will likely have a strong effect. Our speculators did not have any special advantage in terms of information, liquidity or experience. Hence, even when the playing field is completely even, speculators can disrupt markets.

Plenty of questions remain open for future research. While the English auction is theoretically equivalent to the second-price sealed bid auction and allows for the same speculation equilibria as in this study, it is unclear whether it would yield the same results in the lab. It is known that subjects find the bid-your-value equilibrium more appealing in English auctions, while they often fail to play it in second-price auctions (see Georganas, Levin and McGee, 2017, for an extended discussion). The relatively low appeal of the symmetric equilibrium might be a reason why the (asymmetric) speculation equilibrium is played so often in our study.

Garratt and Tröger (2006) also provide results for first-price and Dutch auctions, where speculators are not predicted to make profits. Combining the lack of incentives to speculate with the experimental results from first-price auctions in Georganas and Kagel (2011), where large asymmetries yield less frequent resale, leads to the conjecture that speculators will be less active in first-price auctions than in second-price auctions.

Finally, one might want to go deeper into the issue of a possible experimenter-demand effect. A subject who ends up in the role of the speculator can choose not to bid, however this essentially means that she does not do anything, and wins no money. It is possible that speculators may have chosen to bid out of boredom or because they believed that bidding was expected from them. We note that subjects in the role of speculators stood to make a considerable payoff from speculation, so it is certainly plausible that they were motivated by payoffs. Also, we did not see evidence of late surges in activity that might be evidence of bored subjects. Still, an interesting robustness check would be to allow speculators to choose between speculating in the auction and a second independent task.

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A Fixed Matching

Tables IV and V provide frequencies of equilibrium bidding behavior for the one- and two-private-value bidder auctions with fixed matching and compares these frequencies to the corresponding treatments with random matching. Looking first at Table IV, we see that bidding behavior by both the speculator and the single private-value bidder is similar in two key aspects to the case of random matching (also see Figure 1, right panel). There is no meaningful change in the fraction of speculators that bid greater than 50 or in the fraction of private-value bidders that bid close to their values. However, there is a significant increase in the frequency of private-value bidders that bid near zero and there is a significant decrease in the frequency of speculators that bid near zero (including all rounds, Fisher exact test p-value< 0.01 and < 0.05 accordingly. Taking average frequencies by independent observation and doing a wilcoxon test yields 0.33 and 0.05 respectively).

Turning to Table V, we see a significant movement toward speculative behavior by the speculators when facing two private-value bidders. The speculators bid less than 5 units significantly less often and more than 62.50 significantly more often than under random matching (including all rounds, Fisher exact test p-value< 0.01 in both cases. Using independent observations, the Wilcoxon test yields p< 0.05 and p> 0.1). At the same time, the 2 private-value bidders bid less than 5 significantly more often than under random matching (all rounds, Fisher p-value< 0.001. Using independent observations p> 0.1). There seems to be a slight uptick in value bidding by the private-value bidders, but the increase is not significant.

Instances where the members of matched groups of two private-value bidders and a speculator all conform to the same equilibrium are too rare to make a meaningful comparison across rounds. However, in the auctions with one private-value bidder and a speculator, under fixed matching, we find that the frequency of cases where both the private-value bidder and the speculator value bid (allowing plus or minus 5 ECUs) increase from 4.7% in the first 10 rounds to 10% in the last 10 rounds (Fisher exact test p-value< 0.05. A test using independent observations is conceptually not possible since we are comparing within-

	Speculator				private-value Bidder			
Rounds	$b < 5$	Δ	$b \geq 50$	Δ	$b < 5$	Δ	$\lvert b - V \rvert < 5$	Δ
1-10	5.3	-2.54	61.18	0.64	12.94	5.37	35	1.49
11-20	4.12	-6.15	58.82	-0.64	21.47	9.85	29.41	-3.56
21-30	7.94	0.10	54.71	-2.05	26.17	7.53	36.47	1.6
31-40	10.88	0.34	58.82	3.41	29.11	8.85	30.58	-5.36
All	7.06	-2.06	58.38	0.34	22.43	7.9	32.87	-1.46

Table IV: Percentages of bids of speculators and private-value bidders meeting different thresholds in different round blocks, in the treatment with one private-value bidder, one speculator and fixed matching. V denotes the bidder's private value. The Δs denote percentages in the one-private-value case with fixed matching minus the percentages in the one-private-value case with random matching.

	Speculator				private-value Bidder			
Rounds	$b < 5$	Δ	$b \geq 62.50$	Δ	$b < 5$	Δ	$\lvert b - V \rvert < 5$	Δ
1-10	8.22	5.56	57.55	1.11	6	3.33	38.44	5.44
11-20	11.11	2-89	50.67	8.22	7.55	3.56	43.66	-1.33
21-30	14.21	-15.78	49.75	12.07	9.19	5.86	43.01	1.68
31-40	15.13	-6.2	43.33	10.72	11.8	7.13	44.74	-0.92
All	12.17	-4.83	31.02	8.19	8.64	4.97	42.47	1.21

Table V: Percentages of bids of speculators and private-value bidders meeting different thresholds in different round blocks, in the treatment with two private-value bidders, one speculator and fixed matching. V denotes the bidder's private value. The Δs denote percentages in the two-private-value case with fixed matching minus the percentages in the two-private-value case with random matching.

subjects, but for completeness, a Wilcoxon test averaging by independent groups yields p$>$ 0.1.). In the same type of auctions, the frequency of cases where the private-value bidder bid close to 0 and the speculator bid 50 or above increase from 9.12% in the first 10 rounds to 22% in the last 10 rounds (p-value$<$ 0.01, same by independent groups).

In the following two subsections, we present dynamic analysis for auctions with fixed matching. Appendix A.1 identifies four common behavioral states in auctions with one private-value bidder and one speculator, involving a behavior by the two players which show a high degree of stability once achieved. The most stable states are the two equilibrium states: once achieved, bidders stay in the value-bidding private-value bidder/weak speculator state 78.2% of the time and they stay in the zero bidding private-value bidder/strong speculator state 88.4% of the time. In terms of individual group dynamics, we observe a variety of patterns, shown in Appendix A.2. In some groups the speculator manages to move the group to a speculating equilibrium, usually bidding a constant amount, not always 100. In others there is a prolonged struggle, meaning low profits for both players.

A.1 Individual Group Dynamics: State Transition Probabilities

Consider the following classifications of private-value bidder activity, according to their bids:

$$\text{The private-value bidder is} \begin{cases} \text{zero bidding} & \text{if } b_1 \in [0, v-5] \\ \text{value bidding} & \text{if } b_1 \in (v-5, v+15] \\ \text{overbidding} & \text{if } b_1 \in (v+15, 140] \end{cases}$$

Analogously, consider the following classification of speculator activity

$$\text{Speculator is} \begin{cases} \text{inactive} & \text{if } b_s \in [0, 10] \\ \text{weak} & \text{if } b_s \in (10, 50] \\ \text{strong} & \text{if } b_s \in (50, 140] \end{cases}$$

The classification scheme yields nine possible combinations of bidding in a given period. Under a fixed matching, most individual groups can then be classified to be in one of four states.

(a) Zero bidding private-value bidder, weak speculator

(b) Value bidding private-value bidder, weak speculator

(c) Zero bidding private-value bidder, strong speculator

(d) Value bidding private-value bidder, strong speculator.

Table VI presents a Markov transition matrix between these states. States (a) and (d) are not very stable. Bidder couples do not remain in those states for long, before moving to another state. State (c) is the most stable one. This means that once the speculator starts bidding very high and the private-value bidder very low, a unilateral deviation tends to be unprofitable. On the other hand, state (d) is dangerous for both players; one of the two eventually has to give in and bid less aggressively.

From ↓ To →	State a	b	c	d
State a	**68.7%**	6.4%	8.6%	2.7%
b	4.6%	**78.2%**	1.3%	5.4%
c	3.4%	1%	**88.4%**	4.2%
d	1.6%	6.6%	9.9%	**72.7%**

Table VI: Markov Transition Matrix for the treatment with 1 private-value bidder, 1 speculator and fixed matching.

The Markov analysis above does not make as much sense in the random matching treatment, since players can not expect to face the same opponent in the next period with a high probability. However, it is interesting to note that the same four states are the most frequently observed ones and the Markov transition matrix looks somewhat similar, with less stability overall though (i.e. the numbers on the diagonal are lower).

A.2 Individual Group Dynamics: Plots

In this appendix we present individual groups' bids over time. Figure 4 depicts data from the fixed-matching treatment with 1 private-value bidder and 1 speculator. Figure 5 depicts data from the fixed-matching treatment with 2 private-value bidders and 1 speculator. Every panel plots bids for one individual group.

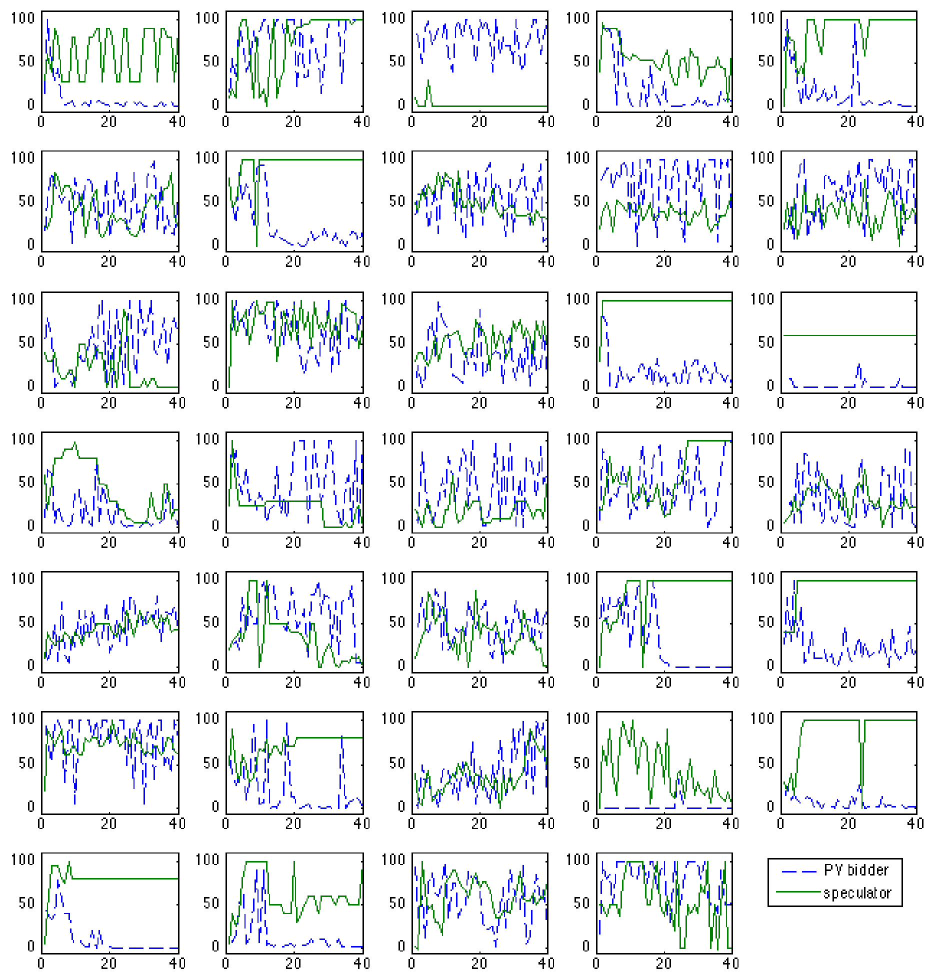
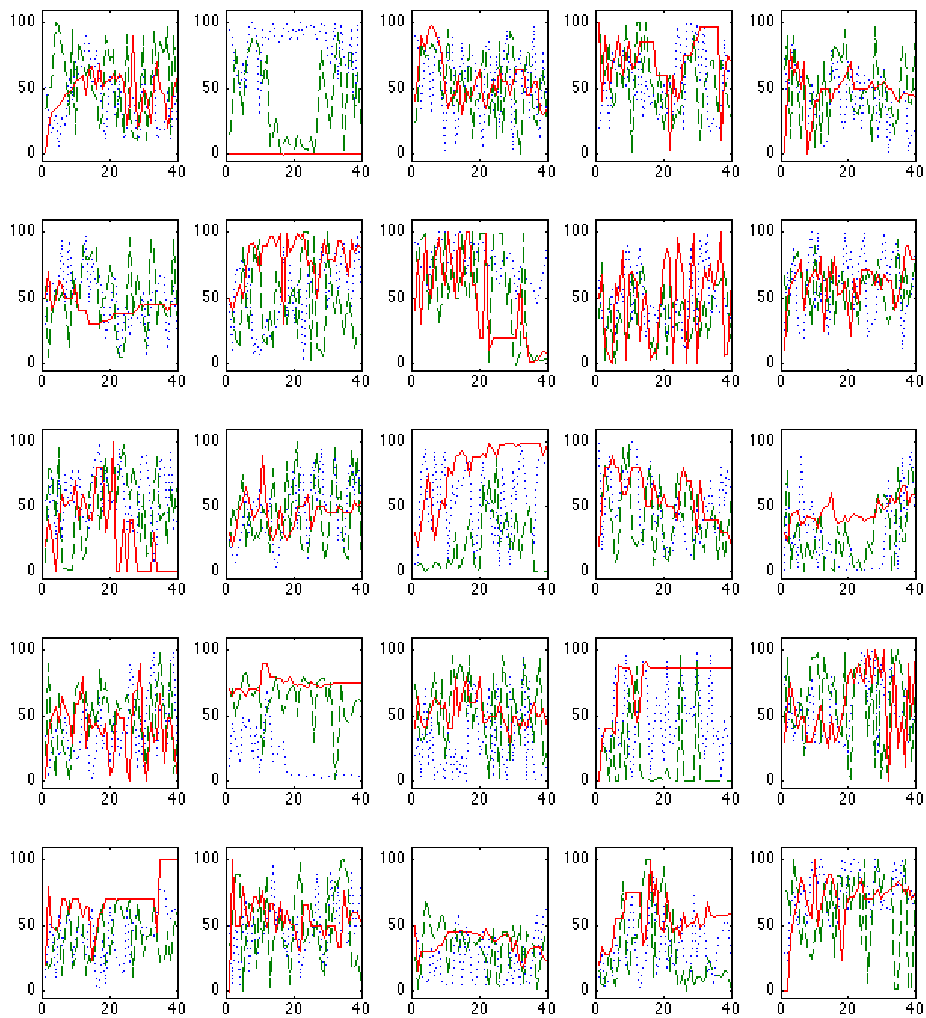


Figure 4: Period 1 bids for all groups in treatment with 1 private-value bidder, 1 speculator and fixed matching.



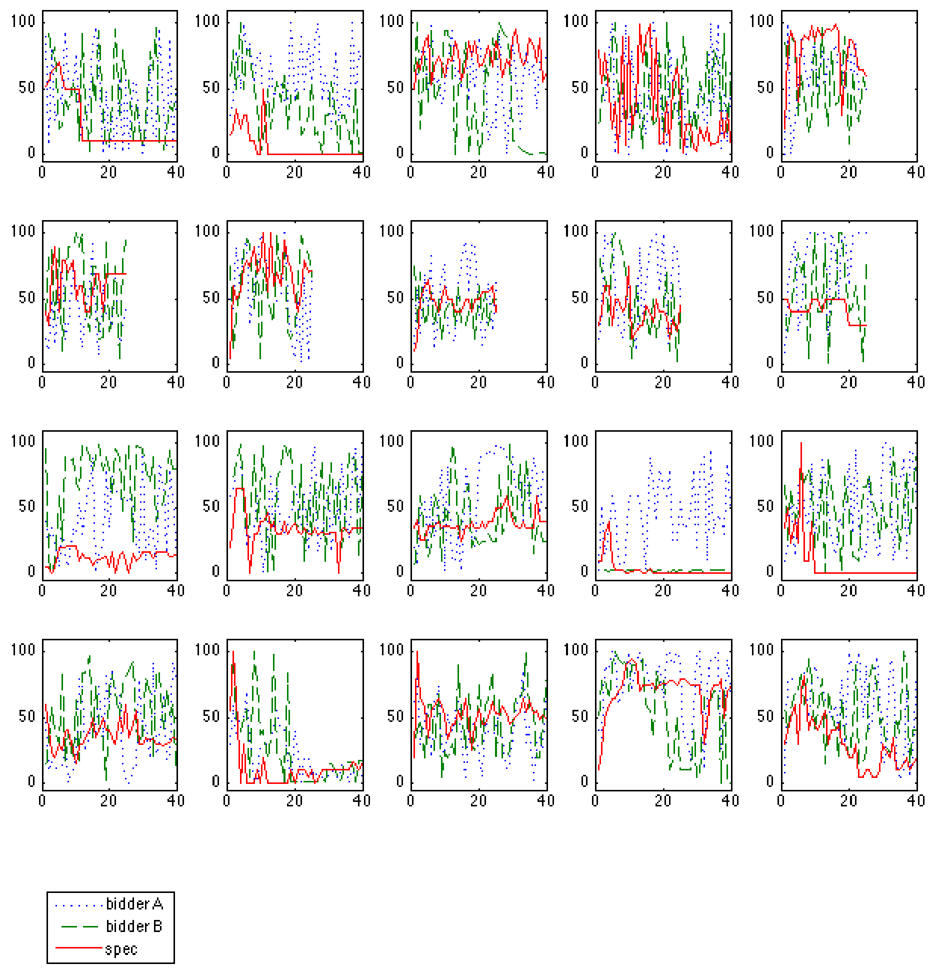


Figure 5: Period 1 bids for all groups in treatment with 2 private-value bidders, 1 speculator and fixed matching.