THE ECONOMIC JOURNAL

The Economic Journal, Doi: 10.1111/ecoj.12392 © 2016 Royal Economic Society. Published by John Wiley & Sons, 9600 Garsington Road, Oxford OX4 2DQ, UK and 350 Main Street, Malden, MA 02148, USA.

DEMAND REDUCTION IN MULTI-OBJECT AUCTIONS WITH RESALE: AN EXPERIMENTAL ANALYSIS*

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We analyse the effects of different resale mechanisms on bidders' strategies in multi-object uniform-price auctions with asymmetric bidders. Our experiment consists of four treatments: one without resale and three resale treatments that vary the information available and the bargaining mechanism in the resale market. Resale markets induce demand reduction by high-value bidders and speculation by low-value bidders, thus affecting the allocation of the objects on sale. The magnitude of these effects, however, depends on the structure of the resale market. Features of the resale market that tend to increase its efficiency result in lower auction efficiency and seller's revenue.

Auctions are often characterised by the possibility of resale by winning bidders, which may dramatically alter the outcome from what would have been observed without resale. US Treasury Bills and the Regional Greenhouse Gas Initiative programme to sell CO_2 allowances are two economically relevant examples of auctions with an active resale market. Resale was explicitly forbidden in the first US and European spectrum auctions but since 2003, in almost all spectrum auctions, bidders are allowed to trade the licences acquired. It is now relatively common to observe small bidders winning and reselling to larger ones.[1] This change in policy was intended to favour a more efficient allocation of the spectrum among its users.

Post-auction resale may emerge because of bidders' strategic behaviour in the auction. Specifically, in multi-object auctions bidders have an incentive to reduce demand, i.e. bid less than their valuations for marginal units, in order to reduce the auction price for inframarginal units.[2] There is substantial experimental evidence of demand reduction by symmetric bidders in auctions without resale (List and Lucking-Reiley, 2000; Kagel and Levin, 2001, 2005; Engelmann and Grimm, 2009). Moreover, Weber (1997), Wolfram (1998) and Wolak (2003) show empirically that demand reduction affected several FCC spectrum auctions, as well as the UK and the California

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We thank Ciro Avitabile, Vincent Crawford, Georgia Kosmopoulou, Dan Levin, Nicola Persico, Tim Salmon, Anastasia Semykina, the editor and the referees for extremely helpful comments, as well as seminar participants at the universities of Cambridge, Padova, Verona and Milan Bicocca, the ASFEE Conference, the ESA conferences in Chicago, Luxembourg, and Zurich, the CSEF-IGIER Symposium on Economics and Institutions, the 2nd EIEF-UNIBO Workshop on Industrial Organization, the NERI Workshop, the Workshop on Economics of Conflict and Cooperation in Bergamo, the Swiss IO Day, and the Brazilian Conference Series on Public Procurement. We also thank Svetlana Pevnitskaya and members of the xs/fs group for use of the laboratory at Florida State University, and Webster University Geneva for funding this project.

[1] For example, in the UK 3.4 GHz auction, two small bidders, Red Spectrum and Public Hub, won one licence each and resold them to Pacific Century Cyberworks, a much larger company that was considered to have the highest valuation for the licences on sale in the auction but chose not to outbid its competitors (Pagnozzi, 2010).

[2] This is the same incentive that a standard monopsonist has to acquire a lower number of units to reduce the market price. For theoretical analysis of demand reduction, see e.g. Wilson (1979) and Ausubel and Cramton (1998).

electricity markets; while Klemperer (2004) describes demand reduction strategies in the 1999 German and the 2000 Austrian spectrum auctions.[3]

Demand reduction reduces the seller's revenue and may result in an inefficient allocation of the objects on sale, in which case bidders will be willing to trade after the auction if they are allowed to do so. The possibility of resale, however, may exacerbate bidders' incentive to reduce demand, since it provides them with a chance to acquire a unit that they do not win in the auction.[4] In addition, the presence of a post-auction resale market may induce low-value bidders to speculate by bidding aggressively, which further increases the likelihood of an inefficient auction allocation.

The recent empirical literature on single-object auctions with resale shows that subjects integrate the strategic effects of a resale market in their bidding behaviour (Haile, 2003*a*; Georganas, 2011; Lange *et al.*, 2011; Saral, 2012). Much less is known, however, about bidder's actual behaviour in more complex auction environments with multiple objects on sale and resale. Specifically, it is unclear whether the presence of a resale market helps correct the inefficiencies resulting from demand reduction, or if it increases bidders' strategic behaviour, thus resulting in a more inefficient auction allocation that may not be corrected by resale.

Using a combination of theoretical and empirical analysis, we address the following questions: How does the possibility of resale in multi-object auctions affect bidders' strategies, efficiency and the seller's revenue? Should resale be allowed? If so, how should the resale market be structured?[5]

We consider a uniform-price auction with two identical units on sale and two asymmetric bidders, one strong and one weak. The strong bidder has a higher valuation and demands both units; the weak bidder has a lower valuation and demands only one unit.[6] Considering bidders with different characteristics allows us to distinguish the different bidding strategies that they adopt in the auction (i.e. demand reduction by strong bidders and speculation by weak bidders) and the different effects that the presence of a resale market has on these strategies.

Actual resale markets take on a variety of forms, including different formal trading mechanisms as well as informal bargaining. Since bidders' ability to trade depends on the characteristics of the resale market, different characteristics are likely to have different effects on bidders' strategies. In our theoretical environment, we assume that bidders share the gains from trade in the resale market, which allows us to obtain uniform theoretical predictions for the experimental treatments.

[3] According to Milgrom (2004, p. 264), '[t]he issue of extreme price equilibria is plainly of great practical importance'.

[4] See Pagnozzi (2007, 2009, 2010). Jehiel and Moldovanu (2000), Haile (2003*a*, *b*), Garratt and Tröger (2006) and Garratt *et al.* (2009) who analyse similar effects in single-object auctions.

[5] We use experiments due to the difficulty of observing bidders' values, controlling whether resale is possible, and controlling the form of the resale market with field data. While our experiments allow a causal examination of the impact of resale on behaviour, they do so in an artificial and simplified context. We discuss these limitations in the conclusions.

[6] For example, in an auction for geographically differentiated mobile phone licences, a strong bidder can be interpreted as an incumbent operator who aims at acquiring a nationwide licence, while a weak bidder can be interpreted as a new and smaller entrant, possibly interested only in a local licence, or even as a pure speculator.

Our controlled laboratory experiments consist of four treatments: no resale, complete information resale, incomplete information resale, and bargain. In the no resale treatment subjects participated in an ascending auction without resale. The complete information and incomplete information resale treatments included a secondary market where one bidder was randomly chosen to make a take-it-or-leave-it offer.[7] In the first of these treatments, subjects were given complete information regarding the competitors' values in the resale market, while in the second, information was restricted to the distribution of the competitors' values. In the bargain treatment, information was restricted to the distribution of values but both bidders were allowed to make multiple offers and to communicate through computerised chat in the resale stage.[8] While the complete and incomplete information resale treatments consider a static and more structured resale mechanism, the bargain treatment replicates a more flexible, and arguably more realistic, bargaining procedure.

In the baseline treatment without resale, consistent with the theoretical predictions, asymmetry among bidders' valuations makes demand reduction less attractive: strong bidders drop out at low prices with much lower frequency when their valuation is relatively high.[9]

Our main result is that regardless of how we implement the resale market and consistent with the theoretical predictions, resale induces strong bidders to increase demand reduction. Indeed, in all resale treatments, strong bidders tend to drop out at low prices regardless of their valuations and they do so significantly more than without resale. This suggests that, with resale, high-value bidders prefer to allow low-value ones to win one of the objects and then try to acquire it in the resale market, rather than outbid them. However, the level of demand reduction depends on the form of the resale market: in the incomplete information resale treatment strong bidders reduce demand less than in the other resale treatments, arguably because of higher resale uncertainty.

While weak bidders bid up to their value without resale, the presence of a resale market significantly increases their bids since winning the auction has the additional option value of providing an opportunity to resell (Haile, 2003*a*,*b*).[10] Similar to the response of strong bidders, the degree of speculation by weak bidders depends on the specific structure of the resale market.

It is often argued that resale after an auction should be allowed because it increases efficiency by allowing bidders to trade, if they are willing to do so in the presence of gains

[7] This resale mechanism was analysed by Calzolari and Pavan (2006).

[8] We are the first to implement an unstructured bargaining game for a post-auction resale market. Feltovich and Swierzbinski (2011) use a similar approach for cheap talk. Our treatment is based on the classic structure of early bargaining experiments (Roth and Malouf, 1979) where anonymous participants were allowed to freely communicate. We also vary the information that participants have about each other's payoffs as in Roth and Murnighan (1982). For experimental surveys of communication see Crawford (1998) and of bargaining see Roth (1995).

[9] This complements previous experimental results on demand reduction by symmetric bidders without resale (Alsemgeest *et al.*, 1998; Kagel and Levin, 2001, 2005; Engelmann and Grimm, 2009; Goeree *et al.*, 2013).

[10] Weak bidders bidding up to their value without resale parallels experimental results in single-object ascending auctions (Coppinger *et al.*, 1980; Kagel *et al.*, 1987; and see Kagel, 1995, for a comprehensive overview) and confirms the robustness of value bidding in a multi-object ascending auctions (McCabe *et al.*, 1990). See Kagel and Levin (2012) and Kwasnica and Sherstyuk (2012) for recent surveys of experimental results in multi-object auctions. Weak bidders speculating with resale mirrors the experimental results for single-object auctions (Georganas, 2011; Georganas and Kagel, 2011).

from trade (Mankiw, 2007), but our analysis suggests this may not always be the case. Although resale does increase efficiency after the auction, it also increases the level of demand reduction which reduces auction efficiency below what is observed without resale. The net effect of resale on efficiency is ambiguous: resale increases final allocative efficiency only in the complete information and bargain treatments. The net effect of resale on revenue is also ambiguous. In theory, allowing resale should always reduce the seller's revenue owing to demand reduction by strong bidders. Our experimental results, however, indicate that resale increases the seller's revenue when strong bidders do not reduce demand since weak bidders bid more aggressively with resale.

Our article contributes to the recent experimental literature on auctions with resale. The first experiments by Georganas (2011), Lange *et al.* (2011) and Saral (2012) focus on the effects of resale on bidding behaviour in single-object auctions, while Georganas and Kagel (2011) and Jog and Kosmopoulou (2014) consider asymmetric bidders in single-object auctions. For multi-object auctions, Filiz-Ozbay *et al.* (2015) compare Vickrey auction and independent second-price auctions (where there is no demand reduction), in the presence of complementarities in bidders' valuations, and focus on the effects of a specific resale mechanism where the auction winner makes take-it-or-leave-it offers to the losers, separately for each object acquired. In contrast to all previous studies, we consider the effects of a range of post-auction resale mechanisms, and focus on demand reduction strategies in multi-object auctions.

The rest of the article is organised as follows. Section 1 presents the theoretical benchmark for our experiments. Section 2 discusses the experimental design, and Section 3 presents the experimental results. Specifically, subsections 3.1 and 3.2 show bidding behaviour by strong and weak bidders respectively, subsection 3.3 discusses efficiency and the seller's revenue, and subsection 3.4 analyses subjects' behaviour in the resale market. Finally, Section 4 concludes. The appendices provide additional theoretical analysis and experimental materials.

1. Model and Theoretical Predictions

We construct the simplest possible model that allows us experimentally to investigate the effects of resale on bidding strategies by asymmetric bidders, and on their incentives to reduce demand and speculate.

Auction. There is a (sealed-bid) uniform-price auction for two units of an identical good, with no reserve price (footnote 2 discusses the effect of a positive reserve price): the two highest bids are awarded the units; and the winner(s) pay a price equal to the 3rd-highest bid for each unit won. Bidders only observe the auction price and not the opponents' bids, at the end of the auction. We consider a uniform-price auction because it is the auction mechanism in which the incentive to reduce demand arises more clearly, and because it is widely used to allocate multiple objects.[11] The qualitative results of the analysis, however, also hold for any mechanism to allocate multiple units in which players face a trade-off between winning more units and paying lower prices. The auction may be followed by a resale market.

[11] Of course, the uniform-price auction is not an optimal mechanism in our context, neither with resale nor without resale.

Bidders and Valuations. There are two risk-neutral asymmetric bidders. Bidders differ both in the number of units that they demand and in their valuations for those units. Specifically, bidder *S*, the strong bidder, demands two units and has valuation $v_S \sim U[\underline{v_S}; \overline{v_S}]$ for each unit on sale (i.e. he has flat demand);[12] bidder *W*, the weak bidder, demands 1 unit only and has valuation $v_W \sim U[\underline{v_W}; \overline{v_W}]$ for that unit. Bidders are privately informed about their valuations, which are independent. We assume that $\underline{v_S} \geq \overline{v_W}$, implying that bidder *S* always has a higher valuation than bidder *W*, and that bidders know the *ex post* efficient allocation of the units on sale before the auction. For simplicity, we also assume that bidder *W* cannot win more than 1 unit in the auction, even if resale is allowed.[13] Hence, bidder *S* submits two bids in the auction (which may be different) and bidder *W* submits one bid only.

Our assumption on bidders' valuations ensures that in our experiments bidders know the role they will have in the resale market when they bid in the auction, i.e. whether they will have a chance to buy or sell in the resale market, allowing us to focus on the different bidding strategies of the two types of bidders and on how these strategies are affected by the possibility of resale. The assumption also implies that bidders know there are gains from trade in the resale market if *W* wins a unit.

Resale Market. When resale is allowed after the auction, if bidder *W* wins a unit he can resell it to bidder *S*. In contrast to previous experiments on auctions with resale that assume different and more structured resale markets,[14] we consider resale through a general bargaining procedure between bidders. We believe that this is a more realistic representation of many real-life situations in which bidders attempt to trade after an auction, but do not follow a formal trading mechanism (e.g. because no bidder has the bargaining power to impose his preferred trading mechanism).

Rather than analysing each bargaining mechanism used in our experiment, we provide a simple framework that captures the main elements of various resale mechanisms in which both bidders expect to obtain some share of the (expected) gains from trade in the resale market. The actual gains from trade in the resale market are $v_S - v_W$, since *W*'s outside option when he trades in the resale market is equal to his valuation, while *S*'s outside option is zero. We assume that bidders' valuations are revealed after the auction, for simplicity, and that bargaining in the resale market results in *S* obtaining a share α of the gains from trade and *W* obtaining a share $1 - \alpha$ of the gains from trade.[15] This bargaining outcome follows from bidders trading at a resale price:

[12] All our qualitative results also hold in the presence of complementarities, although bidder *S*'s incentive to reduce demand is lower in this case, if there is a chance that he may not manage to acquire the second unit in the resale market.

[13] We chose to restrict bidder *W* to single-unit demand to create a simple experimental environment where subject confusion is unlikely, thus eliminating potential confounding effects. This also facilitates the comparison between the weak bidders' behaviour with and without resale. Even if bidder *W* can win two units when resale is allowed, it is an equilibrium for both bidders to reduce demand, as in our model. See footnote 21.

[14] Georganas (2011) use a secondary auction for the resale market, while Georganas and Kagel (2011) and Filiz-Ozbay *et al.* (2015) utilise 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.

[15] We assume that bidders manage to trade when gains from trade are common knowledge and, hence, that the resale market is efficient. In bargaining with incomplete information, efficiency is possible when players' valuations have non-overlapping supports (Ausubel *et al.*, 2002), as in our model.

$$r \equiv v_W + (1-\alpha)(v_S - v_W) = \alpha v_W + (1-\alpha)v_S, \tag{1}$$

and it can be interpreted as a reduced form representation of the final outcome of various different trading mechanisms. Our qualitative results are robust to many alternative models of the resale market and hold for any sharing $\alpha < 1$.

In our experiments, we consider different bargaining mechanisms and information structures for the resale market (see Section 2). In one mechanism, if bidder W wins a unit in the auction, bidders are allowed to freely bargain over the resale price. In another mechanism, one of the two bidders, chosen randomly, is given the possibility of making a take-it-or-leave-it offer to the other bidder (Calzolari and Pavan, 2006).[16] In all of these mechanisms, both bidders expect to obtain some share of the gains from trade in the resale market, which is the feature that drives all our theoretical results. In order to show that our qualitative results do not hinge on the resale market being fully efficient, in Appendix A we analyse a resale market with incomplete information in which one bidder is randomly selected to make a take-it-or-leave-it offer, corresponding to our 'incomplete information' experimental treatment.

Bidding Strategies. There is demand reduction if a bidder bids less than his valuation for a unit, while there is speculation if a bidder bids more than his valuation for a unit. In a uniform-price auction, bidder S may find it profitable to reduce demand and bid less than his valuation for the second unit in order to pay a lower price for the first unit, thus obtaining a higher profit. The logic is the same as the standard textbook logic for a monopsonist withholding demand: buying an additional unit increases the price paid for the first, inframarginal, units. Moreover, when resale is allowed, bidder W may find it profitable to speculate and bid more than his valuation in the auction, if he expects to resell the item.

Because our model has two units on sale and a total demand for three units, to characterise equilibrium bidding strategies, it will be sufficient to describe W's bid for one unit, and S's bid for the second unit. The lowest of these two bids will be the auction price, and either S will win both units on sale at a price equal to W's bid, or the two bidders will win 1 unit each at a price equal to S's bid. When bidder W wins a unit, the auction allocation is inefficient.

1.1. *Auction without Resale*

In an auction without resale, it is a weakly dominant strategy for bidder W to bid his valuation for a unit, i.e. v_W. Given this strategy, bidder S can outbid W and win two units at an expected price $\mathbb{E}[v_W]$, or he can reduce demand and bid 0 for the second unit, thus winning 1 unit only at price 0.[17] Therefore, bidder S prefers to reduce demand if and only if:

$$v_S > 2(v_S - \mathbb{E}[v_W]) \Leftrightarrow v_S < 2\mathbb{E}[v_W]. \tag{2}$$

[16] With complete information, this second resale mechanism, in which in expectation bidders obtain 1/2 of the gains from trade in the resale market, is a special case of our class of bargaining mechanisms, when $\alpha = 1/2$.

[17] Of course, reducing demand but bidding a strictly positive price is never an optimal strategy.

When resale is not allowed, bidder S's incentive to reduce demand in the auction is lower when he has a relatively high valuation, because reducing demand and not winning the second unit is more costly when that unit is more valuable, or when he expects bidder W to have a low valuation and hence to bid less aggressively, because outbidding bidder W to win the second unit is less costly. Accordingly, without resale, if $v_S < 2\mathbb{E}[v_W]$ bidder S and bidder W win 1 unit each and the auction price is equal to 0; if $v_S > 2\mathbb{E}[v_W]$ bidder S wins both units and the auction price is equal to v_W.

1.2. *Auction with Resale*

When resale is possible, a player's 'willingness to pay' for a unit in the auction is represented by the price at which he expects to buy or sell a unit in the resale market.

By assumption, if bidder W wins a unit in the auction, he obtains an actual surplus equal to $(1-\alpha)(v_S - v_W)$ in the resale market. Therefore, bidder W bids:

$$v_W + (1-\alpha)\mathbb{E}[v_S - v_W | v_W] = \alpha v_W + (1-\alpha)\mathbb{E}[v_S], \tag{3}$$

for a unit on sale in the auction.[18] Notice that this can be interpreted as $\mathbb{E}[r|v_W]$, the price at which bidder W expects to sell to bidder S in the resale market. Bidder W speculates because of the option to resell to bidder S and bids higher than his valuation for a unit and, hence, higher than without resale.

Since bidder W bids his expected resale price in the auction, bidder S has a choice between two alternatives. First, bidder S can outbid bidder W and win 2 units in the auction at an expected auction price equal to:

$$\mathbb{E}[\mathbb{E}[r|v_W]] = \alpha\mathbb{E}[v_W] + (1-\alpha)\mathbb{E}[v_S], \tag{4}$$

thus obtaining an expected profit equal to:

$$2(v_S - \alpha\mathbb{E}[v_W] - (1-\alpha)\mathbb{E}[v_S]). \tag{5}$$

Second, bidder S can reduce demand and bid zero for the second unit in the auction, thus winning 1 unit at price 0 in the auction and then buying the second unit from bidder W in the resale market at an expected resale price equal to:

$$\mathbb{E}[r|v_S] = \alpha\mathbb{E}[v_W] + (1-\alpha)v_S. \tag{6}$$

In this case, S obtains an expected total profit equal to:[19]

$$\underbrace{v_S - 0}_{\text{auction profit}} + \underbrace{v_S - \mathbb{E}[r|v_S]}_{\text{resale profit}} = (1+\alpha)v_S - \alpha\mathbb{E}[v_W]. \tag{7}$$

Comparing (5) and (7), bidder S prefers to reduce demand in the auction when resale is allowed if, and only if:

[18] If W wins a unit in the auction at price p, he obtains an expected profit equal to $v_W - p + (1-\alpha)\mathbb{E}[v_S - v_W|v_W]$; while if W loses the auction, he obtains 0. So he bids a price such that his profit from winning is equal to zero.

[19] Notice that bidder S's expected profit from resale can also be interpreted as $\alpha\mathbb{E}[v_S - v_W|v_S]$, his share of the expected gains from trade in the resale market.

$$(1-\alpha)(2\mathbb{E}[v_S]-v_S)+\alpha\mathbb{E}[v_W]>0 \quad \Leftrightarrow \quad (1-\alpha)(\underline{v_S}+\overline{v_S}-v_S)+\alpha\mathbb{E}[v_W]>0. \qquad (8)$$

Since this inequality is always satisfied for every α and for every v_S, bidder S prefers to reduce demand when resale is allowed.[20] Basically, bidder S is willing to bid a much lower price in the auction because of the option to buy in the resale market. And demand reduction allows bidder S to win 1 unit at price 0 in the auction and then purchase the other unit from bidder W at price r in the resale market, rather than pay bidder W's expected resale price for both units in the auction.[21] The first option is more attractive than the second (unless bidder S expects the resale price to be much higher than bidder W, which can be the case when v_S is very high compared to its *ex ante* expected value – see footnote 20 – but this never happens when bidder S's valuation is uniformly distributed).[22]

As a result, when resale is allowed, S and W win 1 unit each and then trade in the resale market. The auction price is equal to 0. (Of course, this can also be interpreted as tacit collusion among bidders, intended to reduce the seller's revenue.)

Summing up, the theoretical predictions of the model that we test using experimental methodology are the following.

RESULT 1. *Without resale, bidder W bids v_W and bidder S reduces demand if and only if v_S is sufficiently low.*

RESULT 2. *With resale, bidder W bids above v_W and bidder S always reduces demand.*

RESULT 3. *The allocation of the units on sale in the auction is more efficient without resale than with resale. The final allocation is more efficient with resale than without resale.*[23]

RESULT 4. *The expected seller's revenue is lower with resale than without resale.*

[20] More generally, i.e. when bidders' valuations are not necessarily uniformly distributed, a sufficient (but not necessary) condition for bidder S always preferring to reduce demand when resale is allowed is that $2\mathbb{E}[v_S] > v_S$.

[21] If bidder W can win 2 units with resale, there is still a zero-price equilibrium with joint demand reduction, in which bidder W bids $\mathbb{E}[r|v_W]$ for the first unit and zero for the second, and bidder S bids v_S for the first unit and zero for the second. Clearly, bidder W has no incentive to deviate since he cannot obtain positive profits by outbidding bidder S, and bidder S faces the same trade-off as in our model and has no incentive to deviate if and only if condition (8) is satisfied.

[22] Our qualitative results do not hinge on the absence of a reserve price, since bidder S has an incentive to reduce demand even if he has to pay a strictly positive reserve price. For example, if the seller chooses the optimal reserve price without resale (which is equal to 30, a take-it-or-leave-it offer to bidder S), when $\alpha = 1/2$ bidder W is willing to pay the reserve price and resell to bidder S if his value is higher than 20. Therefore, exactly as in our model, with resale bidder S prefers to reduce demand and win 1 unit at the reserve price, rather than outbid bidder W to win 2 units at the expected reserve price. (The reserve price may be so high that it is unprofitable for bidder W to win the auction but sellers often lack the information and the commitment power to set high reserve prices.)

[23] The final allocation is always efficient in our stylised theoretical model and should be efficient in the experimental treatments with complete information and with free bargaining but it is not necessarily efficient in the treatment with incomplete information and take-it-or-leave-it offers (see Appendix A). In Pagnozzi and Saral (2016) we analyse the effects of introducing an exogenous probability that bidders fail to trade in a resale market.

2. Experimental Design

The experiment was designed around three primary objectives:

(*i*) analyse bidding behaviour in uniform-price multi-object auctions with asymmetric bidders and no resale;
(*ii*) analyse how post-auction resale between bidders affects their bidding strategies, efficiency, and the seller's revenue; and
(*iii*) investigate how bidders trade in the resale market and how their strategies are affected by different resale mechanisms.

We implemented four treatments, one benchmark treatment without resale and three with different resale mechanisms. The resale mechanisms were designed to evaluate the effects of different levels of information and different trading procedures. Each session of the experiment consisted of a single treatment and each subject participated in a single session. Subjects were randomly assigned to either the role of weak or strong bidder for the duration of the experiment.

In all treatments, each period began with an ascending clock uniform-price auction for two units of a hypothetical good.[24] Each auction always had one strong and one weak bidder. The strong bidder was allowed to purchase up to two units, and randomly drew his private valuation for each unit from a uniform distribution on the range [30, 50]. The weak bidder could purchase two units, and randomly drew his private valuation from a uniform distribution on the range [10, 30]. Throughout the experiment, the strong bidder was referred to as a 2-unit bidder and the weak bidder as a 1-unit bidder to minimise labelling effects. During the auction each bidder was given information about the distribution of his competitor's valuation and the number of units he demanded.

Bidders participated in the auction through a computer interface with a bid clock gradually increasing from 0 in increments of 1, which indicated the auction price for a unit. To bid in the auction, subjects chose to drop out when the clock reached a price at which they wanted to exit the auction. The auction ended as soon as one bidder dropped out and the auction price paid for each unit was equal to the dropout bid. If neither subject dropped out the auction ended at price 50 and the units were awarded randomly. If both subjects dropped out simultaneously, ties were broken randomly. A bidder who won a unit earned the difference between his value and the auction price.

In the three resale treatments, if the weak bidder won a unit, the resale market immediately started with the same participants from the auction. Two resale treatments involved a take-it-or-leave-it offer where the proposer was determined with 50/50 probability. If the weak (strong) bidder was selected as the proposer, he had the opportunity to offer a buy (sell) price to the other bidder, who could then accept or reject the offer. Neither of these two treatments allowed communication between bidders and the sole difference involved the amount of information conveyed. In one case, bidders received complete information about the competitor's valuation after the auction; in the other, bidders only knew the distribution of the competitor's valuation.

[24] We use ascending auctions (rather than sealed-bid ones) because they are widely used in the field and, based on previous experimental evidence, easier to understand for bidders.

The third resale treatment relaxed the no communication and one-shot offer constraints by implementing an unstructured bargaining game where both bidders could communicate and simultaneously make offers through a computerised offer board.[25] One posted offer per participant was allowed at a time but offers could always be changed prior to agreement. Either bidder could accept the offer made by their counterpart and the resale stage terminated once an offer was accepted. Bidders could also send each other messages through anonymous chat. There was a time limit of three minutes to reach agreement.[26] As in the incomplete information treatment, bidders only knew the distribution of the competitor's valuation.

In all resale treatments, bidders could exit the resale market without trading at any point of their choosing. If a resale offer was agreed upon, the weak bidder earned the difference between the resale price and his value, and the strong bidder earned the difference between his value and the resale price. If resale failed, both bidders earned 0. Any resale earnings were in addition to the earnings from the auction. The treatments are summarised below.

(*i*) *No resale*: subjects only participated in the auction.

(*ii*) *Complete information resale* (comp resale): if the weak bidder won a unit in the auction, each bidder's valuation was revealed to the competitor and one bidder was randomly chosen to make a take-it-or-leave-it offer to the other.

(*iii*) *Incomplete information resale* (incomp resale): this treatment was identical to the complete information resale treatment, except that the competitor's valuation was not revealed to bidders and both participants had a calculator tool to determine the probability that an offer led to negative resale earnings for the responder.

(*iv*) *Bargain*: after the auction, if the weak bidder won a unit, both bidders were allowed to make and accept offers and to communicate via anonymous computerised chat in an unstructured bargaining game. As in the incomplete information resale treatment, valuations were not revealed and participants had the calculator tool to facilitate decisions.

We conducted three sessions for each treatment yielding a total of 12 sessions with 16 participants in each session. The no resale, complete information resale, and incomplete information resale sessions each consisted of 30 periods. Since the resale stage of the bargain treatment required more time, each session of this treatment consisted of 20 periods. To ensure the least amount of changes possible, we used the exact same value draws across treatments. In the no resale, complete information resale and incomplete information resale treatments, the 16 subjects were divided into two groups for random rematching of partners in each period, leading to two independent groups in each session. In the bargain treatment, subjects were

[25] While this breaks with design norms of changing one variable at a time, we purposefully chose to advance towards a more realistic resale setting rather than run two additional treatments (one that only allows players to chat and another that only allows them to make multiple offers).

[26] This was not an overly binding constraint. In the bargain treatment we observe 351 resale markets with 44 (12.5%) timing out before agreement was reached. In a large number of the cases, bidders made their final offers with plenty of time remaining on the clock. We conjecture that this is evidence of resale failing because of a holdout strategy, rather than a binding time limit.

Table 1
Average Earnings

	No Resale	Comp Resale	Incomp Resale	Bargain
Weak's earnings	\$12.98	\$15.84	\$14.25	\$14.66
Strong's earnings	\$23.09	\$23.14	\$22.52	\$20.42

rematched within the entire group of 16 subjects to minimise the effect of rematching with the same partner under free-form communication. Examining the chat, we find no evidence of collusion or reputation building.

The subjects were students at Florida State University and were recruited using ORSEE (Greiner, 2004). All sessions were conducted at the xs/fs laboratory in March and June, 2011, and October, 2012. The experiment was programmed using Z-tree software (Fischbacher, 2007) and, prior to the beginning of the paid periods, all subjects were given instructions which included two examples of bidding behaviour and, in the resale treatments, examples of resale market outcomes. To ensure subjects' understanding, they were required to complete a computerised quiz correctly before continuing. Pay-offs during the experiment were denominated in experimental currency units, ECUs, which transformed into US dollars at the rate of \$0.01 per ECU. Table 1 shows the earnings broken down by type and treatment.[27]

3. Experimental Results

In this Section, we describe the main results of our experiments. We begin in subsections 3.1 and 3.2 by describing the bidding behaviour of strong and weak bidders, respectively. Subsection 3.3 discusses efficiency and the seller's revenue; subsection 3.4 describes subjects' behaviour in the resale market. All data from all periods is included in the analysis, unless explicitly noted.[28]

3.1. *Strong Type Bidding*

By Results 1 and 2 in Section 1, without resale the strong bidder should win both units if his value is relatively high (precisely, if $v_S > 2\mathbb{E}[v_W] = 40$), while he should reduce demand otherwise. With resale the strong bidder should reduce demand across all values, regardless of the structure of the resale market or informational conditions.

Figure 1 presents weighted scatterplots of the observed strong bidders' bids against per unit value in the four treatments,[29] with the relative frequency of bid/value combinations as the weighting factor. In the no resale treatment, it is apparent that strong bidders dropped out at low prices with greater frequency for values lower than 40. This is evidenced in two ways. First, we have larger clusters of zero bids for values

[27] Subjects were given an endowment of 150 ECUs to begin the experiment from which losses were subtracted and profits were added. There was no subject bankruptcy.

[28] All data and the stata .do files to replicate these are available online.

[29] The Figure only represents losing bids, since we do not observe a bidder's bid when he wins a unit in an ascending auction.

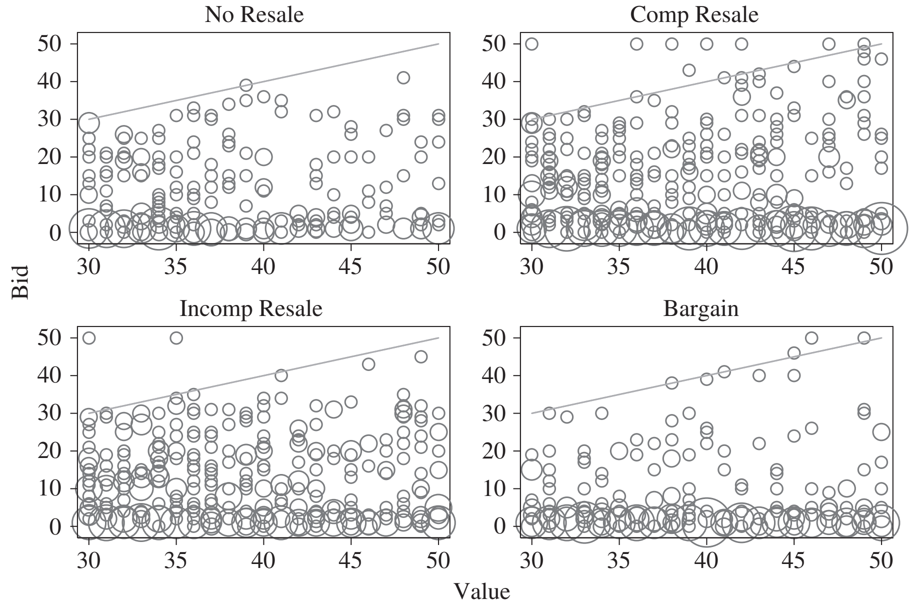

Fig. 1. *Strong Bidding – Weighted Scatterplot of Observed Bids (Dropouts) by Strong Bidders Versus Valuations in the Four Treatments*

below 40 and second, the number of observed bids is also much greater (showing that strong bidders dropped out first).

The remaining three graphs represent the resale treatments and provide visual evidence that strong bidders reduced demand much more often, responding as theoretically predicted in Result 2 to the presence of resale. Not only is there a great frequency of bids lower than values throughout the resale treatments but many of the bids are near the theoretical prediction of 0. The bargain treatment appears to adhere most accurately to the point predictions of the model, while stronger deviations from the point predictions are observed in both the complete and the incomplete information resale treatments.

To account for unobserved winning bids formally, Table 2 presents marginal effects from panel tobit regressions for strong bidders' bids, where unobserved bids are censored at the auction price at which the weak bidder dropped out.[30] Models 1 and 2 use data from all treatments. The variable v_S represents the strong bidder's valuation, while $v_S > 40$ is a dummy indicating when the valuation was higher than 40. Comp Resale, incomp resale, and bargain are treatment dummies indicating the resale treatments, with the no resale treatment serving as the baseline. The variable period tracks the period of play.

[30] This is a censored normal regression model as the censoring point may change in each observation (Wooldridge, 2001). The reported marginal effect = $\partial \mathrm{E}[bid|bid > price]/\partial x_k$, where x_k represents the kth independent variable. The numbers reported in parentheses are bootstrapped standard errors. Models 1 and 2, covering all treatments, include 1,646 uncensored bids and 994 right-censored bids (at the auction price). The resale only models, 3 and 4, include 1,358 uncensored bids and 562 right-censored bids.

The positive significant coefficient on $v_S > 40$ across Models 1 and 2 confirms that strong bidders bid higher when their value was higher than 40 in the no resale treatment, implying less demand reduction for bidders with relatively high values.

Empirical Result 1. *Without resale, strong bidders bid more aggressively when $v_S > 40$.*

Examining the effects of resale, we find partial support for the theoretical predictions. Low-value strong bidders are expected to reduce demand regardless of the presence of resale, and differences should emerge only for high values. In model 1, the negative significant coefficients on the treatment variables indicate that in all resale treatments strong bidders bid less aggressively than without resale, even with low values. Including treatment interactions with $v_S > 40$ in model 2 demonstrates that the effect continues at high-values, as predicted. However, these effects are weaker for the incomplete information resale treatment. As we show in subsection 3.4, this is consistent with the fact that the resale market is less efficient in the incomplete information resale treatment, thus making it more risky for strong bidders to reduce demand.[31]

Empirical Result 2. *With resale, strong bidders bid less aggressively than without resale, principally in the complete information and bargain resale treatments.*

We also find a strong negative effect on period, suggesting that strong bidders were learning to reduce demand over time. To investigate learning effects, models 3 and 4 restrict the analysis to the resale treatments, with the complete information treatment serving as the baseline. We include a variable balance tracking cumulative earnings and a dummy $t - 1$ resale which is equal to 1 if the subject participated in a resale market in the previous round. There is a significant and strong negative effect of past experience in resale on bids across all treatments, but this effect is lessened in the incomplete information resale treatments.

In theory, a strong bidder who reduces demand should drop out at zero. Yet any low bid that is below value or allows the weak bidder to win a unit may be interpreted as demand reduction.[32] Table 3 summarises strong bidders' bids that are lower than 2 and lower than value. In the no resale treatment, there is a larger percentage of low bids when the strong bidder had a value <40. The resale treatments had larger fractions of low bids than the no resale treatments, indicating more demand reduction. Low bids occur more frequently in the complete information resale and bargain treatments.

Since without demand reduction the weak bidder should never win, Table 3 also reports the percentage of auctions where the weak bidder won a unit. In the no resale treatment, weak bidders won more often when strong bidders had low values. All resale

[31] Since strong bidders tended to bid higher in the incomplete information resale treatment than in the complete resale treatment, there is no evidence that they tried to signal lower valuations to weak bidders when valuations were not revealed after the auction, in order to obtain higher profit in the resale market.

[32] Of course, dropping out at a strictly positive price may not be an optimal strategy for a strong bidder, because conditional on the auction price being positive, the expected profit from reducing demand may be lower than the expected profit from outbidding the weak bidder. A positive auction price also generates an information spillover between the auction and the resale market.

treatments resulted in weak bidders winning more often than without resale. Omitting the first 10 periods to account for learning, we observe weak bidders winning even more often with resale, particularly in the complete information and bargain treatments.

As a robustness check for the results on demand reduction, we analyse the probability of the strong bidder winning both units in Table 4 using probit regressions with standard errors clustered at the level of independent observation. While we only observe actual bids when the bidder drops out, we always observe whether or not the strong bidder won both units. The negative coefficients on all three resale treatment variables and the negative interactions of comp and incomp, with the dummy indicating higher values, provide additional evidence that demand reduction is more prominent with resale. The main difference with the results in Table 2 is that demand reduction is now more evident for low values in the incomplete information treatment.

3.2. *Weak Type Bidding*

By Results 1 and 2 in Section 1, the weak bidder should bid up to his valuation without resale, while he should bid more than his valuation in all resale treatments. Figure 2 plots weighted scatterplots of weak bidders' bids,[33] with the relative frequency of bid/value combinations as the weighting factor, and includes a line to indicate bids equal to value, i.e. the weak bidder's theoretical bidding function without resale.

It is clear from the scatterplot that in the no resale treatment the majority of observed bids by weak bidders are equal to value. Quantifying this, we find that the mean absolute deviation of bid from value is 0.80 and 83% of observed bids fall within ± 2 of value. For a more accurate test of value bidding, we ran panel random effects bid regression results on observed bids for the no resale treatment with standard errors clustered at the independent observation level. We find a constant coefficient of -0.172 ($p = 0.894$) and coefficient on v_w of 0.982 ($p < 0.001$). Supporting the theoretical prediction of value bidding, a joint test on the estimated coefficients cannot reject the null that the constant is equal to zero and the coefficient on the value of the weak bidder is 1 ($p = 0.881$).

EMPIRICAL RESULT 3. *Without resale, weak bidders bid up to their valuations.*

It is evident in the remaining scatterplots that the addition of resale changed bidding behaviour. In the complete information and incomplete information treatments, the addition of a resale market increased bids by weak bidders. Using the six independent session averages per treatment, a Wilcoxon-Mann-Whitney (WMW) test confirms this difference in observed bids between the no resale and complete information resale treatments ($p = 0.037$) and between the no resale and the incomplete information resale treatments ($p = 0.078$).

In the complete information and incomplete information resale treatments, many of the observed bids, while certainly higher than value, are lower than 30 – the lowest

[33] The graphs for the complete information and bargain treatments contain fewer observations than the other treatments because weak bidders won more often.

Table 2

Marginal Effects from Panel Tobit Regressions with the Strong Bidder's Bid as the Dependent Variable

	(1)	(2)	(3)	(4)
Strong bid	All treatments		Resale only	
v_s	0.313***	0.306***	0.252***	0.254***
	(0.0641)	(0.0717)	(0.0566)	(0.0715)
Comp resale (comp)	−4.239***	−2.677**		
	(1.268)	(1.355)		
Incomp resale (incomp)	−2.361*	−1.226	0.945	0.0662
	(1.285)	(1.720)	(0.918)	(1.095)
Bargain	−6.636***	−4.865***	−1.834*	−1.808*
	(1.649)	(1.609)	(0.979)	(1.094)
$(v_s > 40)$	7.602**	10.26**	6.098**	6.066*
	(3.509)	(4.122)	(2.994)	(3.555)
$v_s \times (v_s > 40)$	−0.190**	−0.182**	−0.166**	−0.166*
	(0.0847)	(0.0791)	(0.0677)	(0.0862)
Period	−0.204***	−0.208***		
	(0.0271)	(0.0270)		
Comp $\times$ $(v_s > 40)$		−3.930**		
		(1.545)		
Incomp $\times$ $(v_s > 40)$		−2.980*	0.896	0.873
		(1.640)	(1.104)	(1.040)
Bargain $\times$ $(v_s > 40)$		−4.525***	−0.381	−0.343
		(1.717)	(0.903)	(0.872)
Balance			−0.005***	−0.005***
			(0.0006)	(0.0006)
$t-1$ Resale			−2.060***	−2.549***
			(0.313)	(0.544)
Incomp $\times$ $t-1$ resale				1.334*
				(0.752)
Bargain $\times$ $t-1$ resale				−0.0724
				(1.002)
Observations	2,640	2,640	1,920	1,920

Notes. Bootstrap standard errors in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

Table 3

Relative Frequency of Demand Reduction by Strong Bidders (out of all auctions)

	% of Bids ≤ 2		% of Bids $< v_S$		% Weak Wins (all periods)		% Weak Wins (omit first 10 periods)	
	$v_S < 40$	$v_S > 40$	$v_S < 40$	$v_S > 40$	$v_S < 40$	$v_S > 40$	$v_S < 40$	$v_S > 40$
No resale	30	12	53	26	52	25	56	27
Comp resale	37	43	76	72	77	72	87	79
Incomp resale	29	22	73	54	72	53	76	55
Bargain	48	50	74	69	74	71	80	77

possible value of the strong bidder. A plausible explanation is that since weak bidders only had information regarding the competitor's value distribution, they may not have wanted to risk paying more than strong bidders' valuations. The final resale treatment,

Table 4

Marginal Effects from Probit Regressions on S Winning 2 Units

S wins 2 units	(1)	(2)
v_s	0.024***	0.023***
	(0.0059)	(0.0057)
Comp resale (comp)	−0.334***	−0.266***
	(0.0518)	(0.0628)
Incomp resale (incomp)	−0.230***	−0.210***
	(0.0545)	(0.0774)
Bargain	−0.327***	−0.263***
	(0.0358)	(0.0475)
$(v_s > 40)$	0.695***	0.736***
	(0.196)	(0.198)
$v_s \times (v_s > 40)$	−0.019**	−0.018**
	(0.0076)	(0.0077)
Period	−0.009***	−0.009***
	(0.0018)	(0.0018)
Comp $\times$ $(v_s > 40)$		−0.182**
		(0.0769)
Incomp $\times$ $(v_s > 40)$		−0.062
		(0.0984)
Bargain $\times$ $(v_s > 40)$		−0.196***
		(0.0606)
Observations	2,640	2,640

Notes. Robust standard errors in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

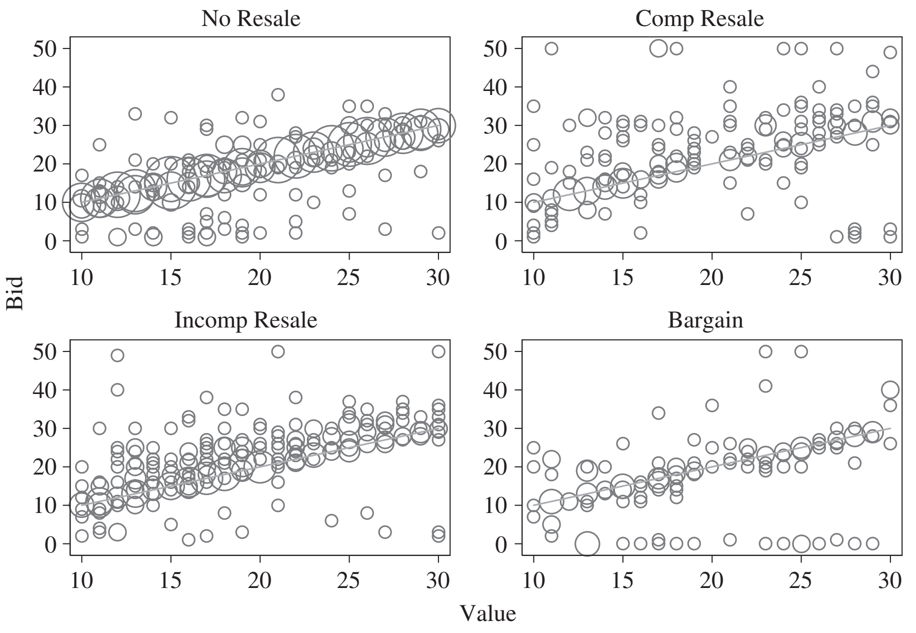

Fig. 2. *Weak Bidding – Weighted Scatterplot of Observed Bids (dropouts) by Weak Bidders Versus Valuations in the Four Treatments*

bargain, resulted in the majority of observed bids at value.[34] Bids appear to be less aggressive in this treatment than in other resale treatments, and a WMW test on session averages confirms no difference in observed bids between the no resale and the bargain resale treatment ($p = 0.796$). However, these scatterplots and tests on observed bids only represent partial results, as they focus on auctions where the weak bidder did not win a unit.

In Table 5, we analyse weak bidding behaviour through random effects tobit models with bootstrapped standard errors, where unobserved winning bids are censored at the auction price. The weak bidder's valuation is represented by v_W. The first three models are run on all four treatments, with the no resale treatment serving as the baseline. Model 4 is restricted to the three resale treatments, with the complete information treatment serving as the baseline.[35]

Models 1–3 demonstrate a strong positive effect on weak bidders' bids when resale is possible, regardless of the form, confirming Result 2 and consistent with the results of Georganas (2011) and Georganas and Kagel (2011) for single-object auctions. While all three resale treatments result in speculation by weak bidders, the strength of this

Table 5

Marginal Effects from Panel Tobit Regressions with the Strong Bidder's bid as the Dependent Variable

	(1)	(2)	(3)	(4)
Weak bid	All treatments			Resale only
v_w	0.660***	0.659***	0.659***	0.478***
	(0.0249)	(0.0289)	(0.0268)	(0.107)
Comp resale (comp)	8.794***	8.789***	8.841***	
	(1.998)	(2.329)	(1.713)	
Incomp resale (incomp)	4.614***	4.604***	4.649***	−4.580**
	(1.153)	(1.345)	(1.218)	(2.099)
Bargain	4.479***	4.423***	4.515***	−4.468*
	(1.551)	(1.690)	(1.632)	(2.397)
Comp × v_w	−0.210**	−0.211**	−0.210**	
	(0.0983)	(0.0990)	(0.0943)	
Incomp × v_w	−0.078*	−0.078	−0.078	0.145
	(0.0428)	(0.0543)	(0.0498)	(0.109)
Bargain × v_w	−0.157**	−0.157**	−0.157**	0.0519
	(0.0750)	(0.0714)	(0.0642)	(0.122)
Period		−0.00870		
		(0.0205)		
Balance			−0.0009	
			(0.0019)	
$t-1$ resale				−0.912
				(0.765)
Observations	2,640	2,640	2,640	1,920

Notes. Bootstrap standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

[34] All bids at 0 and 1 in the bargain treatment were made by a single subject for the duration of the experiment. This bidding behaviour is exceptional given the overall pattern of the data and is difficult to rationalise. Nevertheless, this subject's data is included in all of our graphs and analysis. Our primary results do not change with the exclusion of this subject.

[35] Models 1–3 include 1,023 uncensored bids and 1,617 censored bids (at the auction price), while model 4 includes 583 uncensored bids and 1,337 censored bids.

effect is strongest in the complete information resale treatment. Model 4 confirms that bids in the incomplete information and bargain treatments are lower than the complete information resale treatment but this difference is weaker in the bargain treatment. Models 1–3 include interaction effects between value and treatments, and in all three models the significant negative coefficient on $v_W \times$ bargain and $v_W \times$ comp provides robust evidence that in these treatments higher-value weak bidders bid less aggressively than lower-value ones.

EMPIRICAL RESULT 4. *Weak bidders bid higher with resale than without. Speculation by weak bidders is highest in the complete information resale treatment.*

Models 2–4 include the behavioural variables. Period tests for general learning effects, $t - 1$ resale tests for specific learning effects related to previous experience in a resale market, and balance tests for earnings effects. In contrast to strong bidders, no significant effects were found.[36]

3.3. *Efficiency and Seller's Revenue*

Following Kagel and Levin (2001), auction efficiency is measured as the ratio between the sum of valuations of the auction winner(s) and the sum of valuations of the strong bidder, which is the highest valuation for each unit. Since strong bidders always won the first unit, auction efficiency is lower than 1 when the weak bidder won the second unit. Similarly, post-resale or final efficiency is measured as the ratio between the sum of valuations of the final holders of the units and the sum of valuations of the strong bidder. Final efficiency is 1 if the weak bidder resold the second unit to the strong bidder; while final efficiency is equal to auction efficiency if resale does not take place.

By Result 3 in Section 1, auction efficiency should be lower with resale than without, while final efficiency should be 1 in the bargain and complete information resale treatments, and higher than without resale. Final efficiency may be lower than 1 in the incomplete information resale treatments because bidders may fail to trade with take-it-or-leave-it offers and incomplete information.

Table 6 reports average efficiency, by treatment. No resale resulted in the highest auction efficiency. Pairwise WMW tests on session averages find significant differences in auction efficiency between the no resale treatment and all resale treatments ($p \leq 0.025$). Among the resale treatments, incomplete information resale resulted in the highest auction efficiency.

Resale improved efficiency from the auction allocation to the final allocation, most strikingly when subjects were allowed to bargain or make take-it-or-leave it offers with complete information, consistent with Result 3.[37] Final efficiency in both the bargain and the complete information resale treatments is higher than without resale. However, resale did not always yield higher final efficiency: no significant difference

[36] As a robustness check, we also ran various other specifications that included these behavioural variables interacted with treatments. All other models demonstrated no significant behavioural effects for weak bidders.

[37] We find no significant differences in final efficiency between the complete information resale and bargain treatments ($p = 0.438$).

Table 6

Average Efficiency and Revenue (Standard Deviations in Parentheses)

	No resale	Comp resale	Incomp resale	Bargain
Auction efficiency	0.91	0.82	0.86	0.83
	(0.121)	(0.128)	(0.129)	(0.131)
Final efficiency	0.91	0.97	0.93	0.98
	(0.121)	(0.085)	(0.109)	(0.066)
Revenue	14.61	11.94	14.05	8.47
	(10.062)	(12.448)	(11.099)	(10.567)
Revenue – weak wins	8.01	8.64	9.98	5.25
	(10.117)	(11.339)	(10.387)	(8.873)
Revenue – strong wins	18.81	21.85	21.06	17.22
	(7.440)	(10.181)	(8.493)	(9.849)

exists between final efficiency in the no resale and the incomplete information resale treatments ($p = 0.521$).

These results are confirmed by Figure 3, that graphs the relative frequency of the strong bidder winning both units in the auction (light grey bars), broken down by value for all treatments. In the no resale treatment (first graph of Figure 3), strong bidders won two units more often when their value was higher than 40. A Kolmogorov–Smirnov (K–S) test indicates that the observed difference between strong bidders winning when their value was above 40 and below 40 is statistically significant ($p < 0.001$).

It is evident that the presence of resale resulted in the strong bidder winning less often, although this effect is lessened under incomplete information. We find

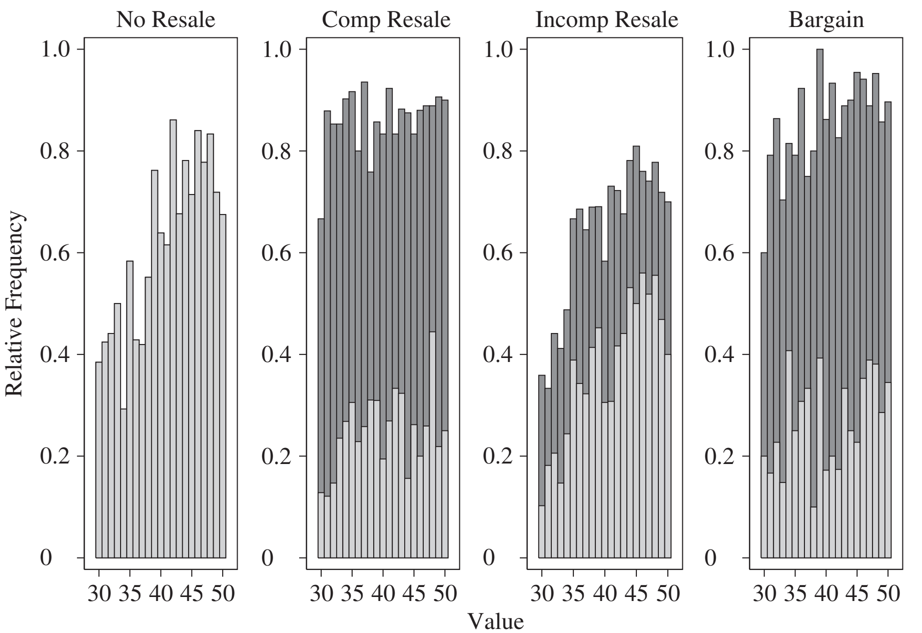

Fig. 3. *Relative Frequency of Auction Allocation (Light Grey) and Final Allocation (Dark Grey) of Two Units to Strong Bidder, by Strong Bidders' Value*

significant differences between the no resale and all resale treatments for both high and low values (K–S, $v_S < 40$, $p \leq 0.007$; $v_S > 40$, $p < 0.001$). There is no significant difference between the complete information and bargain treatments ($p = 0.264$). Between incomplete information and either complete information or bargain treatments, significant differences exist when $v_S > 40$ ($p \leq 0.001$) but not when $v_S < 40$ ($p \geq 0.102$).

To show how the allocation changed after the auction, in Figure 3 we have overlaid the relative frequencies of the strong bidder holding both units after the resale market (dark grey bars) onto the auction allocation. Resale increased allocative efficiency after the auction. With complete information or bargaining, the second unit was almost always transferred to the strong bidder when the weak bidder won it in the auction, and there is no significant difference between the final allocations in these two treatments (K–S, $p = 0.485$). Resale under take-it-or-leave-it offers with incomplete information also increased allocative efficiency but the final allocation was similar to the no resale allocation. A K–S test confirms that there is no significant difference between the no resale and the incomplete information resale treatments ($p = 0.485$).

Empirical Result 5. *Auction efficiency is lower with resale than without. Final efficiency is lowest in the no resale and incomplete information resale treatments.*

By Result 4 in Section 1, auction revenue should be higher without resale than with resale because resale induces demand reduction which reduces the auction price. Table 6 reports average auction revenue per unit sold for each treatment and by the type of the auction winner. The highest overall revenue was achieved in the no resale treatment but revenue in the incomplete information resale treatment was almost as high as in the no resale treatment.[38] The reason is that weak bidders bid more aggressively with resale, and this increased the seller's revenue when strong bidders chose to win both units in the auction rather than reduce demand.

Empirical Result 6. *The seller's revenue without resale is higher than in the bargain treatment but it is not significantly higher than in the incomplete information and in the complete information resale treatments.*

Table 6 also shows that in all treatments the seller obtained a lower revenue when weak bidders won a unit, although strong bidders had a higher value. This is consistent with the fact that strong bidders tended to reduce demand and bid lower than weak bidders, in order to reduce the auction price.

3.4. *Resale Market*

In this subsection, we examine aspects of the resale market that underlie the empirical regularities described previously for the resale treatments.

[38] WMW tests on session averages for revenue find no significant differences between no resale and either complete ($p = 0.200$) or incomplete information resale ($p = 0.872$). By contrast, there are significant differences in revenue between either no resale or incomplete information resale and bargain ($p \leq 0.070$).

Table 7 provides the relative frequency of successful resale, conditional on the resale market opening. Successful resale took place when both participants agreed to an offer, while failure in the resale market was either a result of one of the participants choosing to exit the resale stage, or failed agreement.[39] Resale was more successful in the complete information resale and bargain treatments than in the incomplete information resale treatment because of the mix of incomplete information and the take-it-or-leave-it offer mechanism. The last two columns of Table 6 report the share of the overall success rates by the type of proposer in the take-it-or-leave-it offer mechanisms and show that the majority of successful offers were made by weak proposers, particularly in the incomplete information resale treatment.

From an efficiency standpoint, it is important to understand which factors determined a higher probability of successful resale. Table 8 provides marginal effects from probit regressions with agreement to final resale as the dependent variable. Standard errors are clustered at the level of independent observation. Models 1 and 2 examine the complete and incomplete information resale treatments, respectively. The variable offer represents the take-it-or-leave-it offers. Auction price represents the dropout price from the auction, auction price $> v_W$ is a dummy indicating when the auction price was greater than the weak bidder's value (i.e. losses at the auction stage for the weak bidder), and $v_S - v_W$ represents the difference between the strong and weak values to capture the effect of varying asymmetry between bidders. Weak proposer is a dummy indicating whether the proposer was the weak bidder and period indicates the round of play.

As expected, an increase in the offer made by a strong proposer as well as a reduction in the offer made by a weak proposer significantly increased the probability of acceptance. We also find a significant and large positive effect of weak bidders assigned to the proposer role on the probability of agreement, arguably because weak bidders were less aggressive in the resale market, as we show below. Although in theory the profits from the auction should not affect the resale market, in the incomplete information treatment we find some evidence of a strong positive effect when the auction price was higher than the weak bidder's value. The size of the gains from trade

Table 7

Relative Frequency of Successful Resale (Out of All Periods in Which the Weak Bidder Won a Unit)

	Successful resale		
	Overall (%)	Weak proposer (%)	Strong proposer (%)
Comp resale	81.1	51.83	48.2
Incomp resale	42.2	62.0	38.0
Bargain	79.5	–	–

[39] In the bargain treatment, we observed 72 cases of failed resale (out of 351 resale markets). Of these, 41 were the result of time expiring while the remaining 31 failed because one of the two resale participants chose to exit the stage.

Table 8

Marginal Effects from Probit Regressions on Resale of Unit (Final Resale Agreement), Conditional on Weak Winning

Final resale agreement	(1) Comp Resale	(2) Incomp Resale	(3) Bargain Resale
Offer	0.020***	0.036***	
	(0.0039)	(0.0097)	
Auction price	−0.004	0.001	0.002
	(0.0035)	(0.0070)	(0.0031)
Auction price > v_w	0.064	0.154*	0.010
	(0.0632)	(0.0869)	(0.134)
$v_s - v_w$	0.005	0.023***	0.011***
	(0.0032)	(0.0054)	(0.0016)
Weak proposer	0.662***	0.708***	
	(0.101)	(0.151)	
Offer × weak proposer	−0.022***	−0.032***	
	(0.0052)	(0.0095)	
Auction price × weak proposer	−0.004	−0.004	
	(0.0028)	(0.0069)	
Period	−0.002	0.007	0.006
	(0.0021)	(0.0049)	(0.0041)
Initial offer weak-strong			−0.011***
			(0.0003)
No. offers made			−0.009**
			(0.0037)
Observations	534	445	334

Notes. Robust standard errors in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.

$v_S - v_W$ had little impact under complete information but significantly increased the probability of successful resale in the incomplete information treatment.

Model 3 considers the bargain treatment taking into account the unstructured process of this mechanism, where we typically observe a series of alternating offers. To measure the initial level of disagreement in a bargaining pair, we include a variable equal to the difference between the first offers made by strong and weak bidders.[40] We find that each one unit increase in the initial disagreement is associated with approximately 1% decrease in the probability of successful resale. We also include a variable, no. offers made, which tracks the total number of offers made by a bargaining pair, and find a negative effect on the probability of final agreement. As in the incomplete information resale treatment, higher gains from trade increased the probability of successful resale.

Empirical Result 7. *Resale is more likely to succeed when the weak bidder has more bargaining power, with more information in the resale market, larger gains from trade, and a flexible bargaining mechanism.*

Table 9 summarises average resale prices, earnings (measured as the difference between the resale price and the bidder's value) and proposed offers by type of bidder.

[40] If agreement was reached with a single offer, this difference is defined as zero.

Table 9

Average Resale Prices, Resale Earnings, and Offers by Type

	Resale price	Weak earnings	Strong earnings	Resale offer	
				Weak	Strong
Comp resale	29.56	9.45	10.20	32.47	25.45
	(5.619)	(5.527)	(5.749)	(4.664)	(6.240)
Incomp resale	27.38	8.74	12.59	32.45	17.93
	(7.686)	(7.964)	(7.635)	(6.911)	(7.035)
Bargain	27.44	8.35	12.43	–	–
	(4.474)	(5.866)	(6.559)	–	–

Note. Standard deviations in parentheses.

Resale prices were higher in the complete information resale treatment than either the bargain or the incomplete information resale treatments. WMW tests on the independent session averages for resale prices show significant differences between complete information and incomplete information resale ($p = 0.054$) and between complete information resale and bargain ($p = 0.020$) but no significant difference between incomplete information resale and bargain ($p = 0.796$).

Weak bidders obtained a lower profit than strong bidders in the resale market but less so with complete information, where profits were closer to equal splits of the resale surplus. Weak bidders earned 48% of the resale surplus in the complete information treatment, 30% in the incomplete information treatment and 39% in the bargain treatment.[41] Differences in earnings were mainly driven by strong bidders making more aggressive offers in the resale market, especially with incomplete information. Comparing the average offers between the take-it-or-leave-it treatments, strong proposers made significantly lower offers under incomplete than under complete information ($p = 0.006$), while there is no significant difference between the weak proposers' offers ($p = 0.872$).

Weak proposers were consistently less aggressive than strong proposers in both treatments. However, weak offers were closer to optimal in the incomplete information treatment, and strong offers were higher than optimal in the complete information treatment. In theory, the variance in offers should be higher.

Figure 4 compares the period averages of actual take-it-or-leave-it resale offers by weak and strong bidders to optimal offers (that maximise the expected profit of the proposer) in the complete and incomplete information resale treatments.[42] Weak proposers were consistently less aggressive than strong proposers in both treatments. However, weak offers were closer to optimal in the incomplete information treatment

[41] The resale treatments with take-it-or-leave-it offers are ultimatum games and, in expectation, a bidder should obtain half of the gains from trade in the resale market. It is well-established that experimental tests of ultimatum games often result in substantially different behaviour than predicted by theory: on average, offers that are lower than 40% of the bargaining pie are typically rejected (Cooper and Dutcher, 2011). Our results for the complete information treatment most closely conform to the standard results of ultimatum games.

[42] With complete information, the optimal offer by a bidder is equal to the value of its competitor. With incomplete information, the optimal offer by a weak bidder with value v_W is equal to $25 + (v_W/2)$, and the optimal offer by a strong bidder with value v_S is equal to $5 + (v_S/2)$.

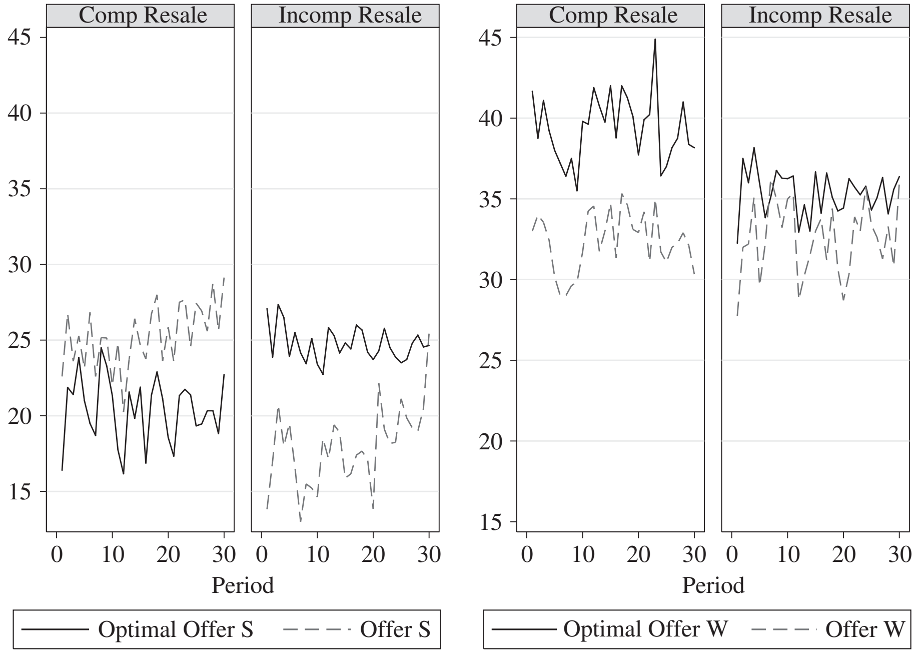

Fig. 4. *Optimal versus Actual Average Offers over Time*

and strong offers were higher than optimal in the complete information treatment. In theory, the variance in offers should be higher with complete information than with incomplete information, yet we observe the reverse. This is particularly true for strong bidders who made extremely low offers in the early periods of the incomplete information treatment.

Comparing average resale prices from Table 9 to average auction prices (which are equivalent to the seller's revenue) from Table 6 it is clear that, in all treatments with resale, auction prices are lower than resale prices on average. Since resale tends to reduce the seller's revenue, it may be expected that bidders always prefer auctions with resale. This is not necessarily the case, however, as shown in Table 10, which reports average total bidders' profits, i.e. auction earnings plus resale earnings in each period, by types and treatments. Pairwise WMW tests on session averages find significant earnings differences for weak bidders across all treatments ($p \leq 0.077$) except between the complete information resale and bargain treatments. Weak bidders obtain higher

Table 10

Average Bidders' Total Profits (Standard Deviations in Parentheses)

	No Resale	Comp Resale	Incomp Resale	Bargain
Weak's profit	4.95	14.47	9.18	15.83
	(8.838)	(14.279)	(11.709)	(12.620)
Strong's profit	38.64	38.82	36.76	44.62
	(16.911)	(17.979)	(18.028)	(17.147)

profits when resale is allowed. By contrast, strong bidders' profits without resale are significantly lower than in the bargain treatment ($p = 0.070$) but are not significantly different from in the complete information and incomplete information resale treatments ($p \leq 0.631$).[43] Therefore, strong bidders obtain higher profits when resale is allowed only when the resale market is sufficiently flexible and efficient, so that they manage to trade with high probability after the auction.

4. Conclusion

The possibility of resale affects bidders' strategies in the auction and the seller's revenue. We use a combination of theory and controlled laboratory experiments to analyse the effects of post-auction resale and asymmetries among bidders in multi-object auctions, with varying information conditions and resale mechanisms.

Our experimental results provide strong qualitative support for the bidding strategies predicted by theory. First, without resale, bidders reduce demand less when they have a relatively higher valuation than competitors. Second, with resale, bidders who expect to sell in the resale market speculate by bidding higher than their valuations, while bidders who expect to buy in the resale market reduce demand much more often than without resale, especially when they have high valuations. So the possibility of resale motivates bidders to bid further away from their values. These results are robust to different resale mechanisms but the magnitude of the response to resale depends on the properties of the resale market: higher uncertainty about the resale market's outcome reduces speculation and demand reduction.

Although resale increases efficiency after the auction, our analysis shows that the increase in demand reduction due to the presence of resale reduces auction efficiency and may not increase final efficiency when resale fails because of incomplete information, or a rigid bargaining environment. In any case, the potential efficiency gains induced by resale come at the cost of the seller's revenue. Specifically, a highly efficient resale market reduces revenue because it allows bidders to exploit mutual gains from trade after the auction.

We have used a simplified experimental design to analyse multi-object auctions with resale, an environment which is potentially extremely complex. This was a deliberate choice which allowed us to isolate the response to resale of different types of bidders. Of course, since our experimental design may differ from external environments in a number of ways, our results should be interpreted cautiously. First, in our experiments resale is likely to succeed because subjects know there are gains from trade. In a more realistic environment bidders may be unsure about the presence of gains from trade, or resale may be costly and require significant delays. This would reduce the efficiency of the resale market, hence, the incentive to reduce demand and speculate. Second, weak bidders can win only one unit in our experiments, which simplifies their strategic problem. In actual auctions with resale, however, bidders may also attempt to acquire objects for which they have no intrinsic value, i.e. they may behave as pure speculators.

[43] The only other significant difference in the pairwise comparison of overall profits for strong bidders is between incomplete information resale and bargain ($p = 0.038$).

Third, we fixed the number of bidders, while in reality the possibility of resale is likely to affect participation in the auction by making entry attractive for weak bidders.[44]

Appendix A. Resale with Take-it-or-leave-it Offers and Incomplete Information

We show that the main qualitative results of our theoretical analysis also hold if the auction is followed by a resale market where a bidder is randomly selected to make a take-it-or-leave-it offer and bidders' valuations are not revealed to the competitors after the auction, i.e. the incomplete information resale treatment. In this case, in contrast to our model, the resale market is not necessarily efficient since bidders may fail to trade. Specifically, we show that there is an equilibrium where bidder W speculates and bidder S always reduces demand, which is the equilibrium that maximises joint bidders' profits. As in our experimental treatment, we assume that $v_S \sim U[30; 50]$ and $v_W \sim U[10; 30]$.

If bidder W wins a unit in the auction, in the resale market he obtains an expected surplus which is at least equal to $(1/2)(30 - v_W)$. The reason is that with probability $1/2$ he is selected to make a take-it-or-leave-it offer to bidder S, and an offer equal to 30 is always accepted. Therefore, bidder W speculates and bids at least:

$$v_W + \frac{1}{2}(30 - v_W) = 15 + \frac{1}{2}v_W,$$

for a unit in the auction.

In order to win two units in the auction, bidder S has to outbid bidder W and, hence, he obtains an expected profit which is at most equal to:

$$2\left[v_S - \left(15 + \frac{1}{2}\mathbb{E}[v_W]\right)\right] = 2v_S - 50. \tag{A.1}$$

If instead bidder S reduces demand and bids zero for the second unit in the auction, in the resale market he obtains an expected surplus which is at least equal to $(1/2)(v_S - 30)$. The reason is that with probability $1/2$ he is selected to make a take-it-or-leave-it offer to bidder W, and an offer equal to 30 is always accepted. Hence, by reducing demand in the auction, S obtains an expected total profit which is at least equal to:

$$v_S + \frac{1}{2}(v_S - 30) = \frac{3}{2}v_S - 15. \tag{A.2}$$

Bidder S always prefers to reduce demand since (A.2) is strictly higher than (A.1).

Because in equilibrium bidder S reduces demand and allows bidder W to win: the seller's revenue is equal to zero, the auction allocation of the units on sale is always inefficient and the final allocation is not necessarily efficient, since offers in the resale market may be rejected due to incomplete information. Moreover, no information on bidders' valuations is transmitted from the auction to the resale market.

In the resale market, the optimal take-it-or-leave-it offer for bidder W with value v_W is equal to:

$$\arg\max_t\{t \times \Pr[v_S > t] + v_W \times \Pr[v_S < t]\} = 25 + \frac{1}{2}v_W.$$

Similarly, the optimal take-it-or-leave-it offer for bidder S with value v_S is equal to $5 + (1/2)v_S$. Hence, the probability of an inefficient final allocation is equal to $1/4$ (while without resale is it equal to $1/2$).

[44] Pagnozzi and Saral (2015) analyse the role of speculators and the effect of resale on players' entry decisions.

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Submitted: 21 November 2014
Accepted: 2 March 2016

Additional Supporting Information may be found in the online version of this article:

Appendix B. Experiment Instructions.
Data S1.

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