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Entry by successful speculators in auctions with resale

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Abstract We experimentally analyze the role of speculators, who have no use value for the objects on sale, in auctions. The environment is a uniform-price sealed-bid auction for 2 identical objects, followed by a free-form bargaining resale market, with one positive-value bidder, and either one or two speculators who may choose simultaneously whether to enter the auction. We show that the bidder accommodates speculators by reducing demand in the auction and subsequently purchasing in the resale market, which encourages entry by speculators. The presence of multiple speculators induces each speculator to enter less often, but increases competition in the auction and the auction price. Speculators earn positive profits on average, except when multiple speculators enter the auction.

Keywords Speculators · Entry · Multi-object auctions · Resale · Economic experiments

JEL Classification D44 · C90

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1 Introduction

Many real-life auctions are characterized by the possibility of post-auction resale and the presence of speculators—agents who have no use value for the items on sale and participate with the sole intention of reselling to bidders with positive values. In fact, one of the main effects of the presence of a resale market is to attract speculators to an auction.[1] Prominent examples of auctions where speculators are known to exist include auctions for spectrum licenses, commodities, and tradable emissions permits.[2]

It may seem paradoxical that a speculator could win an auction—why would a bidder with a positive use value ever let a speculator win only to purchase from him after the auction? Such behavior, however, should not be surprising in a multi-object auction: bidders with positive use values may prefer to reduce demand and let speculators acquire some of the items on sale, because accommodating speculators allows them to reduce competition and the auction price. Indeed, there is extensive evidence of demand reduction in multi-object auctions, even without resale and speculators (Kagel and Levin 2001; Engelmann and Grimm 2009). And the incentive to reduce demand is stronger when resale is possible, because while the presence of a resale market encourages speculative behavior, it also provides a second opportunity for non-speculative bidders to purchase items lost in the auction (Pagnozzi 2010).

When bidders strategically reduce demand, however, additional speculators may be attracted to the auction by the possibility of positive profit. In this case, the increased competition between speculators reduces a bidder's incentive to reduce demand, since this strategy may no longer result in a lower auction price. Consequently, the presence of multiple possible speculators may induce bidders to compete aggressively against them, which in turn would deter entry by speculators.

These considerations raise a number of questions that we aim to address using a combination of theoretical and experimental analysis. How do speculators decide whether to participate in an auction when it is costly to do so? How do bidders react to the presence of speculators in auctions: do they recognize the incentive for strategic demand reduction, or do they compete aggressively against speculators? Can speculators obtain positive profit by participating in an auction?

In our theoretical analysis, we consider an environment consisting of a sealed-bid uniform-price auction with two identical items on sale followed by a resale market. The uniform-price auction is the sealed-bid equivalent of the (simultaneous multiple round) ascending auction that is commonly used in a variety of markets, ranging from large-scale auctions of spectrum licenses, emission permits, and commodities such as cotton and timber, to smaller-scale sales of wine lots. In our baseline model, there are two asymmetric players: a speculator with no use value for the items and a bidder who has the same positive use value for both items. The speculator chooses whether to participate in the auction against the bidder or earn an outside option.

[1] Xu et al. (2013, p. 93) highlight that "resale naturally induces a speculative motivation for entry."

[2] See, for example, the discussion of the European Emission Trading Scheme in Mougeot et al. (2011).

This environment is then extended to two speculators who simultaneously choose whether to enter the auction.

Analyzing a simple environment with the smallest possible number of players, rather than a richer but more complex one, was a deliberate choice. Speculators, in theory, are more likely to be successful when competing against a single bidder, so our results can serve as a baseline for future studies of more complex settings.[3] Our simple environment also provides a clean test of a bidder's response to speculators, by eliminating the additional effects of competition by more bidders as a potential confound.

Despite its simplicity, our model has multiple equilibria, including one in which the bidder always outbids any speculator, but also equilibria where speculators successfully win a unit. Specifically, with one speculator in the auction there is an equilibrium in which both the bidder and the speculator bid a positive price for a single item each, so that each player wins one item at price zero. In this equilibrium the bidder reduces demand and accommodates the speculator, and after the auction the speculator resells to the bidder and obtains positive profit. This equilibrium maximizes joint players' profit and we conjecture that it may be the focal point for actual behavior. By contrast, when there are multiple speculators in the auction, the bidder has a weaker incentive to reduce demand because it is much more difficult for him to directly influence the price by bidding low. Moreover, competition among speculators is likely to reduce their profit to zero, so speculators are best off when they are able to coordinate and limit entry to a single speculator.

Our empirical analysis uses an economic experiment with a design based on the theoretical set-up.[4] The baseline treatment consists of a single bidder and a single speculator who are automatically entered into the auction. The remaining two treatments introduce entry choice by the speculator and vary the number of speculators. In the post-auction resale market the speculator(s) and bidder are allowed to make multiple offers and communicate through a computerized chat to trade the items won by speculators in the auction.[5]

We find strong evidence that bidders do accommodate speculators, even when there are multiple speculators. Bidders bid significantly less aggressively on one item than on the other one, despite having the same value for both items. Conditional on a speculator entering the auction, approximately 85% of all auctions result in the resale market opening because a speculator wins at least 1 item, and speculators manage to resell 82% of the items that they acquire. In auctions with a single speculator, the most frequent outcome is the predicted split of the two items between the speculator and the bidder, but average auction prices are strictly

[3] If speculators choose not to enter, or are unable to make positive profit in our environment, then it is unlikely that speculators could be successful in more complex environments.

[4] We use an experiment rather than field data for a number of reasons including the difficulty of measuring values and controlling for the entry choice of speculators. Moreover, there are very few field data on post-auction resale markets.

[5] The design of the resale market is a modified version of the free-form bargaining game used in Pagnozzi and Saral (2016) and Pagnozzi and Saral (2018), that allows for the trade of two units and the participation of up to three players. Murnighan and Roth (1977) also study a bargaining game with restricted communication between three players, where only a single trade is allowed.

positive. This indicates that players reduce demand in the auction to soften competition, but not enough to reduce the auction price to zero. Speculators obtain positive profits on average in all treatments, except when two speculators enter the auction, in which case competition results in negative profits for speculators.

Accommodating bidders and positive speculator profit did encourage entry: in single speculator markets, speculators entered in 79% of the auctions. In multiple speculator markets, each speculator entered less often than in single speculator markets, but the percentage of auctions with at least one speculator was even higher (87%) and auctions with two speculators were most common (47%).

Summing up, our main result is that when resale is allowed after a multi-object auction, speculators manage to win against a standard bidder and then resell, thus earning positive profit. This induces speculators to enter the auction. Competition among speculators, however, tends to attract too many speculators to participate in the auction, which erodes their profit.

Although we analyze a very specific auction environment, we expect our results to apply more broadly to any auction environment in which: (1) bidders face a trade-off between winning a larger number of units and paying a lower price for the units that they acquire, and (2) the possibility of resale attracts speculators. Moreover, our qualitative theoretical results do not hinge on the presence of a single bidder. In fact, in a uniform-price auction with multiple competing bidders, there is an equilibrium in which all bidders reduce demand, so that speculators win and then resell (provided the number of units on sale is sufficiently large, and the number of speculators is not too large),[6] exactly as in our model.[7]

The speculators' success in our environment has important implications for revenue and efficiency. The seller's revenue in the auction is higher when the bidder does not reduce demand and wins both items, especially when he competes with two speculators. The seller's revenue is also higher in markets with multiple speculators, even if only one of them enters the auction. Auction efficiency is relatively low due to demand reduction, and while resale increases efficiency after the auction, it does not always ensure an efficient allocation of the items on sale because speculators may fail to resell the units that they acquire.

Our paper contributes to the experimental literature on auctions with resale.[8] Experiments on single-object auctions with resale include Georganas (2011), Georganas and Kagel (2011), Lange et al. (2011), Saral (2012) and Chintamani and Kosmopoulou (2015); multi-object auctions with resale are analyzed by Filiz-Ozbay et al. (2015) and Pagnozzi and Saral (2016, 2018). Throughout this literature, the focus is on the impact of resale on the strategies of bidders with positive use values for the items on sale. By contrast, we analyze entry and bidding strategies of speculators. While we focus on multi-object auctions, Garratt and Georganas (2017) show that a speculator often wins against a positive-value bidder even in single-

[6] Specifically, the number of speculators who enter the auction must be smaller than or equal to the difference between the number of items and the number of bidders, so that all players can win at least one unit each in the auction.

[7] It is also straightforward to see that considering identical items simplifies our analysis but does not drive any of the results.

[8] See Kagel and Levin (2011) for a survey of the experimental literature on auctions.

object second-price auctions, when there is a resale market where the auction winner makes a take-it-or-leave-it offer.

Also related to our paper is the examination of emission permits markets by Mougeot et al. (2011). The authors analyze the role of speculators in breaking collusion in sealed-bid and ascending multi-unit auctions and show that bidders are more likely to collude and accommodate speculators in an ascending rather than in a sealed-bid auction. While Mougeot et al. (2011) highlight differences in auction formats, we focus on the response of bidders and speculators to entry choices by speculators and to changes in the number of speculators.

The rest of the paper is organized as follows. Section 2 presents a theoretical analysis of the model that we refer to for our experiments. Section 3 discusses the experimental design, and Sect. 4 presents the results for entry, bidding and resale. Finally, Sect. 5 concludes. The online supplemental material contains proofs of the propositions and supplemental regression results.

2 Theoretical framework

2.1 Model

Consider a (sealed-bid) uniform-price auction for 2 units of an identical good, with no reserve price. Each player submits 2 non-negative bids (which are possibly different), one for each unit on sale; the 2 highest bids are awarded the units, and the winner(s) pay a price equal to the 3rd-highest bid for each unit. As a convention, we label a bidder's highest bid as his "bid for the first unit" and a bidder's lowest bid as his "bid for the second unit." At the end of the auction, players observe the auction price but not their competitors' bids.

There is a bidder who is privately informed about his valuation v_B, which is the same for each unit on sale and is drawn from a uniform distribution on $[50; 100]$. There are either 1 or 2 speculators who have valuation equal to zero for the units on sale, which is common knowledge. Hence, players know the efficient allocation of the units on sale before the auction.[9]

We chose to analyze a model with a single bidder, which is the simplest possible auction in which to investigate the role of speculators, to create an experimental environment where subject confusion is unlikely, thus eliminating potential confounding effects. Our results, however, do not hinge on the presence of a single bidder (see our discussion below). The crucial assumption for our results is that the total number of bidders is lower than the number of units on sale, so that at least one speculator can acquire a unit, if all bidders reduce demand and only acquire one unit each.

The bidder is always present in the auction, while speculators choose whether to enter the auction. Speculators have an outside option equal to $c > 0$, that they lose if they participate in the auction. The outside option may be interpreted as an alternative opportunity that a speculator misses in order to participate in an auction,

[9] See Garratt and Tröger (2006) for a theoretical analysis of speculation in single-object auctions.

or as a measure of bidding costs (for example, costs that have to be paid to convince investors of the opportunity to participate in an auction for speculative reasons, even if the objects on sale have no use value for them). Entry decisions are observed by all players,[10] and all players are risk neutral.

A speculator who wins a unit in the auction can resell it to the bidder in a resale market. We assume that resale takes place through a generic (and unmodelled) bargaining mechanism between players. Let r be the actual resale price at which a speculator and the bidder trade as a result of post-auction bargaining with one-sided incomplete information, where the seller (i.e., the speculator) has value 0 and the buyer is privately informed about his value, which is uniformly distributed on $[50, 100]$.[11] To make the model interesting, we assume that the entry cost is relatively small—i.e., $c < \mathbb{E}[r]$—otherwise a speculator does not enter the auction even if he expects to win a unit at price 0.

There is speculation if a speculator bids a positive price for a unit, while there is demand reduction if the bidder bids less than his valuation for the second unit and bids more for the first unit than for the second unit (see, e.g., Wilson 1979; Ausubel and Cramton 1998). Notice that, since the bidder has exactly the same valuation for both units, there is no reason other than strategic demand reduction why he should make different bids for the two units.

2.2 Auction with 1 speculator

First suppose that only one speculator enters the auction, so that there are two players in total in the auction. In order to show that speculators may be successful, we describe a possible equilibrium in which the speculator manages to acquire a unit and obtain a strictly positive profit, despite competing with a bidder who has a higher valuation.[12]

Proposition 1 *With one speculator, the auction has an equilibrium in which the bidder bids v_B for the first unit and 0 for the second unit and the speculator bids 50 for the first unit and 0 for the second unit.*

In this equilibrium, there is speculation by the speculator and demand reduction by the bidder who accommodates the speculator. Since both players only bid for one unit, each of them wins one unit each at price 0. In other words, the bidder allows the speculator to win a unit and acquires the other unit at the lowest possible price, and the speculator bids for only one unit in order to minimize the auction price. After the auction, players trade at price r in the resale market, since the speculator does not learn any information about the bidder's valuation in the auction.

[10] As will become clear from the analysis, speculators always have an incentive to reveal their presence in the auction to the bidder, since he would not have any incentive to reduce demand otherwise.

[11] See Ausubel et al. (2002), who show that with one-sided incomplete information and a "gap" between the seller's valuation and the support of the buyer's valuation, any bargaining procedure in which players sequentially exchange offers has essentially a unique sequential equilibrium, which is stationary and in which trade occurs in finite time. Our qualitative results are robust to many alternative models of the resale market.

[12] All proofs are in the online supplemental material.

Therefore, the bidder obtains a total profit equal to $2v_B - r$, because he buys one unit at price 0 in the auction and one unit at price r in the resale market, and the speculator obtains a resale profit equal to r, because he buys one unit at price 0 in the auction and sells it at price r in the resale market. The seller's revenue in the auction is equal to 0.

In the proof of Proposition 1, we show that neither the bidder nor the speculator have an incentive to deviate from the equilibrium described because in order to win more than one unit, a player has to increase the auction price so much that he obtains lower profit than in equilibrium.

Notice that the same type of equilibrium arises even in a more general environment with multiple competing bidders. Specifically, with $k > 2$ units, $n < k$ bidders and $m = k - n$ speculators, there is an equilibrium which is analogous to the one characterized in Proposition 1, in which each bidder bids his valuation for the first unit and 0 for all other units and each speculator bids 50 for the first unit and 0 for all other units.[13] In this equilibrium, as in the equilibrium of Proposition 1, all bidders reduce demand and accommodate speculators, each player wins one unit each at a price of 0, and players then trade in the resale market.

There are other equilibrium strategies that result in players winning one unit each at price zero, as in the equilibrium of Proposition 1.[14] And there are also equilibria in which each player wins one unit at a strictly positive price, but in these equilibria both players obtain a strictly lower auction profit than in the equilibrium described in Proposition 1.

Moreover, there are other equilibria in which a player wins both units by bidding a high price that makes it unprofitable for the competitor to win (exactly as in a single-object second-price auction). The next proposition characterizes one such equilibrium.

Proposition 2 *With one speculator, the auction has an equilibrium in which the bidder bids v_B for both units and the speculator bids 0 for both units.*

In this equilibrium, the bidder does not accommodate the speculator and wins both units, so that there is no trade in the resale market. The auction price is equal to 0 and the bidder obtains the highest possible profit.[15] Of course, there is also another equilibrium, which is arguably far less compelling, in which the speculator wins both units by bidding 100 for both units and the bidder bids 0 for both units.

[13] This is not surprising given the strong incentive of competing bidders to reduce demand, even without speculators (Ausubel and Cramton 1998). An analogous equilibrium also exists with $m < k - n$ speculators. Of course, if $n > k$ then bidders have no incentive to reduce demand to win a unit at a lower auction price, since it is impossible for each bidder to acquire one unit.

[14] These equilibria are constructed by varying players' first-unit bid (compared to the strategies described in Proposition 1), but still ensuring that players have no incentive to deviate by winning two units in the auction.

[15] This equilibrium requires the speculator to bid a sufficiently low price because, otherwise, the bidder would have an incentive to deviate and acquire the units in the resale market. However, because the speculator does not win any unit, he has no direct incentive to reduce his bid to keep the auction price down, unlike when the bidder reduces demand.

Hence, although with one speculator there is an equilibrium in which the bidder accommodates the speculator, this is definitely not the unique possible outcome.[16]

2.3 Auction with 2 speculators

Even with 2 speculators in the auction there are multiple equilibria. However, in this case there is no scope for profitable demand reduction for all players because, with 2 units on sale and 3 players, it is not possible for each player to win one unit in the auction. So competition between speculators tends to increase the auction price up to the expected resale price.

We show that there are equilibria in which the bidder wins no units, and either one speculator wins both units (Proposition 3), or the two speculators win one unit each (Proposition 4).

Proposition 3 *With two speculators, the auction has an equilibrium in which one speculator bids 100 for both units, the other speculator bids* $\mathbb{E}[r]$ *for both units, and the bidder bids 0 for both units.*

In this equilibrium, one speculator wins no units while the other speculator wins both units at price $\mathbb{E}[r]$ and then resells both of them at price r to the bidder (since the speculator does not learn any information about the bidder's valuation in the auction). Hence, speculators obtain no profit, in expectation, from participating in the auction, regardless of whether they win the units or not. The bidder obtains a profit equal to $2(v_B - r)$ from buying the units in the resale market. The seller's revenue is higher than in the equilibrium described in Proposition 1 with only one speculator.

In the proof of Proposition 3, we show that the players who win no units in the auction have no incentive to deviate from the equilibrium described because in order to win a unit they have to increase the auction price so much that they cannot obtain positive profit.

Proposition 4 *With two speculators, the auction has an equilibrium in which each speculator bids 100 for the first unit and* $\mathbb{E}[r]$ *for the second unit, and the bidder bids 0 for both units.*

In this equilibrium, speculators win one unit each at price $\mathbb{E}[r]$ and then each resells at price r to the bidder. Hence, speculators obtain no profit, in expectation, from participating in the auction. The bidder's profit and the seller's revenue are as in the equilibrium of Proposition 3.[17]

[16] This multiplicity of equilibria arises even in a single-object second-price auction and depends on the fact that the auction winner does not pay his bid.

[17] Although the bidder allows speculators to win in the equilibria described in Propositions 3 and 4, notice that the bidder has no strict incentive to reduce demand, in contrast to the case with a single speculator. The reason is that the presence of 2 speculators and 2 units prevents the bidder from sharing the units with them. Of course, there are many other equilibria with the same allocation as in the equilibrium described in Propositions 3 and 4 but a different auction price.

In the proof of Proposition 4, we show that no player has an incentive to deviate from the equilibrium described because in order to win an additional unit any player has to increase the auction price so much that he cannot obtain positive profit.

Notice again that the same results arise even in a more general environment with multiple competing bidders. With $k > 2$ units, $n < k$ bidders and $m > k - n$ speculators (i.e., when the total number of players is larger than the number of units), there are equilibria similar to the ones characterized in Propositions 3 and 4, in which all bidders bid 0 and all units are acquired by speculators at price $\mathbb{E}[r]$ and then traded in the resale market.

Moreover, as we show in the following proposition, there are also equilibria in which the bidder wins all the units in the auction.

Proposition 5 *With two speculators, the auction has an equilibrium in which the bidder bids v_B for both units and each speculator bids* 0 *for both units.*

In this equilibrium, the bidder wins both units and does not accommodate the speculators, and there is no trade in the resale market. As in the equilibrium characterized in Proposition 2, the auction price is equal to 0 and the bidder obtains the highest possible profit. No speculator obtains positive profit.

Summing up, because of the presence of multiple equilibria in our environment, both with one and with two speculators, players' actual bidding behavior is ultimately an empirical question that we analyze using experiments.

2.4 Entry by speculators

Suppose that a speculator expects to play the equilibrium described in Proposition 1 if he competes in the auction against the bidder, and that speculators obtain no profit if they both enter the auction. Then, when there is only one speculator, he enters the auction since he expects to obtain a profit $\mathbb{E}[r] > c$ by winning a unit and reselling.

When there are two speculators who may enter the auction, a speculator who enters expects to obtain a profit equal to $\mathbb{E}[r]$ if the other speculator does not enter, and a profit equal to 0 if the other speculator also enters. While if a speculator does not enter the auction, he always obtains a profit equal to the outside option c. In other words, taking into account the anticipated outcome of the auction with 1 or 2 speculators, the entry game with two speculators can be represented as follows:

	Enter	Stay out
Enter	$0 \quad 0$	$\mathbb{E}[r] \quad c$
Stay out	$c \quad \mathbb{E}[r]$	$c \quad c$

This entry game has two pure-strategy asymmetric equilibria, in which one speculator enters and the other stays out. Moreover, there is a unique *symmetric* mixed-strategy equilibrium in which each speculator enters with probability $q^* \in$

$(0, 1)$ such that his expected payoff from entering the auction is equal to the outside option—i.e.,

$$(1 - q^*)\mathbb{E}[r] = c \quad \Leftrightarrow \quad q^* \equiv 1 - \frac{c}{\mathbb{E}[r]}.$$

Speculators enter because of the possibility of winning the auction and reselling when they compete only with the bidder in the auction. However, if both speculators enter the auction they lose the outside option and competition among speculators drives their profit to zero. In the mixed-strategy equilibrium, the probability that at least one speculator enters the auction is $\left(1 - \frac{c^2}{\mathbb{E}[r]^2}\right)$.

Of course, speculators have different incentives to enter if they expect to play a different equilibrium from the one described in Proposition 1 in the auction against the bidder. Specifically, if a speculator expects to win no unit against the bidder, as in Proposition 2, then he never enters the auction. Similarly, if he expects to win but pay a strictly positive price, then he enters with a lower probability than q^* in a mixed-strategy equilibrium. By contrast, if he expects to win both units, then he enters with a higher probability.

In a more general environment with multiple competing bidders, where speculators expect to obtain positive profit if and only if a sufficiently low number of speculators enter the auction, there is a symmetric mixed-strategy equilibrium where each speculator enters with a probability which is strictly positive and lower than 1 and equalizes his expected profit from entering to the outside option, exactly as in our model.[18]

Notice that by entering the auction a speculator gives up an outside option, which is certain, in exchange for the possibility of obtaining positive profit in the auction, which is uncertain and depends on the behavior of his competitor(s) in the auction and in the resale market, and on the entry choice of the other speculator (when there are two speculators). Hence, for a risk-averse speculator, entry is less attractive than for a risk-neutral one; and when there are two speculators, in a mixed-strategy equilibrium each speculator enters with a probability which is strictly lower than q^*.

Therefore, for all of these reasons, players' actual behavior and the effects of the presence of speculators in the auction is ultimately an empirical question.

3 Experiment design

The experiment design is based on the theoretical environment described above. In the baseline treatment, 1 speculator (S) and 1 bidder (B) participated in the auction and the remaining two treatments introduced entry choices for speculators and added an additional speculator.

In all treatments, each round had two identical hypothetical items (units) offered for sale via a sealed-bid uniform-price auction. Each auction always had 1 bidder,

[18] More precisely, with $k > 2$ units, this is true if if there are $n < k$ bidders and if: (1) bidders reduce demand and each speculator wins at least one unit when $m \leq k - n$ speculators enter (as discussed above), and (2) speculators obtain no profit when $m > k - n$ speculators enter (as discussed above).

who randomly drew his private per-unit valuation (identical for both items) from a uniform distribution on [50, 100], and at least 1 speculator with no use value for the units. The distribution of the bidder's value and the fact that speculators had no use value were common knowledge. A subject's role as a bidder or speculator was randomly assigned at the start of the experiment, and stayed the same for the duration of the experiment.[19] In treatments where speculators had entry choice, they decided whether to enter the auction or earn an outside option equal to 10. With multiple speculators, entry decisions were simultaneous. If no speculator entered, the bidder automatically won both units at price zero.[20]

Auction participants placed one bid between 0 and 100 for each of the two units,[21] and the two highest bids were each awarded one unit at a price equal to the third-highest bid. Ties were broken randomly. After the auction, participants were informed of the number of units they won and the auction price. Bids were not publicly revealed. A participant who won a unit in the auction earned the difference between his value for the unit and the auction price.

If a speculator won at least one unit, a resale market opened where the speculator could resell to the bidder through an unstructured bargaining game (as in Pagnozzi and Saral 2016).[22] Both the speculator and bidder could make offers through a computerized offer board, and could also send messages and discuss offers through anonymous chat. Only one offer per participant was allowed at a time, but offers could always be changed prior to agreement. The resale stage terminated once a participant's offer was accepted by the counterpart. Participants had up to 3 min to agree to an offer and could exit the bargaining game without trading at any point.

When two speculators won one unit each, each speculator participated in a simultaneous and isolated bargaining game with the bidder and the two speculators could not communicate with each other. The bidder could make different offers in each bargaining game and could exit one game but remain active in the other. If a single speculator won 2 units, he could sell each unit at a separate price, or bundle them at a single price.

If agreement was reached in a bargaining game, the unit was resold from the speculator to the bidder. For each unit resold, the speculator earned the difference between the resale price and the auction price, and the bidder earned the difference between his value and the resale price. Resale earnings were in addition to the earnings from the auction.

The experimental treatments are summarized below.

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[19] To minimize labeling effects, the speculator was referred to as a "blue player" and the bidder was referred to as a "green player." This was a deliberate choice to avoid experimenter demand effects and possible confounds in our results. See Zizzo (2010) for a discussion of experimenter demand effects.

[20] To lower the probability of boredom driving entry decisions, speculators who chose not to enter and bidders who won by default played an unpaid computerized version of tic-tac-toe against the computer.

[21] While we did not allow bidders to refrain from bidding, the instructions were clear that bidders could bid 0.

[22] Previous experiments on auctions with resale assume different and more structured resale market mechanisms. Georganas (2011) use a secondary auction for the resale market; Georganas and Kagel (2011) and Filiz-Ozbay et al. (2015) utilize take-it-or-leave-it offers by the auction winner; Lange et al. (2011) and Saral (2012) assume automatic transfers to bidders with higher valuations.

1. *1 speculator (1S)* one speculator competes in the auction against the bidder.
2. *1 speculator entry (1SE)* one speculator chooses whether to participate in the auction against the bidder.
3. *2 speculators entry (2SE)* two speculators choose whether to participate in the auction against the bidder.

Each session of a treatment had 15 auction/resale rounds and, on average, 20 subjects.[23] Two sessions of the baseline 1S treatment and three sessions of the entry treatments (1SE and 2SE) were conducted. A subject was only allowed to participate in one session of one treatment. Table 1 shows the number of subjects who participated in each treatment. At the start of all sessions, we elicited risk preferences using a mechanism adapted from Eckel and Grossman (2008). Subjects were offered a choice between five binary 50/50 gambles with increasing expected value and risk, so that choosing a lower gamble indicates higher risk aversion. Subjects were then randomly assigned to roles and groups (of 2 or 3 subjects depending on the treatment) for the auction rounds. After each round, subjects were randomly rematched into new groups. To ensure the least amount of changes, we used the same value draws across treatments. Subjects were students at Florida State University recruited using ORSEE (Greiner 2004). The experiment was programmed using Z-tree software (Fischbacher 2007).

Payoffs during the experiment were denominated in experimental currency units, ECUs, which transformed into US dollars at the rate of $0.01 per ECU. Since subjects could make losses, each bidder had an initial endowment of 50 ECUs and each speculator received 400 ECUs to hopefully ensure that they did not have negative cumulative earnings at any point during the experiment. We employed standard rules for dealing with bankruptcy: subjects who went bankrupt a single time received a new endowment, while subjects who went bankrupt a second time were removed from the session and only received the participation fee. Two subjects assigned to the bidder role went bankrupt once (both in the first round of the 2SE treatment), and no subjects went bankrupt twice. Table 1 shows average earnings (including the $10 participation fee and lottery earnings), by type and treatment.

4 Experiment results

In this section, we describe the main experimental results. Section 4.1 presents summary statistics that provide a broad overview of the results. The remaining sections provide formal analysis of observed behavior in the order of the actual timing of decisions: Sect. 4.2 considers entry decisions by speculators; Sect. 4.3 bidding behavior by speculators and bidders; Sect. 4.4 the resale market; Sect. 4.5 revenue, efficiency, and earnings.

[23] The minimum number of subjects in a session was 16 (1 session of 1SE) while the maximum was 21 (2 sessions of 2SE).

Table 1 Average experiment earnings

	1S	1SE	2SE
Bidder (*B*)	\$20.12	\$23.52	\$19.16
Speculator (*S*)	\$16.51	\$16.70	\$15.70
Number of subjects	40	56	60

4.1 Summary statistics

Table 2 presents the frequency of entry by speculators and the resulting number of participants in the auction in treatments 1SE and 2SE. Entry choices in the 1SE treatment were lower than the risk neutral prediction of 100% (based on the equilibrium described in Proposition 1), indicating either that speculators were risk averse or that they expected to earn less than the outside option in the auction.[24] In line with the theoretical predictions, speculators entered less frequently in the 2SE than in the 1SE treatment. The number of auction participants, n, could reach 2 in the 1SE treatment and 3 in the 2SE treatment. Despite each speculator entering less often in the 2SE treatment, a high percentage of auctions opened with at least 1 speculator ($n = 2, 3$) because of the presence of multiple speculators who did not coordinate.

Table 3 summarizes bids, conditional on a speculator entering. Adopting the same convention used in the theoretical analysis, we label a bidder's highest bid as his "bid for the first unit" (bid 1) and a bidder's lowest bid as his "bid for the second unit" (bid 2). If bids were identical, the same value was assigned to both bid 1 and bid 2.[25] As bidding behavior may vary depending on the number of auction participants, we separately consider $n = 2$ and $n = 3$ in the 2SE treatment. Across all treatments, observed first unit bids are higher than second unit bids for both speculators and bidders, which supports the theoretical prediction of demand reduction by players. The average first unit bid is higher for speculators than for bidders, and reaches the highest level in the 1S treatment. The average second unit bid is higher than zero for both types, with speculators bidding higher for the second unit than bidders.

The theoretical equilibrium described in Proposition 1 prescribed second unit bids at zero. The modal results in Table 3 for both speculators and bidders is consistent with this equilibrium in most cases (the one exception is 1SE for speculators). We also observe a high frequency of zero bids for the second unit, particularly for bidders. When restricted to the last 5 periods of play, this frequency increases modestly for bidders in all treatments and for speculators in the 1S and 2SE $n = 3$ treatments.

To provide further evidence of strategic bidding, we compare actual bids to simulated random ones. Following the zero-intelligence constrained (ZI-C) bidder approach of Gode and Sunder (1993), with bidders restricted to bid below their

[24] The effects of risk preferences are discussed in Sect. 4.2.

[25] This occurred in 31% of bid pairs overall. See Supplementary Material Table A.1 for a break down by treatment.

Table 2 Frequency of S entering and number of auction participants

% (obs)	S Enter	$n = 1$	$n = 2$	$n = 3$
1SE	79.1 (332)	21.0 (88)	79.1 (332)	–
2SE	67.2 (403)	13.0 (39)	39.7 (119)	47.3 (142)

Table 3 Average, median, modal bids; percentage of bid 2 equal to zero

	Bid 1/bid 2	1S	1SE	2SE $n=2$	2SE $n=3$
S	Avg.	68.9/34.0	60.3/36.1	63.3/41.0	66.3/42.2
	Median	71.5/30	60/30	65/45	69/47.5
	Mode	100/0	60/30	65/0	70/0
	% bid 2 = 0 (last 5)	17.7 (23.0)	2.4 (0)	14.3 (11.5)	13.0 (22.2)
B	Avg.	57.2/28.7	57.8/27.4	55.8/34.2	60.6/35.1
	Median	60/20	60/20	60/40	59.5/36
	Mode	50/0	40/0	40/0	50/0
	% zero bid 2 = 0 (last 5)	36.0 (45.0)	22.3 (23.5)	31.9 (36.5)	26.8 (29.6)

value,[26] we consider ranked random draws from a uniform distribution on [0, 100] for speculators, and on $[0, v_B]$ for bidders.[27] One-sample Kolmogorov–Smirnov tests for equality between the distributions of these random bids and the observed distributions of bids 1 and 2 show significant differences ($p < 0.01$) in all treatments for both types. In the online supplemental material, we present further comparisons between observed and random bids. Although simulated random bids track observed average and median bids relatively well, the key aspect that differentiates the observed bidding behavior from zero-intelligence random bidding is the percentage of zero bids for the second unit, for both bidders and speculators (see Supplementary Material Figures A.1 and A.2, and Table A.1 in the online supplemental material).

Table 4 summarizes auction prices and average final resale prices for auctions where at least one speculator entered, and also reports data restricted to the last 5 periods of a session.[28] Average auction prices were strictly positive, which is expected given the average bids in Table 3, and were highest in the 2SE treatment, especially with three participants.[29] Auction prices were higher when the bidder

[26] We thank an anonymous referee for suggesting this approach.

[27] Specifically, a simulated random bid by a player consists of two draws from the prescribed distribution that are ranked and labeled using our convention as bid 1 and bid 2. Analogous results arise with alternative supports for the random bids (namely, [0, 50] for both speculators and bidders, and [0, 100] for bidders).

[28] For auction prices, we omit auctions where the bidder won at price 0 because no speculator entered. Average final resale prices (unit 1 and unit 2 averaged together) are the unit of observation for resale prices.

[29] Wilcoxon rank sum tests on session averages for revenue demonstrate a marginally significant difference between the 1S and 1SE treatments ($p = 0.08$) and a significant difference between the 1SE and 2SE treatments ($p = 0.05$).

Table 4 Summary statistics for auction prices and average resale prices (across both units)

Auction price (last 5)				*B* won <2 (last 5)		*B* won 2 (last 5)		Resale price (last 5)	
1S	Avg.	36.6	29.8	35.9	29.8	39.7	29.3	50.0	42.8
	Median	40	30	40	30	40	25	50	40
	Mode	0	0	0	0	60	40	50	50
1SE	Avg.	37.2	35.6	36.2	32.7	42.3	51.1	47.5	41.1
	Median	40	37.5	40	30	40	50	45	40
	Mode	40	40	40	40	30	50	40	40
2SE $n=2$	Avg.	40.9	39.2	39.4	36.8	49.0	52	54.5	56.7
	Median	45	43.5	43.5	40	52	55	51	55
	Mode	50	0	0	0	65	60	60	55
2SE $n=3$	Avg.	59.3	59.7	58.5	59.4	66.5	62.3	65.8	64.4
	Median	60	60	60	60	67.5	67	64	67.5
	Mode	60	60	60	60	67	72	80	80

won 2 units, than when the bidder won less than 2 units (i.e., with demand reduction), especially in the 1SE and 2SE $n = 2$ treatments and in the last periods. While average prices are above the prediction of zero (Proposition 1 and 2), modal prices are zero for the 1S and 2SE $n = 2$. Average resale prices were higher than auction prices.[30] The comparison to simulated auction prices with zero-intelligence bidders show a large deviation from actual prices when the bidder won 2 units (see Supplementary Material Table A.3 in the online supplemental material).

Multiple equilibria exist in our environment (see, e.g., Propositions 1–5). Rather than the specific point predictions of bidding, we consider the key difference between these equilibria to be the allocation of the units on sale.[31] When bidders outbid speculators, they choose to win all units in the auction (as in Propositions 2, 5); when bidders engage in demand reduction, this could result in speculators acquiring units in the auction (as in Propositions 1, 3, 4). Table 5 presents the relative and absolute frequency of speculators wining 0, 1, or 2 units, conditional on at least one speculator entering the auction, where 2 indicates that a single speculator won both units and (1, 1) indicates that two speculators won one unit each in the 2SE treatment. In auctions with 1 speculator and 1 bidder, the most frequent outcome was each player winning 1 unit, which is consistent with the equilibrium in Proposition 1. In the 2SE $n = 3$ case, the most frequent outcome was speculators winning both units (57.1% of auctions), which is consistent with the equilibria in Propositions 3 and 4. Across all treatments, very few auctions ended

[30] Wilcoxon rank sum tests on session averages for final resale prices only demonstrate a marginally significant difference between the 1S and 2SE treatments ($p = 0.08$).

[31] In fact, the point predictions from Propositions 1–4 are rarely followed. Using the average empirical resale price as the expected resale price (for bids in Propositions 3 and 4), we find that speculators bid strictly according to theory in 11 auctions, while bidders followed the equilibrium strategies 21 times. This results in a follow rate of 2% (32 out of 1896 observations). However, since these equilibria are not unique, using them for specific point predictions may be too restrictive.

Table 5 Frequency of units won by S; frequency of the resale market; resale success rate (units resold/units won by S)

% (obs)	Units won by *S*				Resale market	Resale success
	0	1	2	(1, 1)		
1S	16.3 (49)	57.7 (173)	26.0 (78)	–	83.7 (251)	0.81
1SE	15.7 (52)	61.1 (203)	23.2 (77)	–	84.3 (280)	0.85
2SE $n=2$	16.0 (19)	44.5 (53)	39.5 (47)	–	84.0 (100)	0.86
2SE $n=3$	9.9 (14)	33.1 (47)	31.0 (44)	26.1 (37)	90.1 (128)	0.74

with the speculator winning no units, indicating that bidders accommodate speculators even when two speculators enter.[32]

The last two columns of Table 5 present the frequency of the resale market opening, conditional on at least one speculator entering, and the resale success rate, defined as the ratio between the number of units resold and the number of units in the resale market. Most treatments have similar frequencies of the resale market opening, except for auctions with two speculators where there was a resale market after 90% of auctions. This treatment, however, also had the lowest resale success rate.

Table 6 summarizes total earnings, combining both auction and resale earnings, conditional on at least one speculator entering.[33] A speculator could make positive earnings by purchasing a unit in the auction and reselling it at a higher price, but losses were possible if a speculator failed to resell.[34] When one speculator entered the auction, he obtained positive earnings on average, especially in the 2SE treatment. When 2 speculators entered, they made losses on average, particularly when both units were won by a single speculator. Although average earnings were lower than the outside option of 10, speculators continued to enter.[35] To provide a more complete picture of earnings, we also report the standard deviation of earnings, the frequency of a speculator entering and earning more than the outside option, and data restricted to the last 5 periods of a session. All treatments have high earnings variability for speculators and the majority of auctions where a speculator

[32] Supplementary Material Table A.2 in the online supplemental material provides a comparison to the simulated allocation with zero-intelligence bidders. Simulated bidders won both units less often than actual ones and consequently, resale is less frequent in the observed data.

[33] For earnings, we exclude auctions where no speculator entered (so that speculators earned the outside option and the bidder won at price 0). This happened 88 times (out of 420 auctions) in the 1SE treatment (21%), and 39 times (out of 261 auctions) in the 2SE treatment (13%).

[34] Speculators made losses in 18% of all auctions where they entered in the 1S treatment, 16% in the 1SE treatment, 14% in the 2SE$n = 2$ treatment, and 22% in the 2SE$n = 3$ treatment.

[35] Wilcoxon rank sum tests on session averages demonstrate that the only significant difference in speculator earnings is found between the 1SE and 2SE treatments ($p = 0.05$).

Table 6 Average earnings conditional on S entering (standard deviations in parentheses); frequency of S earning more than 10

Earnings	S (last 5)		$S > 10$ (last 5) (%)		B (last 5)	
1S	7.7 (42.0)	15.9 (40.2)	51.7	52.0	52.4 (45.5)	66.5 (46.9)
1SE	6.7 (33.9)	12.5 (32.2)	56.3	64.7	54.9 (37.7)	62.0 (36.4)
2SE	− 2.4 (39.2)	7.3 (40.7)	32.3	43.4	31.9 (37.0)	41.9 (43.2)
2SE $n=2$	11.2 (45.8)	17.6 (47.5)	58.8	67.3	42.6 (43.5)	49.6 (48.4)
2SE $n=3$	− 8.1 (34.6)	− 2.6 (30.1)	21.1	20.4	23.0 (27.8)	27.0 (25.7)

(Last 5) indicates data restricted to the last 5 rounds

entered resulted in earnings above the outside option, except when both speculators entered. Moreover, in the last 5 periods, speculators earned more than the outside option on average, except when both speculators entered, which suggests that learning plays an important role in this environment.[36]

Average bidders' earnings were always higher than speculator earnings and were highest with a single speculator and lowest when two speculators entered the auction.[37] Similar to speculators, all treatments have high earnings variability and higher average earnings in the last 5 periods.

Table 7 shows the average efficiency of the auction allocation and of the final allocation after the resale market. The efficiency of the auction outcome (auction efficiency) is measured as the ratio between the sum of the use values of the winners of the two units in the auction and the highest use values; the efficiency of the final outcome (final efficiency) is measured as the ratio between the sum of the use values of the final holders of the units and the highest use values. Therefore, auction (final) efficiency is equal to 0 if the speculator won (holds) both units, 0.5 if the speculator won (holds) 1 unit, and 1 if the bidder won (holds) both units.[38]

The low efficiency of the auction allocation in all treatments reflects the fact that units were frequently won by speculators. Auction efficiency is particularly low in 2SE $n = 3$, and lower than a random allocation (0.5) in all treatments except 1SE.[39] Resale increases efficiency after the auction, but final efficiency is always lower than 1 because of resale failure: speculators failed to resell all units in 19% of resale markets in the 1S treatment, 15% of resale markets in the 1SE treatment, and 25% of resale markets in the 2SE treatment.[40]

[36] We investigate learning formally through regression analysis in subsequent sections.

[37] Wilcoxon signed-rank tests on session averages demonstrate a significant difference in earnings between speculators and bidders ($p = 0.01$). Wilcoxon rank sum tests on session averages of bidder earnings demonstrate that significant differences emerge between all treatments (between 1S and either 1SE or 2SE, $p = 0.08$; between 1SE and 2SE, $p = 0.05$).

[38] Since we average across all observations, the reported values in Table 7 differ from these three possible outcomes.

[39] Wilcoxon rank sum tests on session averages for auction efficiency demonstrate a marginally significant difference between the 1S and 1SE treatments ($p = 0.08$) and a significant difference between the 1SE and 2SE treatments ($p = 0.05$).

[40] Wilcoxon rank sum tests on session averages for final efficiency only demonstrate a significant difference between the 1SE and 2SE treatments ($p = 0.05$).

Table 7 Average efficiency

Efficiency	1S	1SE	2SE	2SE $_{n=2}$	2SE $_{n=3}$
Auction	0.45	0.58	0.41	0.38	0.26
Final	0.89	0.93	0.87	0.91	0.80

Table 8 Marginal effects from population-averaged probit regressions with S choosing to enter as dependent variable

S entry choice	(1)	(2)	(3)	(4) 2SE only
2SE	− 0.138**	− 0.374**	− 0.373**	
	(0.069)	(0.150)	(0.154)	
Female	0.012	0.007	0.002	0.066
	(0.072)	(0.067)	(0.067)	(0.083)
Risk measure (1–5)	− 0.006	− 0.067	− 0.067	0.001
	(0.024)	(0.043)	(0.047)	(0.031)
2SE × risk measure		0.086*	0.063	
		(0.049)	(0.052)	
Period	− 0.023***	− 0.023***	− 0.022***	− 0.027***
	(0.004)	(0.004)	(0.004)	(0.005)
Win_{t-1}		0.072**	0.066*	0.044
		(0.034)	(0.035)	(0.045)
$\text{Earn}_{t-1} < 10$		− 0.086***	− 0.172***	− 0.076*
		(0.033)	(0.060)	(0.042)
$\text{Earn}_{t-1} < 10\times$ risk measure			− 0.005	
			(0.023)	
$\text{2SE}\times\text{Earn}_{t-1} < 10\times$ risk measure			0.054***	
			(0.019)	
$(n = 3)_{t-1}$				− 0.094
				(0.074)
$(n = 3)_{t-1}\times$ Risk measure				0.064***
				(0.021)
Observations	1020	952	952	560

Robust standard errors in parentheses

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

4.2 Entry

In the remaining sections, we proceed with regression analysis to formally examine decisions and outcomes in the order of the timing of the game.

Table 8 examines speculators' entry decisions using probit regressions with the speculator choosing to enter the auction as the dependent variable (marginal effects reported). The first three models use data from both entry treatments 1SE and 2SE, with 1SE as the baseline, while the last model only uses 2SE data. In models 2–4, we include lagged dummy variables to determine how previous rounds influenced entry decisions: Win_{t-1} indicates whether the speculator won at least 1 unit in the previous round, $\text{Earn}_{t-1} < 10$ indicates whether the speculator earned less than the outside option in the previous round, and $(n = 3)_{t-1}$ indicates whether the speculator competed with another speculator in the previous round. Female is a binary variable indicating if the subject was a female, Risk measure (1–5) represents the gamble chosen in the Eckel-Grossman mechanism, where lower numbers correspond to higher risk aversion, and Period tracks the round of play.[41]

The negative coefficient on 2SE in models 1–3 provides robust evidence that the probability of an individual speculator entering in the 2SE treatment was significantly lower than in the 1SE treatment.

Empirical Result 1 A speculator is less likely to enter an auction when there may be another speculator.

The negative coefficients on Period and $\text{Earn}_{t-1} < 10$ indicate that speculators were less likely to enter in later periods and less likely to enter after earning less than the outside option in the previous round. Including interactions between the risk measure and treatment in model 3 reveals strong differences for risk tolerant speculators in the 2SE treatment, who were more likely to enter despite earning less than 10 in the previous round. Model 4 restricts the analysis to the 2SE treatment and the positive coefficient on $(n = 3)_{t-1}\times$ risk measure shows that competition with another speculator in the previous round increased entry for risk tolerant speculators.

4.3 Bidding

4.3.1 Speculator

Figure 1 provides a jittered scatterplot of the two bids made by speculators across treatments, where bid 1 (or the first unit bid) indicates the highest bid and bid 2 (or the second unit bid) the lowest bid. Treatment differences are most apparent in the 1SE treatment for bid 1, which appears lowest, and in the 2SE $n = 3$ treatment for bid 2, which appears highest. Most first unit bids appear higher than 50, which is consistent with speculation. A number of second units bids are at zero and almost all second unit bids are strictly lower than first unit bids.

To analyze treatment effects on bids, Table 9 reports results from random effects regressions with bid 1 (bid 2) as the dependent variable in models 1, 3, and 5 (models 2, 4, and 6). Standard errors are clustered at the session level. The first two models are run on all data, with the 1S treatment as the baseline; the last four models only consider the entry treatments, with the 1SE treatment as the baseline. In all models we include treatment dummies and, for the 2SE treatment, we differentiate auctions with 2 or 3 participants.[42]

[41] The number of observations differs between models 1, 2, and 3 due to the inclusion of lagged terms in models 2 and 3, where the first period of observation is dropped.

[42] The number of observations differs between models 3–6 due to the inclusion of lagged terms in models 5 and 6, which drop the first period of observation.

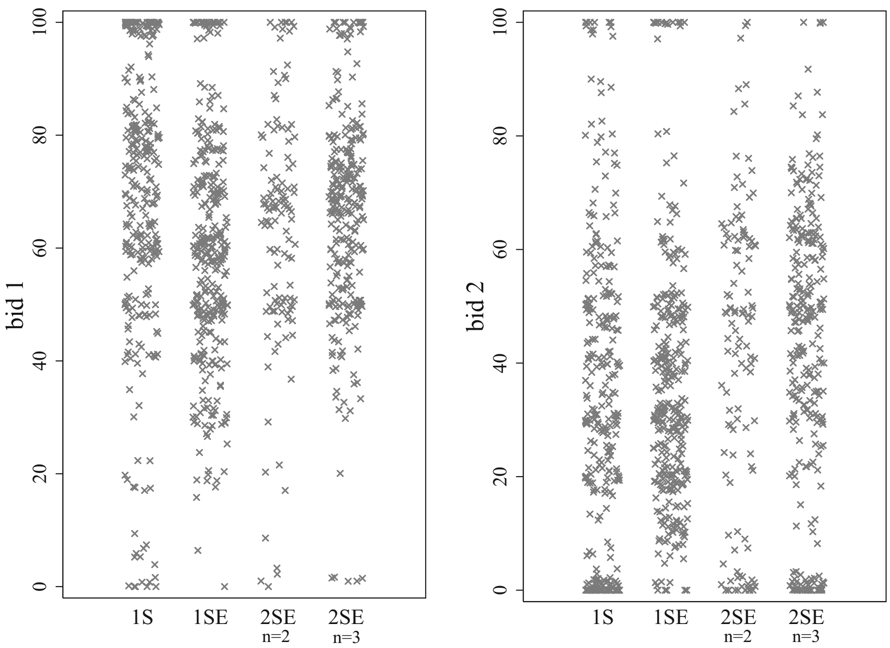

Fig. 1 Scatterplot of S's bids for unit 1 and unit 2

For first unit bids, the main treatment difference is in model 1, where bids are significantly lower in the 1SE than in the 1S treatment. Coefficient tests of equality between treatments indicate weakly significant differences between the 1SE and 2SE $n = 2$ treatments ($p = 0.07$) and significant differences between the 1SE and 2SE $n = 3$ treatments ($p = 0.01$). These results are also confirmed in model 3 using data restricted to the entry treatments. Model 5 includes additional controls and two new dummy variables, 1 Unit win$_{t-1}$ and 2 Unit win$_{t-1}$, which indicate whether the speculator won 1 or 2 units in the previous round, respectively. The negative significant coefficient on 2 unit win$_{t-1}$ shows that winning 2 units in a previous round decreases first unit bids.

For second unit bids, models 2 and 4 show a treatment effect of more aggressive bids in the 2SE $n = 3$ treatment. In model 6, the negative coefficient on female provides evidence that female speculators bid less aggressively on the second unit and the negative coefficient on period indicates that second unit bids were falling over time.

4.3.2 Bidder

The bidder has a strong incentive to reduce demand and accommodate a single speculator in the auction, but this incentive is lower with two speculators. Figure 2 presents scatterplots of bidders' bids against values, where bid 1 (bid 2) is the

Table 9 Random effects regressions with S's bids as dependent variables

S Bid	(1)	(2)	(3)	(4)	(5)	(6)
				1SE and 2SE only		
	Bid 1	Bid 2	Bid 1	Bid 2	Bid 1	Bid 2
1SE	− 10.570***	1.504				
	(2.703)	(4.510)				
2SE $n = 2$	− 4.449	5.874	6.098*	4.385*	5.638	5.023**
	(3.143)	(4.592)	(3.442)	(2.641)	(3.514)	(2.196)
2SE $n = 3$	− 2.927	9.014*	7.624**	7.479***	7.451**	5.922**
	(2.726)	(4.714)	(3.046)	(2.852)	(3.127)	(2.859)
Female					0.833	− 6.167**
					(2.244)	(3.050)
Risk measure (1–5)					0.939	0.013
					(0.879)	(1.146)
Period					− 0.054	− 1.018***
					(0.272)	(0.333)
1 Unit win_{t-1}					2.167	0.522
					(1.344)	(1.109)
2 Units win_{t-1}					− 3.260**	1.489
					(1.301)	(1.990)
Losses_{t-1}					− 3.407	− 3.427
					(3.846)	(7.114)
$\text{Losses}_{t-1} \times$ risk measure					1.282	0.230
					(1.041)	(1.904)
Constant	68.863***	34.023***	58.314***	35.543***	56.090***	48.897***
	(1.724)	(4.176)	(2.139)	(1.747)	(4.162)	(5.028)
Observations (clusters)	1035 (8)	1035 (8)	735 (6)	735 (6)	672 (6)	672 (6)

Robust standard errors in parentheses

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

highest (lowest) bid. All graphs include a simple regression dashed line and a reference solid line for bids equal to value.

Many first unit bids are slightly below value, but clustering towards value is apparent, particularly in the 1S treatment. The regression lines indicate that bids tend to be increasing in value. We use panel random regressions to test the hypothesis that first unit bids are equal to value. In all treatments, joints tests that the constant is 0 and the coefficient on value is 1 reject value bidding ($p < 0.001$). Almost all second unit bids are below value, and the regression line is further away from the value line, indicating demand reduction.

Consistent with demand reduction, the majority of first unit bids are strictly higher than second unit bids, which is confirmed by a Wilcoxon signed-rank test on session averages for the two bids ($p = 0.01$). Compared to speculators, a larger

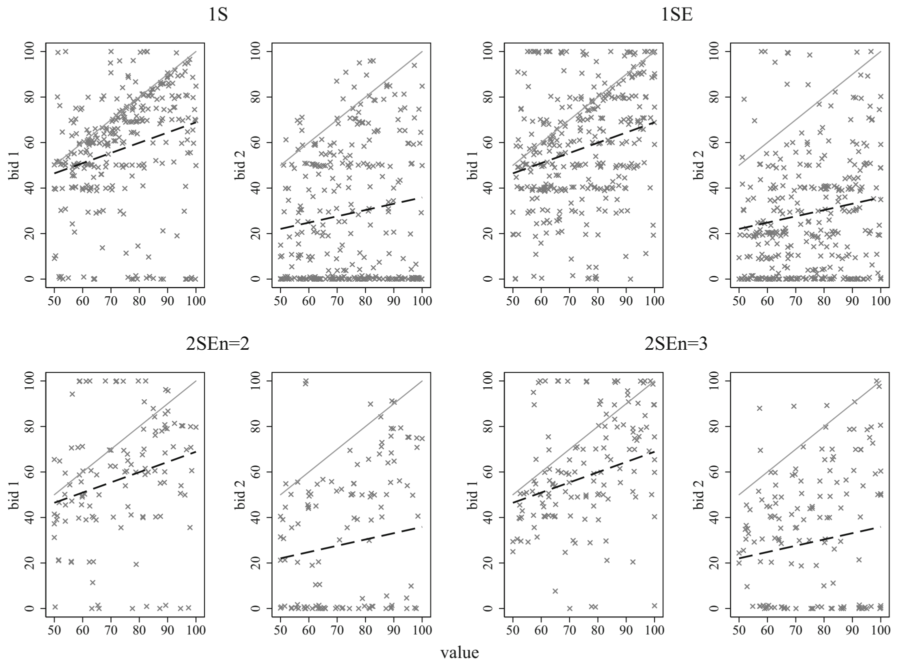

Fig. 2 Scatterplot of B's bids for unit 1 and unit 2

number of second unit bids are equal to 0, which suggests that bidders were less aggressive.

Empirical Result 2 *In all treatments, bidders bid less than their value for the first unit, and bid strictly more for the first unit than for the second unit.*

To analyze treatment effects, Table 10 presents results from random effects regressions with bidders' bid 1 and 2 as dependent variables, and standard errors clustered at the session level. In addition to the variables used for speculators, we include the bidder's unit value and its interactions with treatment. The first four models are run on all treatments, with 1S as the baseline, and the last two models only consider the entry treatments, with 1SE as the baseline.[43]

There are no significant treatment effects found on first unit bids in either model 1 (coefficient tests of equality, $p > 0.38$), or in model 3 with additional controls. In contrast, second unit bids do exhibit treatment differences. Post-estimation equality of coefficient tests from model 2 demonstrate significant differences between the 1SE and the 2SE $n = 2$ treatments ($p = 0.02$) and the 1SE and the 2SE $n = 3$ treatments ($p = 0.01$). This result is confirmed in model 6, which restricts the analysis to the entry treatments. So, for the entry treatments, second unit bids are more aggressive with multiple speculators than with one.

[43] The number of observations differs between models 1–4 due to the inclusion of lagged terms in models 3 and 4, which drop the first period of observation.

Table 10 Random effects regressions with B's bids as dependent variables

B Bid	(1)	(2)	(3)	(4)	(5) 1SE and 2SE only	(6)
	Bid 1	Bid 2	Bid 1	Bid 2	Bid 1	Bid 2
v_B	0.549***	0.379***	0.523***	0.292**	0.569***	0.443***
	(0.026)	(0.067)	(0.011)	(0.130)	(0.036)	(0.037)
1SE	− 0.525	− 1.216	− 8.500	− 17.024***		
	(4.032)	(2.599)	(7.564)	(6.298)		
2SE $n = 2$	− 0.426	6.010	− 9.337	− 11.478*	0.124	7.283**
	(6.856)	(3.667)	(8.141)	(6.704)	(7.640)	(3.159)
2SE $n = 3$	2.152	5.690*	4.246	− 7.965	2.665	6.863**
	(5.648)	(3.391)	(7.885)	(9.585)	(6.463)	(2.824)
1SE×v_B			0.111**	0.209		
			(0.050)	(0.144)		
2SE $n = 2 \times v_B$			0.150***	0.267*		
			(0.023)	(0.151)		
2SE $n = 3 \times v_B$			− 0.020	0.184		
			(0.066)	(0.179)		
Female			9.609*	7.008		
			(5.114)	(6.865)		
Risk measure (1–5)			1.491	1.523		
			(1.673)	(2.045)		
Period			− 0.570**	− 0.848***		
			(0.243)	(0.251)		
1 Unit win$_{t-1}$			1.851	1.924		
			(1.202)	(1.318)		
2 Units win$_{t-1}$			− 0.452	3.101		
			(1.012)	(1.959)		
Constant	16.587***	0.679	14.864**	5.555	14.605***	− 5.307**
	(2.755)	(3.544)	(6.471)	(11.299)	(5.578)	(2.660)
Observations (clusters)	893 (8)	893 (8)	828 (8)	828 (8)	593 (6)	593 (6)

Robust standard errors in parentheses

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

In all models, the positive and significant coefficient on value indicates that bids are increasing in value, although the magnitude of this effect is much lower for bid 2. Models 3 and 4 show a significant negative effect of period on bids for both unit 1 and unit 2 bids.

4.4 Resale

Table 11 analyzes the success of resale using probit regressions, where the dependent variable is equal to 1 if all units won by a speculator are resold to the

Table 11 Marginal effects from population-averaged probit regressions with resale success as dependent variable

Resale success	(1)	(2)
v_B-auction price	0.004***	0.004***
	(0.001)	(0.001)
Last offer difference	− 0.006***	− 0.005***
	(0.001)	(0.001)
Period	0.005	0.005*
	(0.003)	(0.003)
# *S* offers	− 0.002	− 0.000
	(0.008)	(0.009)
# *B* offers	− 0.025***	− 0.022**
	(0.009)	(0.009)
1SE	− 0.034	
	(0.049)	
2SE	− 0.004	
	(0.053)	
S win 1		0.100**
		(0.049)
S win 2		0.010
		(0.050)
Observations	566	566

Robust standard errors in parentheses

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

bidder. We include variables which measure the difference between the bidder's value and the auction price, the difference between the speculator's and the bidder's last resale offers, period of play, and the number of offers made by players. Model 1 tests for treatment effects, with the 1S treatment as the baseline. Model 2 tests if the success of resale depends on the number of units won by speculators.

The positive and significant effect on the difference between the bidder's value and the auction price suggests that higher auction prices due to more aggressive bidding reduces the probability of successful resale. Model 1 shows no treatment effect (coefficient tests, $p = 0.49$). Model 2 compares the baseline case where 2 speculators win one unit each with the cases where only one speculator wins one unit and where one speculator wins both units: the probability of successful resale is higher when there is only one speculator who wins a single unit (coefficient test, $p = 0.01$).

Empirical Result 3 *Resale is more likely to succeed if a single speculator wins one unit.*

The difference between success rates for markets with one speculator and two speculators is not surprising, since it is more difficult for the bidder to bargain with more speculators. It is somewhat surprising, however, that resale with a single speculator who won both units is less likely to succeed, since the bidder could obtain zero total earnings in this case. Moreover, speculators were allowed to bundle the units, which may make trading easier, or sell them separately at possibly different prices. In most cases, speculators who won both units chose to bundle them (173 out of 246 resale markets), and resale failure was rarely the result of 1 unit selling without the other (8 out of 188 failure cases).

4.5 Prices, efficiency, and earnings

Table 12 presents pooled OLS regressions for auction prices, auction efficiency, and final efficiency. Standard errors are clustered at the session level.

Model 1 examines auction prices. The average auction price is above zero, as indicated by the significant constant, and is increasing in the bidder's value. There is no significant difference between treatments with two participants ($p = 0.10$), but prices are significantly higher in the 2SE $n = 3$ treatment ($p < 0.01$). The negative significant coefficient on period indicates that the auction price decreases over time.

Models 2 and 3 examine auction and final efficiency. In both models, efficiency is positively correlated to the bidder's value, indicating that bidders with higher values tend to obtain the units more often in the auction and in the resale market. Model 2 shows that auction efficiency is lower in the 2SE treatment, especially when both speculators enter the auction. Treatment differences for final efficiency are reduced in model 3 as resale raises efficiency.

Table 13 examines total earnings, including both auction and resale earnings, for speculators (models 1–3) and bidders (models 4 and 5), through random effects panel regressions with standard errors clustered at the session level. In all models

Table 12 Pooled OLS regressions with auction price and efficiency as dependent variables

	(1) Auction price	(2) Auction efficiency	(3) Final efficiency
v_B	0.179***	0.005***	0.005***
	(0.041)	(0.001)	(0.001)
1SE	0.321	0.007	0.014
	(3.271)	(0.017)	(0.023)
2SE $n = 2$	5.373	− 0.065*	0.012
	(3.664)	(0.033)	(0.029)
2SE $n = 3$	21.280***	− 0.198**	− 0.087*
	(3.298)	(0.065)	(0.039)
Period	− 0.668***	− 0.002*	0.006*
	(0.179)	(0.001)	(0.002)
Constant	30.058***	0.076	0.465***
	(5.366)	(0.064)	(0.105)
Observations (clusters)	893 (8)	893 (8)	893 (8)
R-squared	0.161	0.097	0.093

Robust standard errors in parentheses

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Table 13 Random effects regressions with players' earnings in a round as dependent variables

Earnings	(1) S	(2) S	(3) S	(4) B	(5) B
v_B		0.565***	0.569***		1.473***
		(0.099)	(0.106)		(0.086)
1SE	− 1.182	− 0.845	10.327	2.195	1.214
	(7.375)	(7.348)	(12.204)	(4.016)	(3.567)
2SE $n=2$	3.168	2.223	29.488**	− 9.830**	− 11.660***
	(8.631)	(8.386)	(12.848)	(4.913)	(3.112)
2SE $n=3$	− 15.951**	− 15.326**	2.233	− 29.459***	− 30.536***
	(8.021)	(7.203)	(12.320)	(3.007)	(2.114)
Female		− 0.836	− 2.121		− 5.050*
		(3.665)	(3.333)		(2.879)
Risk measure (1–5)		1.026	5.055**		− 0.960
		(1.185)	(2.205)		(0.864)
Period		0.913***	0.930***		1.035***
		(0.185)	(0.190)		(0.266)
1SE × risk measure			− 3.819		
			(2.528)		
2SE $n=2\times$ risk measure			− 9.276***		
			(2.412)		
2SE $n=3\times$ risk measure			− 5.879**		
			(2.407)		
Constant	7.660	− 45.740***	− 56.981***	52.427***	− 61.254***
	(7.308)	(14.079)	(17.713)	(1.338)	(8.274)
Observations (clusters)	1035 (8)	1035 (8)	1035 (8)	893 (8)	893 (8)

Robust standard errors in parentheses

***$p<0.01$, **$p<0.05$, *$p<0.1$

the 1S treatment serves as the baseline. Observations are restricted to rounds where a speculator entered.[44]

The negative significant coefficient on 2SE $n=3$ and coefficient tests between this treatment and 1SE or 2SE (for both, $p<0.01$) demonstrates that speculators' earnings are lower when two speculators entered the auction. There are no other significant differences between treatments ($p=0.35$). In Model 2, the bidder's value and the period of play both have a positive effect on speculators' earnings. Model 3 interacts speculators' risk preferences with treatments. The significant coefficient on the risk measure shows that risk tolerant speculators earned more in markets with a single speculator, while the coefficients on the interactions of the risk

[44] Specifically, we only include speculators who participated in the auction and bidders who did not win by default.

measure with the 2SE treatment shows that risk tolerant speculators earned less in markets with two speculators.

The last two models examine bidders' earnings. Model 4 tests for basic treatment effects and shows that bidders are worse off in markets with two speculators, particularly when both entered the auction (coefficient test comparisons of all treatments, $p \leq 0.05$). The bidder's value in model 5 has a positive and significant effect on earnings, as expected, and period also has a positive effect. Earnings are increasing over time, which corresponds to falling auction prices observed in Table 12.

Empirical Result 4 *Speculators' and the bidder's earnings are lowest when there are 2 speculators in the auction.*

5 Conclusion

Speculators are attracted to an auction by the possibility of resale. Non-speculative bidders who anticipate a resale opportunity may strategically choose to accommodate speculators, thus reducing competition and consequently the auction price. However, bidders may also choose to compete aggressively against speculators, in order to eliminate their incentive to participate in the auction. Therefore, the success of speculators depends on non-speculative bidders' reaction to their presence.

We use a combination of theory and controlled laboratory experiments to examine the role of speculators in multi-object auctions, varying the number of speculators and their entry choice. Our experimental results provide strong support for the theoretical prediction of demand reduction by bidders: regardless of the number of speculators, bidders consistently bid less aggressively on the second unit, allowing speculators to win. Thanks to bidders' accommodating behavior, single speculators earned positive profit by reselling, which induced other speculators to enter the auction. In markets with multiple speculators, individual speculators entered less often, as predicted, but coordination failure resulted in most auctions having multiple speculators who almost always earned negative profit.

Speculators were more responsive than bidders to the presence of other speculators and bid significantly higher on both units in auctions with multiple speculators. This competition between speculators was the driver for their losses, but it also led to higher seller's revenue despite demand reduction by other bidders, who also earned less as a consequence.

Aggressive speculators and accommodating bidders resulted in lower auction efficiency than in a random allocation, and resale did not fully restore efficiency in our environment. The main reason for resale failure was an auction price too close to the bidder's value, which was most likely to occur when the speculator(s) won all units.

In sum, our results suggest that in multi-object auctions bidders generally reduce demand whenever speculators are present. Therefore, a seller who aims to increase his revenue should attract multiple independent speculators by reducing their participation costs. However, more speculators also reduce the efficiency of the resale market and of the final allocation, implying a revenue/efficiency trade-off.

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