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 Troeger (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 the 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. As expected, fixed matching yields more speculation than random matching. 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 an extreme case of speculator, one 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 Troeger (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, as 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 is also increasingly well understood in auctions (see theoretical work of Haile 2000, 2001, 2004; Garratt and Troeger, 2006; Calzolari and Pavan, 2006; Hafalir and Krishna, 2008; Garratt, Troeger and Zheng, 2009 and experimental work Lange et al., 2004; Georganas, 2011; Georganas and Kagel, 2011; Jabs-Saral, 2012; Pagnozzi and Saral, 2016).

We report results from four treatments, where we vary the number of private value bidders and the matching between subjects. The aim of this variation is to study how the frequency of interaction facilitates or impedes speculation, and whether results hold when there is increased competition among bidders. We find strong evidence that players play a speculative equilibrium in which the zero-value bidder wins the item and resells it to the private-value bidder. This occurs despite the fact that a simple, value-bidding equilibrium also exists. A higher frequency of interaction (fixed instead of random matching in the experiments) yields more speculation, as expected. Stronger competition between the private-value bidders makes speculation harder, but does not eliminate it.

Our results show that allowing speculation in standard auction markets most likely leads to an increase in seller revenue. When the speculator is highly effective in squashing competitive bidding in the initial auction the result is that the seller obtains almost no surplus (zero revenue). The surplus is instead split between the speculator and the private value bidders in the resale market. In contrast, in cases where the speculator is present, but less effective, private-value bidders 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. Specifically, for markets with two private-value bidders, the introduction of a speculator raised revenue by 18%, from 39.4 to 46.2 in the case of fixed matching.

We also examine the impact the speculator has on efficiency, both in the initial auction and following resale. Efficient outcomes in the initial auction are more frequent in the two private-value bidder, one speculator auctions than the one private-value bidder, one speculator auctions, reflecting the decreased likelihood in the former case that the speculator wins the auction. Resale improves the likelihood of efficiency in both case, but a gap remains. Efficient outcomes are most frequently observed in the treatment without a speculator. Speculators tend to reduce efficiency in our setting since they use reserve prices in the resale market (and private value bidders' bids in the initial auction do not reveal their values) while the initial seller does not.

While our design is quite spartan, it is exactly its simplicity that allows us to control for confounding factors that would be present in richer lab environments (say multi-unit auctions) or in the field. An additional, more abstract aspect of our study, that should be interesting to both theorists and experimentalists, is that we find evidence of asymmetric equilibria. In most applications in the theoretical literature, symmetric equilibria are intuitively regarded as more appealing. Whenever a multitude of equilibria exists, for example, symmetry is used as a selection criterion. The same is true in lab studies, where the tendency is to look for symmetric equilibria. Our results show that this practice is not entirely innocuous. Real humans can identify and coordinate on asymmetric equilibria, even in moderately complex two stage games, as the one in our experiments.

As mentioned above, there is a very rich literature on standard auctions without resale, both in theory (see Milgrom and Weber, 1982) and the lab (see Kagel, 1995, for a survey). There are also increasingly many 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. 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 asymmetric equilibria described above that are qualitatively different to the previous papers. We find evidence that these equilibria, while not always 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 presents the symmetric and asymmetric equilibria of the game.[1] Section 3 covers the experimental design and procedures. Results are reported in Section 4. Section 5 summarizes the findings.

2 Theoretical Implications

The theory permits a wide range of behavior on behalf of private-value bidders and the speculator. However, we present arguments which narrow the set of predictions and identify testable hypotheses. We begin by outlining hypotheses that follow directly from the equilibrium analysis. We then present high-level predictions that capture qualitative features of the more specific hypotheses. The high-level hypotheses identify behaviors that are required by subjects playing a speculative equilibrium and are wholly inconsistent with value-bidding equilibria.

2.1 Model and Predictions

The experiments use auction environments that are special cases of those considered in Garratt and Troeger (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

[1] In auctions with one or more private-value bidders and speculator we call an equilibrium symmetric if all bidders use the same bid function; value-bidding would be the obvious example of a symmetric equilibrium.

and Troeger 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.

2.2 1 private-value bidder, 1 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]

We consider a two-period interaction. Before period 1, the private-value bidder privately learns the realization of her 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.[3] 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 she fails to resell the good 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] 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.

[3] In theory, an English auction instead of sealed bid would not change the results here, at least with two bidders (more bidders would complicate the resale offer problem). Of course, given that subjects do not respect the strategic equivalence of the two formats in simple no-resale auctions experiments, the choice of format would very likely matter in the lab for our setup too.

2.2.1 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 1 and Proposition 1). 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

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

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 Garratt and Troger (2006). The key point 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. High-λ beliefs are more punishing. We are not suggesting that off-path beliefs are chosen by the speculator, however this is an intruiging idea. Rather, we are emphasising that equilibria exist for a variety of off-path beliefs and this should be allowed for when examining experimental data.

For all $\theta_1 \in [0, 100]$ and $b_1 \in [0, 100]$, the speculator's updated belief about the value of the private-value bidder is given by

$$\Pi(\theta_1 \mid b_1) \quad = \quad \begin{cases} \min\{\frac{\theta_1}{\theta^*}, 1\} & \text{if } b_1 = 0 \text{ and } \theta^* > 0, \\ \mathbf{1}_{\theta_1 \geq t} & \text{if } b_1 \in (0, \theta^*), \\ \mathbf{1}_{\theta_1 \geq b_1} & \text{if } b_1 \in (\theta^*, 100]. \end{cases} \tag{3}$$

The speculator's updated beliefs must, of course, support the resale price function stated in (2) and the equilibrium bidding strategies in period 1. If the speculator wins at a price of 0, she believes the private-value bidder's value is uniformly distributed between 0 and θ^*. If the speculator wins at a price between 0 and θ^*, then she puts unit mass on some value between b_1 and θ^*. If the speculator wins at a price above θ^*, then she believes the private-value bidder is a value-bidder.

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 bidders 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 she 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.[4]

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

$$\Pi_1(\theta^*) \quad = \quad \begin{cases} 0 & \text{if } \theta_1 \in [0, \frac{\theta^*}{2}), \\ \theta_1 - \frac{\theta^*}{2} & \text{if } \theta_1 \in (\frac{\theta^*}{2}, 100] \end{cases} \tag{4}$$

and

$$\Pi_s(\theta^*) = \theta^* \left[\frac{\theta^*}{2} \frac{\theta^*}{2} \right] = \frac{(\theta^*)^3}{4} \tag{5}$$

In principle, any of the equilibria could emerge, however the value-bidding equilibrium corresponding to $\theta^* = 0$ and the active speculator equilibrium corresponding to $\theta^* = 100$

[4]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 (2001, 2004).

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 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. In any event, there is a compelling reason why we should expect to see equilibria with an active speculator and $\theta^* = 100$.

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, equilibria with $b_s > \frac{\theta^*}{2}$ and $\theta^* < 100$ do not exist. A private-value bidder with value θ such that $\theta^* < \theta < b_s$ is better off bidding 0 and getting resale price $\frac{\theta^*}{2}$, than value-bidding, losing to the speculator and getting a resale price equal to her value. But this means the speculator's beliefs, in the event she wins at price 0, are not valid as these beliefs are based on the θ^* threshold which we just argued is no longer correct when $b_s > \frac{\theta^*}{2}$. In contrast, all bids $b_s \geq \frac{\theta^*}{2}$ for the speculator are in the best response set and are part of an equilibrium when $\theta^* = 100$.[5]

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 *Non-zero losing period 1 bids by the private-value bidder will result in resale offers above the losing bid.*

Hypothesis 3 requires additional discussion. A given subject will either have the type of punishing beliefs need to support a speculative equilibrium or she will not. And, the private-value bidder will either believe the speculator has punishing beliefs or not.[6] So basically, the private-value bidder may or may not choose to acquiesce to the speculator and bid zero and the speculator may or may not attempt a speculative bid. But, if the speculator

[5] This argument was not made in Garratt and Troger (2006) because it only applies to the no-discounting case.

[6] Of course, even if the private-value bidder believes the speculator has punishing beliefs, he may still attempt to play the value-bidding equilibrium.

does attempt a speculative bid, then she should be the type that has punishing beliefs and therefore we would expect her to respond to strictly-positive losing bids with higher resale offers. It would be inconsistent with any (pure-strategy) equilibrium prediction if we saw a speculator bid aggressively in the initial auction, win the item, and then resell at a price less than what she paid.

Note that all three hypotheses test for equilibrium behavior, not for equilibrium. They do not depend on the bidders have common expectations as to which equilibrium will be played.

2.2.2 Fixed Matching

Fixed matching introduces new possibilities for coordinating on strategic equilibrium outcomes and it opens the door to cooperative behavior.

Strategic equilibria with fixed matching

With fixed matching, players have the opportunity to signal their beliefs. In particular, speculators with punishing beliefs can demonstrate this to private-value bidders who should then be more inclined to acquiesce and play a speculative equilibrium. If beliefs are fixed, then we should see no change in the behavior of speculators, but we should see more equilibrium outcomes (i.e., more instances where both player coordinate on the speculative equilibrium or the value-bidding equilibrium if the speculator does not have punishing beliefs). Of course, repeated play allows players to coordinate better on equilibrium selection, so even without learning about beliefs, we should see more equilibrium outcomes of either kind.

Hypothesis 4 *More instances of the value-bidding equilibrium and the speculative equilibrium will be seen in later rounds with fixed matching.*

Cooperative solutions

It is possible that players will try and achieve a cooperative outcome. Thus, we might think of the 2-period interaction as a bargaining game with private information. The size of the surplus to be divided is determined by the private-value bidder's private value, which is unknown to the speculator. This surplus is obtained at zero cost if at least one of the bidders bids zero in the period 1 auction. However, division of the surplus through the resale market is only possible if the speculator wins the period 1 auction.

Bargaining without signals

Suppose the speculator believes that the private-value bidder will bid 0 for all realizations of her private value. Consider the period 2 resale market after the speculator wins the period 1 auction at price 0. Then the bargaining problem is related to Samuelson (1984) and others who consider bargaining with a privately informed seller – the difference is that here we have a privately informed buyer and we are not looking for an optimal solution for either player. An attempt to split the surplus would be achieved by setting reserve price so that the exante payoffs to each player are equal. The expected payoff to the speculator of setting a reserve r after winning the auction at price 0, and assuming all private-value bidder types bid 0, is

$$(1 - \frac{r}{100})r \tag{6}$$

The ex ante, expected payoff to the private-value bidder if the speculator sets reserve price r is

$$(1 - \frac{r}{100})(E(\theta_1|\theta_1 > r) - r) = (1 - \frac{r}{100})(\frac{1-r}{2} - r) \tag{7}$$

Setting these two expected payoffs equal to each other yields the solution $r = 20$. Hence, the speculator would repeatedly set a reserve equal to 20.

Hypothesis 5 *In instances where the private-value bidder bids 0, the speculator will offer a resale price well below the monopoly price (of 50).*

Bargaining with signals

An interesting possibility is that the private-value bidder can signal her private value to the speculator, without sacrificing much of the surplus, through small variations in low value bids in the period 1 auction.[7] This sets up a game with a form of cheap talk, or cheap signalling, similar to that studied elsewhere in the experimental literature. See, Croson, Boles, and Murnighan (2003), for example. For instance, if signals were credible, then the bidders could split an amount close to the maximum possible surplus if the private-value bidder bid his value in cents and the speculator made a resale offer at the price

$$\frac{b_1}{2} * 100. \tag{8}$$

Such signals would not be credible. Nevertheless, it is possible that bidders will attempt to coordinate in this way.

2.2.3 High-Level Hypotheses

The following hypotheses make general predications that do not depend on precise details of the auction environment, such as the private-value bidder's actual distribution of values.

Hypothesis 6 *The private-value bidder's bid will be uncorrelated with her value.*

Note: It is possible that the private-value bidder's bid will be correlated with her value even in a speculative equilibrium if she is trying to signal her value to the speculator in an attempt to reach a cooperative solution (see discussion above). In such cases we should be able to check that the bids are much lower than values.

Hypothesis 7 *The speculator bids a positive amount.*

3 Experimental Design and Procedures

We ran thirteen sessions of the treatment with one private-value bidder and one speculator. Six of these sessions involved fixed matching and seven involved random matching of subject pairs for the auctions. We conducted fourteen sessions of the treatment in which the auctions

[7]We thank Marek Pycia for suggesting this possibility.

had two private-value bidders and one speculator. Nine of these sessions had fixed matching and five had random matching. 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.

In order to assess the impact of a speculator on auction price we needed a control treatment in which resale is permitted, but there is no speculator. We conducted two such sessions with fixed matching. The minimum number of subjects in a session was 6 and the maximum was 18. In total, across all sessions, we had participation from 346 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.[8] All sessions began with two unpaid periods followed by 40 auctions for cash. The experiment lasted for about two hours.

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.[9] In the fixed matching treatments subjects were playing with the same partner throughout the experiment, while in the random matching treatments a new partner was randomly chosen before each auction.

In resale auctions, sellers did not have any choice whether to put the item up for sale, but were advised that if they did not want to sell they could set $r = 101$. Feedback after the final allocation consisted of bidders' net profits, both players' bids and their corresponding valuations, along with their type, with information from past periods available on subjects' computer screens.

[8]Instructions are available in the web appendix.

[9]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, even in stranger matchings. 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

All results in this section exclude the first 10 periods, unless stated otherwise. We begin by examining our high level hypotheses for the one speculator-one regular bidder case, as these address the basic question of whether or not the presence of a speculator matters.

The first major result, corresponding to Hypothesis 7, is that the speculator almost always bids a positive amount. A bid of zero is observed in only 5.5% of the cases with fixed matching and 7.7% of the cases with random matching. Hypothesis 6 is partially confirmed, as the correlation between private-value bidder bids and values is below .5 for 41.18% of the subjects under fixed matching and 27.03% of the subjects with variable matching.[10] The low correlation observed under both variable and fixed matching reflects the fact that some private-value bidders bid zero or near zero, regardless of their private values. In short, behavior consistent with speculative equilibrium is clearly present, although it is not present in all groups all the time.

Moving to the more specific hypotheses, there is support for hypotheses 1 and 2, that for the most part, subjects attempt to play either the value bidding equilibrium or the speculative equilibrium. Speculator bids are either below 5 ECUs 9.5% or above 44 ECUs 60.42% of the time under random matching. [11] Private-value bidder bids are either below 5 ECUs or within 5 ECUs of value 54.58% of the time with random matching. Under fixed matching, the corresponding numbers are 68.88% for speculators and 58.35% for private-value bidders. There is more conformity to the speculative equilibrium by speculators than by private-value bidders under either random or fixed matching.

The frequency of interaction, as determined by the matching scheme, had a a strong effect on bidding. As presented in Figure 1, speculators bid more aggressively (KS test p-val < 0.01) under a fixed matching, while the private-value bidders bid more aggressively under

[10]The choice of .5 as a "low" correlation level is arbitrary. The average correlation between bids and values, taken across subjects, in the fixed matching treatments is 0.561 and the average under random matching is 0.627.

[11]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.

the random matching, with a substantial number of bids at the maximum of the private value interval (Figure 2). This translates into significantly higher average prices under the random matching (28.4 vs 23.9, p-value< 0.01).

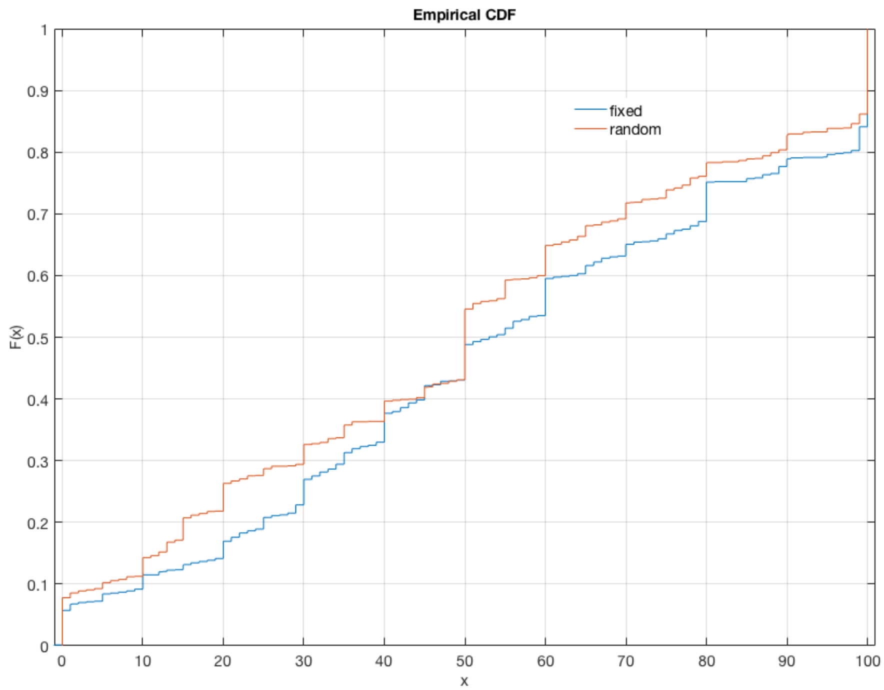

Figure 1: Speculator Bids

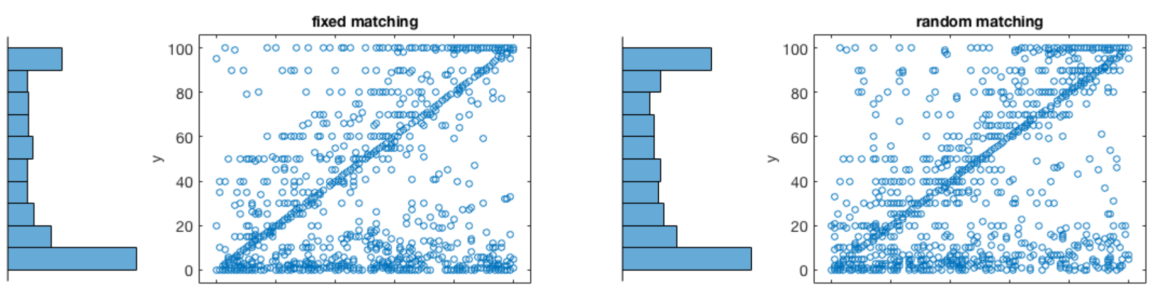

Figure 2: PV Bidders

A look at first stage prices over time (Figure 3) reveals there were some learning effects, and learning is stronger/faster under a fixed matching, lending support to Hypothesis 4. The fact that prices are going down does not necessarily reveal what kind of equilibrium the subjects are playing, as it could be the result of a move towards a speculation equilibrium (with the private-value bidder bidding zero more often) or a move towards a symmetric equilibrium (with the speculator bidding zero).

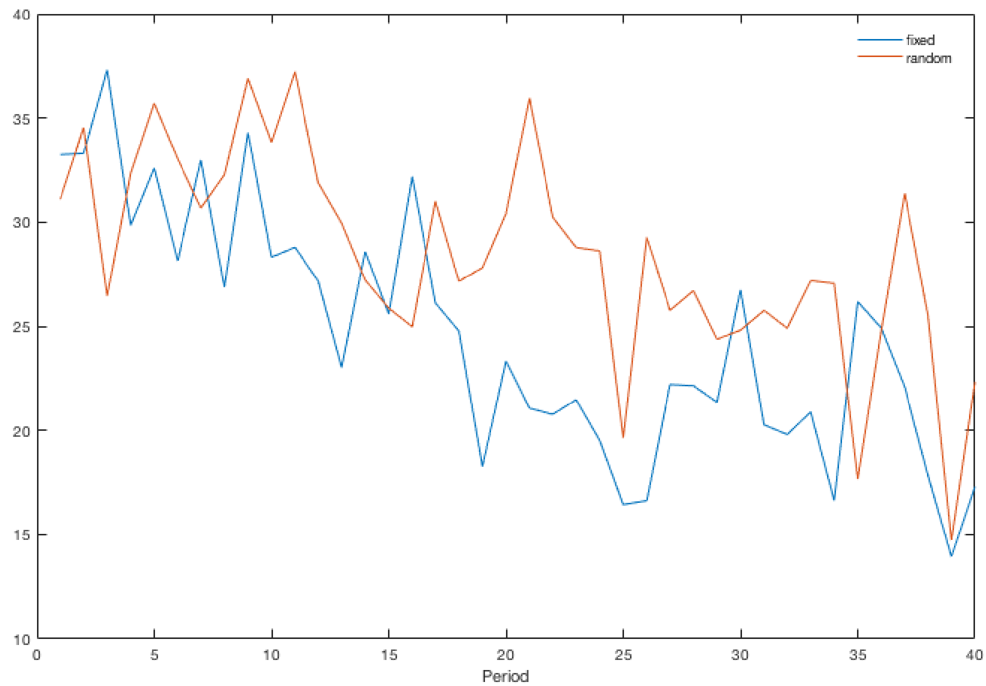

Figure 3: Auction Prices over time

In fact, both scenarios are visible in the data. Table I shows that fewer speculators attempted to win the auction in later rounds, the fraction fell from 94.1 percent to 86.2 percent, but many of the speculators that continued to attempt to play the speculative equilibrium became more aggressive as the fraction placing bids above 90 increased 18.5 percent to 24.7 percent. The fraction of private-value bidders bidding near 0 more than doubled from 12.3 percent to 29.1 percent, while the fraction that bid in an accommodating fashion increased from 20.4 percent to 40.6 percent. These bidders are not playing the speculative equilibrium in a strict sense, but they are clearly opening the door for successful speculative bidding.

Rounds	Speculator			PV Bidder	
	$b > 10$	$b > 50$	$b > 90$	$b < 5$	$b < .5V$
0-10	94.1	59.1	18.5	12.3	25.4
11-20	94.1	58.8	20.6	21.5	39.7
21-30	90.0	54.7	21.8	26.2	38.5
31-40	86.2	58.8	24.7	29.1	40.6

Table I: Percentages of bids of speculators and private-value bidders meeting different thresholds in different round blocks. V denotes private-bidder value.

4.1 Take-it-or-leave-it resale offers

In cases where the speculator wins the first stage auction at a positive price, hypothesis 3 predicts that the speculator will offer the item for resale at a price above the private-value bidders losing bid. Figure 4 plots second-stage resale offers, versus first stage auction prices, for those auctions in which the speculator has won initially. We observe that resale prices are almost always above the period 1 auction price, which is consistent with speculative equilibrium behavior.

In cases where the private-value bidder bids 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, be equal to her period 1 bid. However, we find that in these cases, winning speculators have a mean bid of 52.8 in the first period and a mean resale offer of only 39.37 (Wilcoxon test p-value< 0.01) in the rounds with fixed matching. A reason for this could be that players are attempting to achieve a cooperative solution. In fact, in cases where the speculator wins at a price near zero (below 5 ECUs) the resale offer is below 45 (the monopoly price of 50, minus a margin of 5 ECUs) in 78.55% of the cases, providing strong support for Hypothesis 5.

In cases where the speculator wins the first stage auction at a positive price, Hypothesis 3 predicts that the resale offers should be above the losing bid. This is true regardless of whether the treatment has random or fixed matching. In the treatment with random

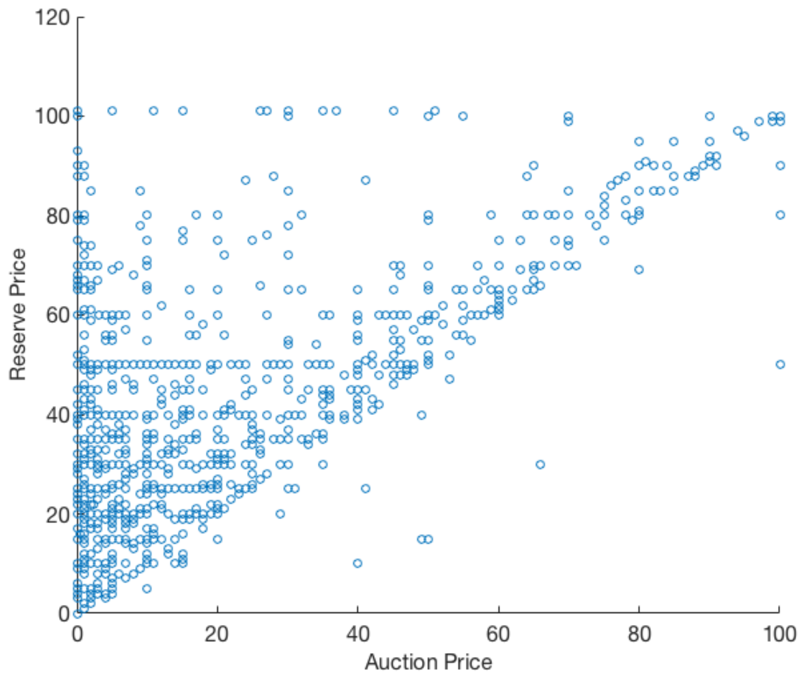

Figure 4: Reserves prices vs first stage auction prices, given speculator won

matching, speculator resale offers are above the losing bid in 93.5% of the cases where the speculator won the initial auction (Wilcoxon test p-value < 0.01) and in the treatment with fixed matching speculator bids are above the losing bid in 90.7% of the cases where the speculator won the initial auction (Wilcoxon test p-value < 0.01). These results provide strong support for Hypothesis 3.

As noted in the theory section, there is a possibility that private-value bidders will try to signal their value, to ensure that the resale market will be efficient. The most efficient bid function would be of the type λv_i with λ being very small (see discussion on bargaining with signals). Running a regression, among private-value bidders who are underbidding, we do find a positive relationship between bid and value, but the estimated λ is too high, at 0.6.[12]

[12] A natural question that arises is whether pre play communication would allow for more efficient signalling. We did not explore this possibility. It is possible communication of this type would be regarded as collusion and hence be illegal in some instances.

4.2 Individual Group Dynamics

In the case of fixed matching it is interesting to see how subject behavior varied over the 40 rounds of the experiment. The simplest and most informative way to do this is to look at plots of stage 1 bidding behavior. In Figure 7 of the appendix we provide a graph for each 2-player group under fixed matching. These reveal a variety of behaviors including some instances, (2,2), (3,5) and (5,4), that conform closely to the theory of speculative equilibrium in the later rounds.[13] There is only one case, (1,3), that conforms closely to the value bidding equilibria. Most reflect more or less successful attempts by the speculator to impose her will on the private-value bidder.

One simple way to quantify the success or failure of bidders to play a speculative equilibrium is to count the number of sessions in which the speculator won the item in at least 9 out 10 of the final rounds. 15 out of 34 groups (or 44.12%) satisfy this condition. In these auctions, the average auction price was 9.87 compared to 27.97 in the other groups. Likewise, second stage efficiency drops from 0.72 to 0.6 when comparing the non-speculative to the speculative groups. This is compelling evidence that speculators matter.

Since the speculator has very strong incentives to be active, there arises the question why speculation does not always work. It turns out that the success of the speculator depends on whether or not she can convince the private-value bidder to follow the speculative equilibrium.

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

[13] Instances are identified by their (row,column) position in the figures.

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

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 II 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 II: Markov Transition Matrix

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 bidder group that ends up playing the speculative equilibrium will only remain in that state, if the outcome of the second stage is satisfactory to both players. This in turn depends on the resale offers that the speculator is setting.

4.3 Two private-value bidders and one speculator

We have seen that speculators are active and often successful when facing just one private-value bidder. Here we examine whether this is true in an environment with more than one private-value bidder. In particular, we are interested in seeing if speculators can, by bidding aggressively, convince multiple private-value bidders to bid less than their values and wait for a resale offer. This is important in terms of assessing the practical implications of this study. 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 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 equilbirum in which the private value bidders play symmetric strategies. Hence, we will be looking to see whether subjects play the value-bidding equilbirum or whether they play the multi-private-value bidder version of the equilibrium described in Section 2.1.1 with an active speculator.[14]

The speculative equilibrium has stage-one bidding strategies similar to those described in equation (1): For every $\theta^* \in [0, 100]$, there exists an equilibrium where private-value bidders 1 and 2 use the bid function defined in (1) and the speculator submits a bid $b_s = \frac{5\theta^*}{8}$. 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. Since the reserve

[14] 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.

price in the resale market does not depend on the number of bidders (Myerson, 1981) there is no difference in the expected payment of a private-value bidder with value $\theta^* > 0$ in the resale market if she wins the auction at the reserve. But there is also a possibility that the losing private value bidder's bid will be between the reserve and θ^*. Since private values are uniformly distributed, with probability .5 she wins at price $\frac{\theta^*}{2}$ and with probability .5 she wins at a price equal to the expected value of the losing bidder's bid, conditional on it being between $\frac{\theta^*}{2}$ and θ^*, i.e., at a price $\frac{3\theta^*}{4}$. Hence her expected payment is $.5\frac{\theta^*}{2} + .5\frac{3\theta^*}{4} = \frac{5\theta^*}{8}$. Note that for any θ^* the speculator's equilibrium stage-one bid is higher in the case where there are two private-value bidders.[15]

Hypothesis 8 *The speculator's stage-one bid will be higher when there are two private-value bidders.*

Figure 6 presents average bids for the speculators and average overbids for the private-value bidders across the four treatments we ran in the experiment. Speculator bids are stable in T1-T2, fall slightly in T3 and fall substantially in T4 (random matching and two private-value bidders is the toughest environment for speculators). Nevertheless, the figure confirms that speculators continue to be active in treatments with two private value bidders, despite the fact that in later rounds fewer speculators attempted to achieve the speculative equilibrium. This is confirmed by looking at the frequencies of speculators bidding over 50 and over 90; these values were 48.34% and 6.96% in T3 and 35.34% and 8.17% in T4 (compare to Table I). However, conditional on bidding more than 50 the average bid of speculators decreased from 79.74 to 70.61 when moving from one to two private value bidders with fixed matching (T1 to T3) and 75.01 to 69.08 when moving from one to two private-value bidders with random matching (T2 to T4), which is not consistent with hypothesis 8.

More private value bidders succumbed to the speculative equilibrium in later rounds of T3 and T4. This is most notable in T3 with fixed matching where underbidding increased in the final ten rounds. This is confirmed by looking at the frequencies of private-value bidders bidding less than 5 or less than half their value; these values for the last ten rounds, were

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

14.1% and 20% in T3 and 7% and 8.67% in T4 (compare to Table I). This result is perhaps not surprising. With two private-value bidders there is less inclination to play a speculative equilibrium initially, but if a speculator is sufficiently aggressive she can eventually persuade the private value bidders to reduce their bids. We point the reader to Figure 8 of the appendix, where a graph is plotted for each 3-player groups under fixed and random matching, for further evidence of these dynamics.

Using the metric for successful speculation form the previous section we find 5 out of 39 groups (or 12.8%) satisfy the condition that the speculator wins the item in 9 of the last 10 rounds. In these auctions, average auction price was 52.86 compared to 42.4 in the other groups. Likewise efficiency drops from 77.65% to 60% when comparing the non-speculative to speculative groups. These results are weaker than the previous section, but still provide compelling evidence that can influence auction outcomes even when there are multiple private value bidders.

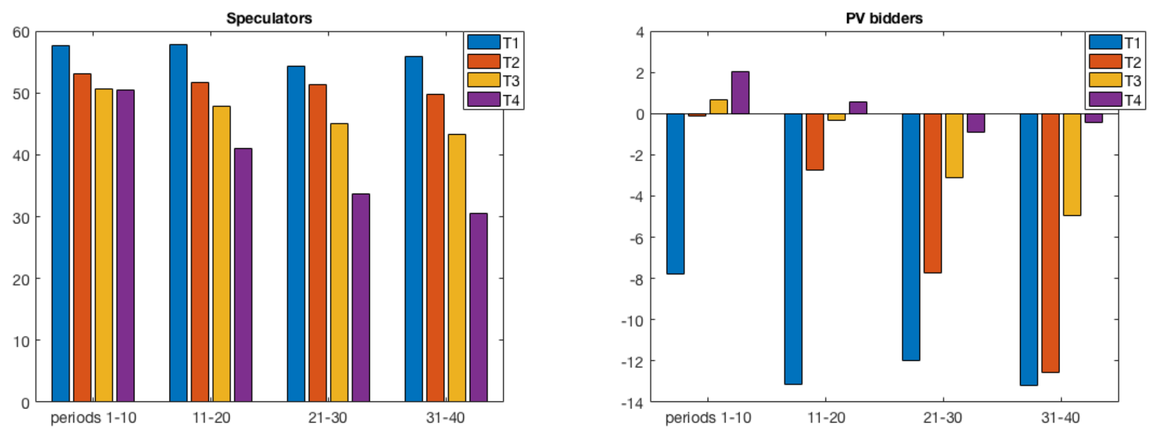

Figure 5: Speculator and private-value bidders' overbids in the four treatments: T1=one PV bidder, fixed matching, T2=one PV bidder, random matching, T3=two PV bidders, fixed matching, T4=two PV bidders, random matching. Values depicted are averages.

4.3.1 Seller Revenue

Unlike the case of a single private-value bidder (where in the absence of a speculator, seller revenue is 0) the impact of speculation on seller revenue is ambiguous theoretically: 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 reasoning is provided in Section 5 of Garratt and Troeger (2006a). Essentially, the idea is that seller revenue in a speculative equilibrium only differs from the value-bidding equilibrium if at least one of the 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 decreses. 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 high than the losing private value bidder's value). For low values of θ^* the latter case become 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 anticipated that speculation would reduce seller revenue even in the multi-private-bidder case.

Figure 6 presents theoretical and average actual bids with one and two private-value bidders. The theoretical bid for the private-value bidder is calculated assuming a symmetric equilibrium and using the actually drawn values. We find that the speculators bid more aggressively, while the private-value bidders bid less aggressively when the number of private-value bidders rises.

The overall effect on stage-one prices (i.e., seller revenue) is clear, as we observe a rise from 24.8 in the one private-value bidder case to 44.7 (p-value< 0.01) in the two private-bidder case. The symmetric theory would predict a similar shift but much lower prices, at 0 and 33.02 respectively.

To isolate the effect of the speculator from any potential "resale" effect, we ran two supplementary sessions, including two private-value bidders but no speculator (using a fixed matching). The lack of a speculator led to a highly significant drop in revenue, to 39.4, compared to both treatments 3 and 4 (p-value< 0.001 in both cases), as summarized in the next table.[16]

[16]In general, bidding in these sessions of second price auctions with no speculator looked remarkably similar

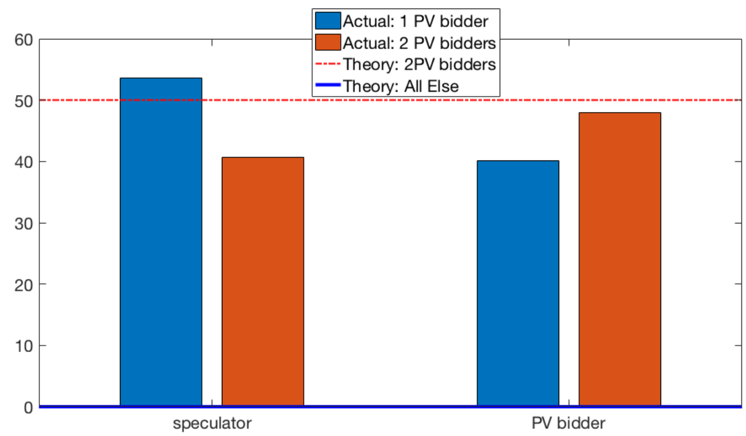

Figure 6: Average bids in auctions with one and two private-value bidders. The dashed horizontal line represents the symmetric equilibrium prediction (value bid) for the PV bidders, when two of them are participating. The solid line represents the symmetric equilibrium bid of zero, for all other cases.

treatment	**1fix**	**1rand**	**2fix**	**2rand**	**nospec**
bidders	1	1	2	2	2
speculator	yes	yes	yes	yes	no
matching	fixed	random	fixed	random	fixed
revenue	22.4	27.2	46.2	43.1	39.4
efficient 1st stage	0.3691	0.4298	0.5381	0.6631	0.8254
efficient 2nd stage	0.6746	0.6225	0.7077	0.7398	0.8810

Table III: Summary of treatments

4.4 Limited Liability

Limited liability can be a potential issue in such an experiment. 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

to the English auctions with resale and no speculator (complete information treatment) in Georganas, 2011. 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. The highest value bidder did not win the initial auction in about 17.5% of the cases, and successful resale happened in about 8.7% of the auctions.

model. There are several facts indicating that the speculative equilibrium is not played just due to 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. Recall we chose five periods randomly to actually 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 regular 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.

5 Conclusions

We have run experiments on auctions with resale opportunities, in the (commonly known) presence of speculators. The main purpose of the study was to investigate whether speculators will be actively trading in primary and secondary markets, despite having no advantages with respect to private-value bidders, or whether they will follow the standard symmetric bid your value equilibrium and always bid zero, allowing the private-value bidders to bid for the good as they would in the absence of speculators.

We find that speculators are indeed very often active and this affects the private-value bidders. Subjects in our markets often partially follow an asymmetric equilibrium where the speculator gets the good in the first stage and resells it in the second. The main deviation from the (asymmetric) theory is that the resale offers can be less aggressive than predicted in equilibrium. Risk aversion or inequity aversion could be a factor leading to this outcome. Adding more private-value bidders raises prices as would be predicted in all equilibria. The speculators remain active, although their absolute effect on first stage auction prices is smaller.

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. Note that our speculators did not have any special advantage, be that in terms of information, liquidity or experience. Even when the playing field is completely even, speculators can greatly disrupt markets.

We also find that in markets with inexperienced private-value bidders, sellers and regulators have opposing incentives: while sellers will want to encourage the participation of speculators, as they raise revenue, regulators caring about efficiency might want to ban speculation. As the private-value bidders gain experience, especially when there is frequent interaction with speculators, the trade off weakens: speculators both lower efficiency and prices, as the private-value bidders learn not to participate in the initial auction.

Our results are also of interest for general applications of game theory. Symmetric equilibria are often held to have intuitive appeal, and as such are thought to be selected by human subjects. We find that players can be selecting asymmetric equilibria, even in a moderately complex game of incomplete information with two stages.

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 Troeger (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.

References

[1] Lysias. Lysias with an English translation by W.R.M. Lamb, M.A. Cambridge, MA, Harvard University Press; London, William Heinemann Ltd. 1930.

[2] Calzolari, Giacomo, and Alessandro Pavan. (2006) "Monopoly with Resale." The RAND Journal of Economics 37, no. 2: 362-75

[3] Croson, R; Terry Boles and J. Keith Murnighan, (2013) “Cheap talk in bargaining experiments: lying and threats in ultimatum games,” *Journal of Economic Behavior & Organization*, 51, 143-159.

[4] Fishbacher, U. (2007). “z-Tree: Zurich Toolbox for Ready-Made Economic Experiments,” *Experimental Economics*, 10, 171-178.

[5] Garratt, Rod and T. Troeger (2006a). “Speculation in Standard Auctions with Resale,” *Econometrica* 74, 753-769.

[6] Garratt, Rod and T. Troeger (2006b). “Supplement to 'Speculation in Standard Auctions with Resale',” https://www.econometricsociety.org/content/supplement-speculation-standard-auctions-resale

[7] Garratt, Rod, T. Troeger and C. Zheng (2009). "Collusion via Resale," *Econometrica* 77, 1095-1136.

[8] Goeree, Jacob and Theo Offerman (2004). "The Amsterdam Auction," *Econometrica,* 72, 281-294.

[9] Georganas, Sotiris (2011). "Auctions with Resale: An Experimental Study," *Games and Economic Behavior*, 73(1), 147-166

[10] Georganas, Sotiris and J. Kagel (2011) "Asymmetric auctions with resale: An experimental study", *Journal of Economic Theory*, 146, 359-371

[11] Georganas, Sotiris, D. Levin, P. McGee (2017) "Optimistic irrationality and overbidding in private value auctions", *Experimental Economics*

[12] Hafalir, Isa Emin and Vijay Krishna (2008). "Asymmetric Auctions with Resale,"*American Economic Review,* 98, 87-112.

[13] Hafalir, Isa Emin and Vijay Krishna (2009). "Revenue and Efficiency Effects of Resale in First-Price Auctions," *Journal of Mathematical Economics*, 45, 589-602.

[14] Haile, Philip A. (2000). "Partial Pooling at the Reserve Price in Auctions with Resale Opportunities," *Games and Economic Behavior*, 33(2), 231-248.

[15] Haile, Philip A. (2001). "Auctions with Resale Markets: An Application to U.S. Forest Service Timber Sales," *American Economic Review*, 91, 399-427.

[16] Haile, Philip A. (2003). "Auctions with Private Uncertainty and Resale Opportunities," *Journal of Economic Theory,* 108, 72-110.

[17] Jabs-Saral, Krista (2012) "Speculation and Demand Reduction in English Clock Auctions with Resale," *Journal of Economic Behavior and Organization*, 84(1), 416-431.

[18] Kagel, J. (1995). "Auctions: A Survey of Experimental Research." In: Kagel, J.H., Roth, A. (Eds.), The Handbook of Experimental Economics. Princeton University Press, pp. 501-86.

[19] Lange, Andreas, John A. List, Michael K. Price (2011). "Auctions with Resale When Private Values Are Uncertain: Evidence from the lab and field", *International Journal of Industrial Organization* 29, 54-64

[20] Milgrom, Paul R. and Robert J. Weber (1982) "A Theory of Auctions and Competitive Bidding", *Econometrica* 50, 1089-1122.

[21] Myerson, R. (1981) "Optimal Auction Design", *Mathematics of Operations Research*, 6, 58-73.

[22] Pagnozzi, M. and Saral, K. J. (2017), "Demand Reduction in Multi-Object Auctions with Resale: An Experimental Analysis." Economic Journal

[23] Samuelson, William (1984) "Bargaining under asymmetric information", *Econometrica*, 52, 995-1006.

A Appendix

In this appendix we present individual groups' bids over time. The following figure depicts data from the fixed matching treatment, with one speculator and one private value bideer. Every panel plots bids for one individual group.

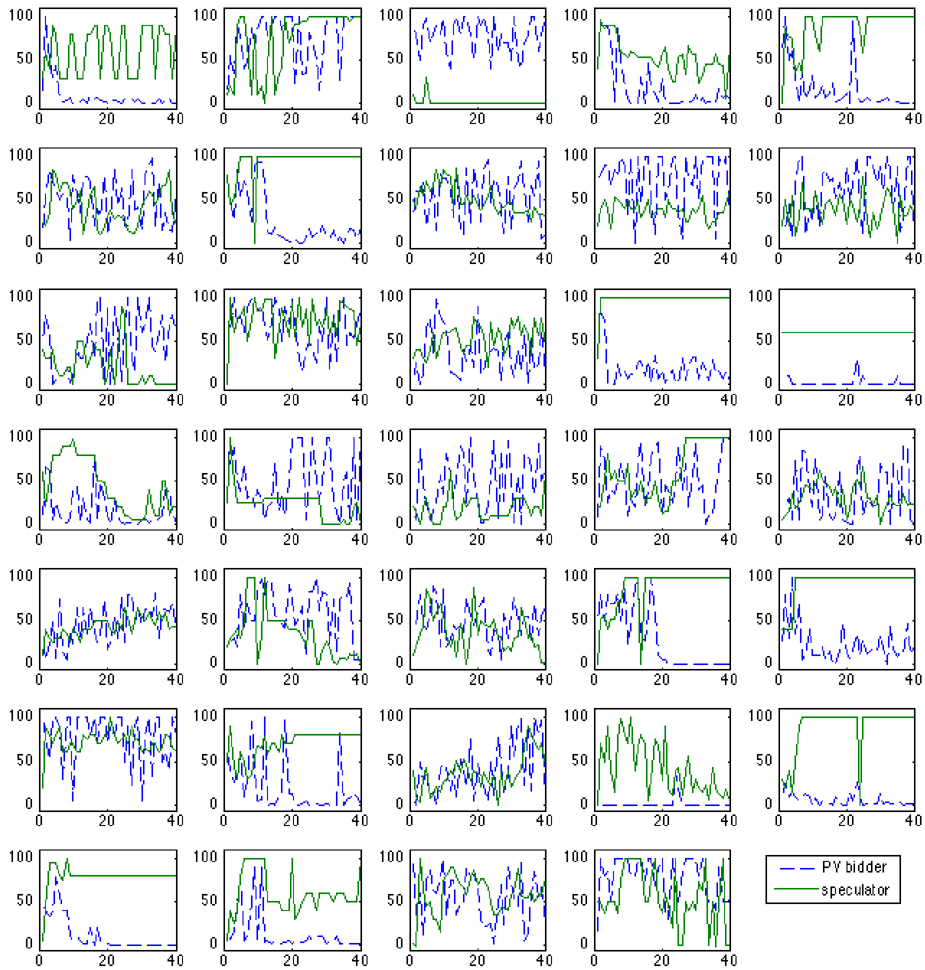

Figure 7

The next figures depict data for the fixed matching treatment, with one speculator and two private value bidders.

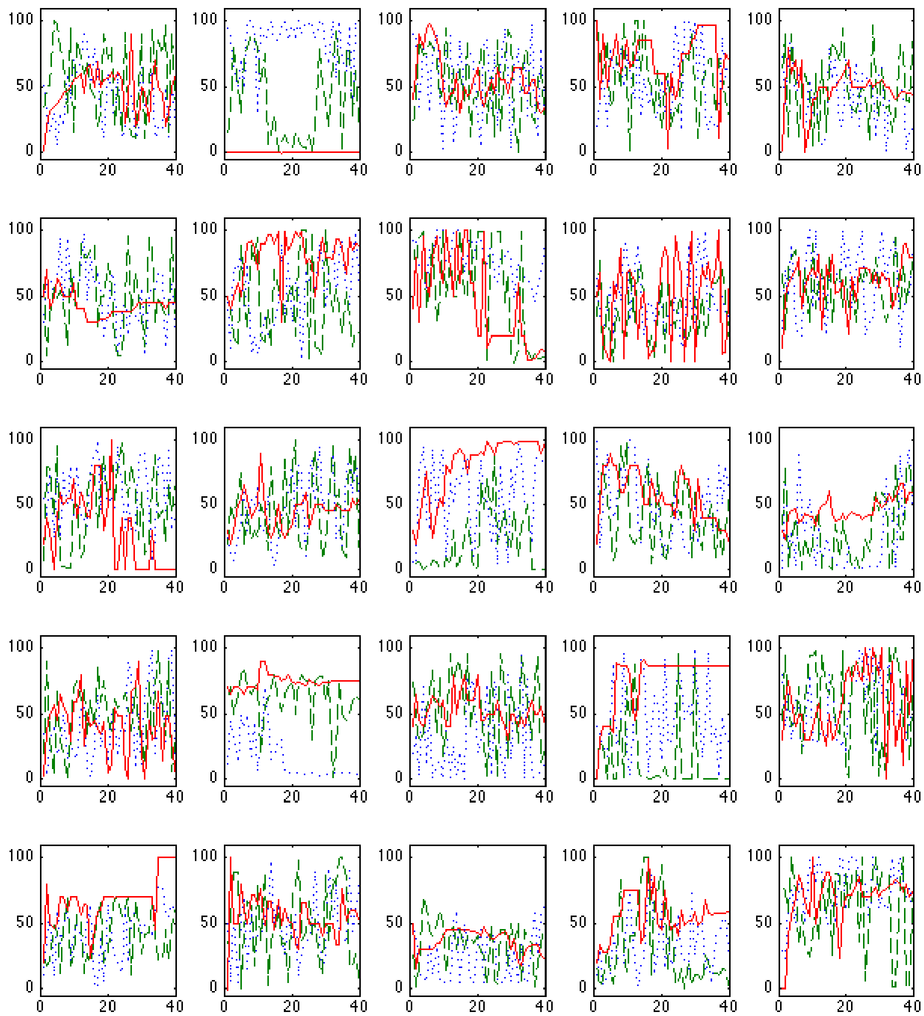

Figure 8

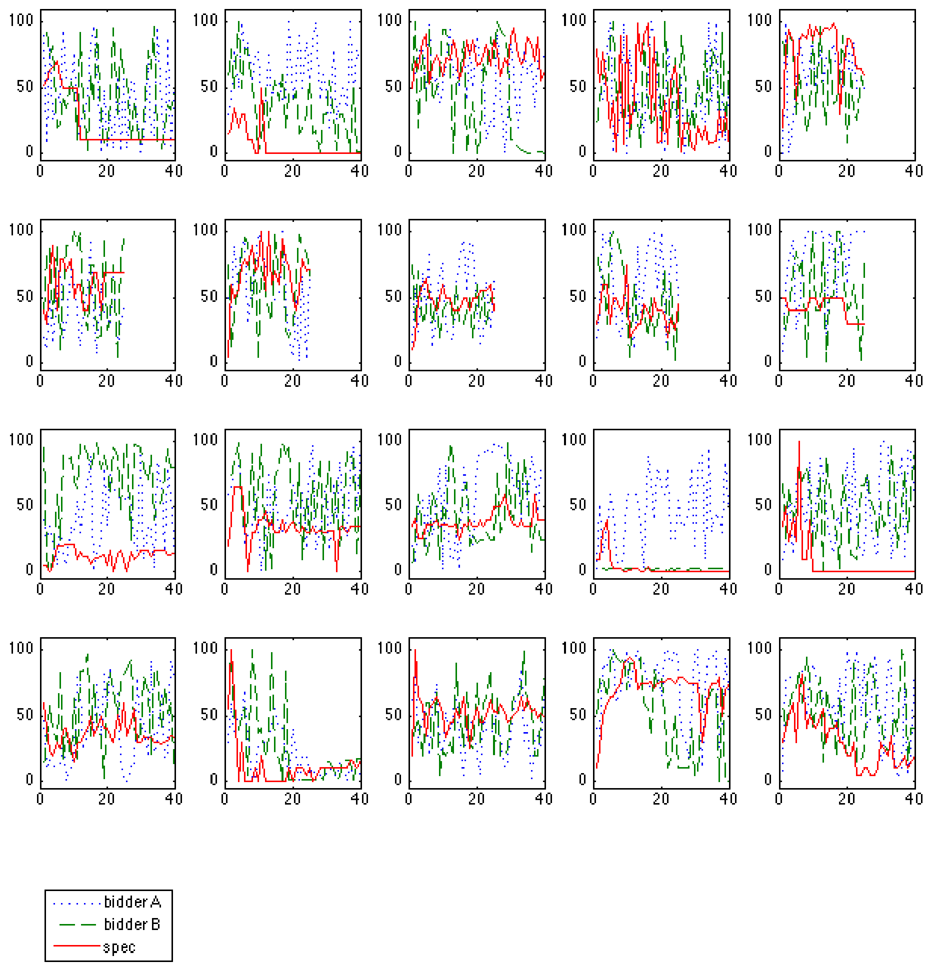

Figure 9