Experimental evidence on English auctions: oral outcry vs. clock*

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Abstract

This paper tests experimentally, in a common value setting, the equivalence between the Japanese English auction (or clock auction) and an open outcry auction, where bidders are allowed to call their own bids. We find that (i) bidding behaviour is different in each type of auction, but also that (ii) this difference in bidding behaviour does not affect significantly the auction prices. This lends some support to the equivalence between these two types of auction. The winner's curse is present: overbidding led to higher than expected prices (under Nash bidding strategies) in both types of auction.

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1 Introduction

One of the most remarkable results in auction theory, the revenue equivalence theorem, first stated by Vickrey (1961), has been the object of substantial research over the recent years, not only theoretical[1] but also experimental[2]. Its prediction that the average price of the four main types of auction (English, oral outcry or ascending bid, Dutch or descending bid, first-price and second-price sealed bid) is the same (in the independent private values model) has been one of the targets of that research. However, the also striking result on the strategic equivalence between the English and second-price sealed bid auctions has been widely accepted. Milgrom and Weber (1982), in a more general model which nests the independent private value and common value auctions as special cases, have analysed the symmetric equilibrium of all the main types of auction, and have found that the English auction, on average, generates a higher revenue for the auctioneer than the second-price sealed bid auction when the number of bidders is higher than two. When the number of bidders is exactly two, they suggest that the two types of auction are strategically equivalent, and hence yield the same equilibrium price[3], and this applies both to private or common value settings.

However, the English auction model used to obtain this equivalence result is quite different from a real world oral outcry auction. Milgrom and Weber (1982) model a Japanese English auction, in which all bidders depress a button while the price is posted on a screen and is continuously increasing. Any bidder who wishes to drop out only needs to release the button. The auction finishes when only one bidder is left, and he pays the price at which his last opponent dropped out. This type of English auction, also known as a clock auction, and its theoretical predictions have been tested experimentally in Levin, Kagel and Richard (1996) and Avery and Kagel (1997). But real world English auctions, commonly referred to as oral outcry auctions, usually involve bidders stopping to bid and then restarting again later on, and also discrete bidding, where they have to shout their own bid (or where the auctioneer calls for discrete bidding increments). The latter is the key difference we would like to test. Some recent papers (Rothkopf and Harstad (1994), Sinha and Greenleaf (2000), Isaac *et al* (2007), Cheng (2004), David *et al* (2005), Gonçalves (2007a)) have shown that theoretically differences are to be expected between those two auction types. The first experimental test of such discrete bidding auctions is, to the best of our knowledge, Isaac *et al* (2005) who focus on testing the different types of equilibrium which could emerge in independent private value English auctions.

In a common value auction, we test experimentally the clock auction and an oral outcry auction

[1] For comprehensive surveys, the reader is referred to McAfee and McMillan (1987) or Klemperer (1999).

[2] See Kagel (1995) for an overview.

[3] With more than two bidders, the two types of auction are strategically equivalent in a weaker sense (Milgrom and Weber (1982)), and if the drop out prices of the quitting bidders are publicly revealed, the English auction will generate more expected revenue than the second-price sealed bid auction (see Milgrom and Weber (1982)).

with discrete and endogenous bidding, based on the 'Wallet Game' (Klemperer (1998), tested experimentally by Avery and Kagel (1997)). In such common value settings, a common feature (see Kagel (1995) or Avery and Kagel (1997)) is the presence of the winner's curse: overbidding compared to what is predicted in equilibrium, often leading to negative payoffs for the auction winner. The purposes of this paper are twofold: (i) to test experimentally whether allowing for discrete bidding leads to significantly different outcomes when compared to the clock auction; and (ii) to analyse the winner's curse (if present) and see under which setting its effects are more pervasive.

Our experiments contain a small departure from the standard assumptions in common value auctions: we assume that the ordering of the private signals, i.e. the identity of the highest signal holder, is common knowledge. By contrast, the exact value of each bidder's signal is private information, a standard assumption. Recent literature has analysed the impact of such an assumption on the revenue equivalence theorem. Fang and Morris (2006) assume that each bidder in an independent private values auction observes his private valuation as well as a noisy and private signal about their opponent's valuation. Revenue equivalence breaks down, although there is no general price ranking between the first-price and the second-price auction. Kim and Che (2004) assume that subgroups of bidders perfectly observe their own valuations in an independent private value auction. Revenue equivalence also breaks down, but in this case the second-price auction yields a higher expected price than the first-price auction. Kim (2007) proposes a further extension where each bidder's noisy signals about their opponent's valuations are common knowledge. Under a specific signal-contingent tie-breaking rule, Kim (2007) shows that the second-price auction also generates higher revenue than the first-price auction. This phenomenon may arise in real world auctions. Jofre-Bonet and Pesendorfer (2003) suggest that in highway construction procurement auctions, a bidder's capacity utilization can be a determinant of their costs; Fang and Morris (2006) note that rival firms may thus try to infer a bidder's costs based on their capacity utilization levels.

Gonçalves (2007a) shows that in a common value oral outcry auction, assuming the ranking of the private signals and the bid structure (the minimum increments the auctioneer will use after each bidding round) are common knowledge, a sequential equilibrium exists[4] in which the high signal bidder always prefers to start the auction, and will choose his starting bid in a payoff maximising way: he either starts with the lowest possible bid or the second lowest possible bid, thus choosing the bidding path which favours him the most. This result is similar to Avery (1998). From then on, both bidders strictly prefer to increase their bid by the least amount possible, until their bidding limit is reached. Rothkopf and Harstad's (1994) private values result holds: increasing the current bid by the least amount possible is a symmetric equilibrium. The bidding limits of this equilibrium are those found in the symmetric equilibrium by Milgrom and Weber (1982). By contrast, the

[4] Assuming there are no ties: a tie occurs when both signal realizations belong to the same interval within the bid structure.

knowledge of the signal ranking in a clock auction should not affect each bidder's equilibrium strategies: Klemperer (1998) and Gonçalves (2007b) highlight that for the low signal bidder, once the symmetric equilibrium bidding limit is reached, he realizes he is the low signal bidder and that the good is certainly worth more than that. However, this knowledge brings him no advantage in subsequent bidding, because given his rival's symmetric bidding strategy, winning would yield a negative payoff.

The two main experimental results reported in this paper are that (i) bidding behaviour is different in each type of auction, but also that (ii) this difference in bidding behaviour does not affect significantly the auction prices. In the clock auction, all bidders seemed to follow a "statistical" bidding rule: bidders used the signal distribution to calculate the expected value of their opponent's signal and then used it to compute their drop out price. By contrast, in the oral outcry auction, only low signal bidders seemed to make use of this "statistical" bidding rule; high signal bidders seemed to follow the symmetric Nash equilibrium prediction. These different bidding strategies turned out not to affect significantly the final auction price: the difference between the final average prices in the oral outcry and the clock auction was not statistically significant. This, we conclude, provides some support to the equivalence claim between these two auction types. As in other experiments of English auctions[5], we also found significant overbidding compared to the Nash prediction and a strong presence of the winner's curse. Such overbidding led to 19% of bidders in the clock auction and 23% in the oral outcry auction receiving negative profits.

We will leave the discussion of our findings to section 7. Section 2 presents the theoretical models and discusses their implications; Sections 3 and 4 discuss some alternative bidding theories; Section 5 describes the experimental details and Section 6 contains an extensive analysis of the results.

2 Theoretical foundations

The model we make use of is based on Klemperer's (1998) 'Wallet Game', which was tested experimentally by Avery and Kagel (1997). Two bidders compete for an object of unknown common value, V. Each bidder receives a signal X_i, $i = 1, 2$. The common value, known after the auction finishes, is given by the sum of the signals, i.e. $V = v(x_1, x_2) = x_1 + x_2$. Klemperer (1998) calls it the Wallet Game because it is easily played in a classroom: we could ask two students to privately check how much money they each had in their wallets, and then make them bid for an object worth the combined amount of their wallets. X_i follows an independent uniform distribution on an interval (a, b).

[5] See Kagel (1995).

2.1 The clock auction

The symmetric Nash equilibria for the second-price sealed bid and for the clock auction (or Japanese English auction) are equivalent and yield equilibrium bid functions $b_i^* (x_i) = v (x_i, x_i) = 2x_i$, $i = 1, 2$. This result has been derived by Klemperer (1998) and by Avery and Kagel (1997), so we refer the interested reader to those papers[6]. Any of the players has no incentive whatsoever to deviate from it, given that the other player is playing that strategy. Suppose $x_1 > x_2$. In equilibrium, the low signal bidder should bid $2x_2$; if he deviates, to win the auction, he will have to stay active until the price reaches $2x_1$, the equilibrium bid of his opponent. This, in turn, is more than the good's true value, hence yielding a negative profit for that bidder if he wins. The high signal bidder also has no incentive to bid less than $2x_1$ because this will have no influence on the price (it is a second-price auction). Hence, like Avery and Kagel (1997) call it, there is no *ex post* regret with this equilibrium, in the sense that even after learning the other bidder's signal, any of the bidders will not regret having bid how they actually did. Another important property is that profits are always positive for the winner, who in turn is always the high signal bidder. In the above example, the price to pay will be $p = b_2^* (x_2) = 2x_2$, and the winning bidder's profits will be $v (x_1, x_2) - p = x_1 + x_2 - 2x_2 = x_1 - x_2 > 0$, because $x_1 > x_2$ by assumption.

The expected revenue for the auctioneer in the clock auction at the symmetric equilibrium will be:

$$E \left[P^{Clock} \right] = 2 (2a + b) /3 \tag{1}$$

(Avery and Kagel (1997), Theorem 2.5). This is because the expected price will be simply $E [\min (b^* (x_1) , b^* (x_2))] = E [\min (2x_1, 2x_2)] = 2.E [\min (x_1, x_2)] = 2 (2a + b) /3$.

2.2 The oral outcry auction

In the oral outcry auction, any of the two bidders could start the auction with an initial bid. After the initial bid, there exists a minimum bid which his opponent will face in the next bidding round. We define $\mathbf{a} = (a_0, a_1, ..., a_L)$ as the bid structure which contains the minimum bids, where $a_L \geq v (b, b)$. For example, if the starting bidder places a bid of $y \in [a_0, a_1)$, then his opponent will face a minimum bid of a_1 in the next bidding round. This bid structure is common knowledge.

If the signal ranking (i.e. the identity of the bidder holding the highest signal) is also common knowledge, Gonçalves (2007a) shows that the bid functions $b_i^* (x_i) = v (x_i, x_i) = 2x_i$, $i = 1, 2$, are a sequential equilibrium of this auction, provided there are no ties[7]. In this equilibrium, the

[6] Milgrom and Weber (1982) have derived the symmetric equilibrium in a general model; Klemperer (1998) has applied it to the 'Wallet Game'.

[7] A tie occurs when both signal realizations belong to the same interval within the bid structure $\mathbf{a}$, i.e. when $x_1, x_2 \in [a_k, a_{k+1})$ for some k. If there is a tie, the equilibrium fails to hold because both bidders would prefer to start the auction and choose the auction path which favours them the most. But by revealing the signal ranking, it is not possible to know whether there is a tie. In the experiment, we relied on the high signal bidder realizing his relative

highest signal holder always starts the auction with an initial bid of a_0 or a_1. This choice depends on his particular signal realization and is made so as to secure a bidding path leading to the lowest possible expected price (and thus the highest possible expected profit). After the initial bid, and in this equilibrium, both bidders bid the minimum allowed bids until their bidding limit is reached, i.e. until an auction round where the minimum bid is higher than one of the bidder's bidding limit.

Note that the knowledge of the signal ranking in a clock auction does not affect the equilibrium strategies. The *ex post* no regret property (Avery and Kagel (1997)) tells us that bidders should not deviate from the symmetric equilibrium given this additional information. For the low signal bidder, once his bidding limit is reached he realizes he is the low signal bidder and knows the good is certainly worth more; and yet this knowledge brings him no advantage in subsequent bidding, because given his rival's bidding strategy, winning would yield a negative payoff (Klemperer (1998)).

In the sequential equilibrium, the expected price for the auctioneer depends on the bid structure **a**. Therefore, the bid structure adopted for the experiment yields an expected price which is approximately the same as in the clock auction:

$$E\left[P^{Oral}\middle|\mathbf{a}\right] \approx 2\left(2a+b\right)/3 \tag{2}$$

To obtain this expected price, we have simulated a sequence of (one million) random draws from the uniform distribution. Then, for each pair of random signals, we have computed the high signal bidder's preferred initial bid (a_0 or a_1) and simulated the bidding path until the low signal bidder's bidding limit was reached, thus obtaining the respective final auction price[8]. The expected price above is the average of all the final auction prices in the simulation[9].

Our oral outcry auction setup is a hybrid between an auction where the auctioneer calls for bids and an auction where bidders call for bids themselves. The auctioneer calls for a starting price of at least a_0; bidders may choose to start at this price or to raise it. The key feature is that if bidders choose to raise any bid (above the minimum bid in that round), they know exactly what the effect will be on the minimum bid faced by their opponents in the next round.

2.3 Summary of the theoretical predictions

We now summarize the main theoretical predictions we would like to test in this experiment:

advantage (the expected benefit to him is greater than the expected benefit to the low signal bidder) of starting the auction, rather than ruling out ties altogether (as we will shortly see, the probability of a tie in our experiment was very small: 0.025).

[8] Under this bid structure, the expected price for the oral outcry auction is not very sensitive to the assumption that the highest signal bidder always starts the auction: we ran several simulations assuming either bidder would start the auction with some probability between 0 and 1 and for most starting probabilities the difference between the average price in the clock auction and the oral outcry auction is smaller than 1.

[9] As we will see later, the signal distribution is the uniform distribution between 0 and 100. The expected price in the clock auction is 66.67, whereas the expected price obtained by our simulations is 66.75.

Prediction 1 In the both types of auction, the winning bidder should always make a positive profit in equilibrium.

Prediction 2 The final price of the clock auction is expected to be approximately equal to that of the oral outcry auction.

Prediction 3 In the oral outcry auction, we expect the high signal bidder to start the auction: his starting bid should be either a_0 or a_1.

Prediction 4 In the oral outcry auction, after the starting bid has been submitted, we expect both bidders to raise the bid by the least amount possible, i.e. to submit the minimum bids contained in $\mathbf{a}$ in each bidding round.

3 Alternative hypotheses

The objective of this experiment was to test the theoretical predictions summarized in section 2.3. However, we need alternative models against which to compare our results. These alternative models do not produce an equilibrium in any of the two types of auction. In other words, if one of the bidders knew his opponent's bidding strategy, his best reply would *not* be to use that same strategy. However, the bidding strategies they prescribe are simple to understand and play, and may well be used as an alternative to the Nash bidding hypothesis.

3.1 Expected value

According to this bidding strategy, bidder i's strategy would be to stay active in either type of auction until the price reaches:

$$b_i^{EV} = x_i + \overline{x} \tag{3}$$

where $\overline{x}$ is the *ex ante* expected value of his opponent's signal. This strategy strikes us as a natural one, which we thought bidders might use, because it makes use of the (common knowledge) signal distribution. It results in aggressive bidding (compared to the Nash equilibrium prediction) if $x_i < \overline{x}$ and more passive bidding if $x_i > \overline{x}$. The strategy is not an equilibrium. Assume $\overline{x} > x_1 > x_2$. If $b_2^{EV} = x_2 + \overline{x} > 2x_2$ is the current price, bidder 2 will drop out. Bidder 1 would win because his bidding limit was $b_1^{EV} = x_1 + \overline{x} > b_2^{EV}$. At this price, bidder 1's payoff is $\pi_1 = x_1 + x_2 - x_2 - \overline{x} = x_1 - \overline{x} < 0$. Hence, bidder 1 would not want to win this auction at this price would deviate from this bidding strategy if he knew bidder 2 was using it.

3.2 Adjusted expected value

This bidding strategy is based on the previous, but with one difference. At the start of the auction (in both types of auction), bidders know the signal ranking and can use this information to try and make a more accurate guess of their opponent's signal. Suppose bidders are told that $x_1 > x_2$. Bidder 1 knows that X_2 is uniformly distributed. Hence, his "adjusted" expectation of his opponent's signal is

$$\widehat{x}(x_1) = (a + x_1)/2 \tag{4}$$

Thus, his bidding strategy would be to stay active in the auction until the price reaches

$$b_1^{AEV} = x_1 + \widehat{x}(x_1) \tag{5}$$

If, on the other hand, $x_1 < x_2$, his "adjusted" expectation of his opponent's signal would be

$$\widehat{x}(x_1) = (x_1 + b)/2 \tag{6}$$

Note that this bid strategy is equivalent to the expected value strategy *given the signal ranking*. This strategy results in aggressive bidding by bidder 1 (compared to the Nash equilibrium prediction) if $x_1 < x_2$ and more passive bidding if $x_1 > x_2$. Once again, the winning bidder may lose money if he follows this bidding rule.

4 A closer look at the competing theories

Each of the theories described in sections 2 (Nash), 3.1 (EV) and 3.2 (AEV) implies a different bidding strategy, and AEV suggests a different bidding strategy conditional on whether the bidder holds the highest or the lowest signal. Given the signal distribution (independent uniform between 0 and 100), each theory predicts the following bid functions:

$$b_i^{Nash} = 2x_i, \ \forall x_i \tag{7}$$

$$b_i^{EV} = 50 + x_i, \ \forall x_i \tag{8}$$

$$b_i^{AEV} = \begin{cases} \frac{3}{2}x_i, \ \text{if } x_i > x_j \\ 50 + \frac{3}{2}x_i, \ \text{if } x_i < x_j \end{cases} \tag{9}$$

Note that the AEV bid function depends not only on x_i (bidder i's signal) but also on the signal ranking. When representing the AEV bid function on a graph, we hold bidder j's signal fixed.

Figure 1 shows the 3 competing bid functions, assuming $x_j = 50$. Note that the EV bidding function is more aggressive than Nash for low signals ($x_i < 50$) but less aggressive for high signals ($x_i > 50$). AEV is somewhat similar, but its bidding function depends on the particular realization of x_j we assume. Generally, AEV is more aggressive than Nash for signals $x_i < x_j$ and less aggressive for signals $x_i > x_j$. Additionally, AEV is a more asymmetric strategy than EV: when

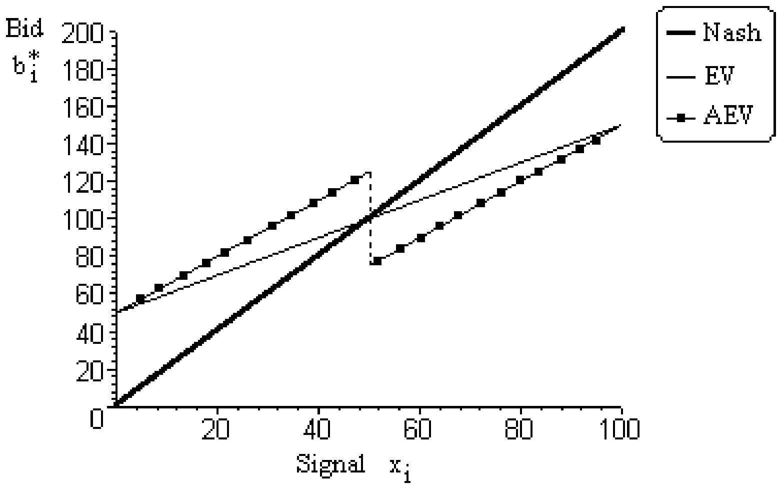

Figure 1: Bid functions for the 3 competing theories (assuming $x_j = 50$).

bidder i holds the lowest signal, he bids more aggressively under AEV than under EV; if he holds the highest signal, he bids less aggressively under AEV than under EV.

We anticipated that bidders could play a combination of these three different strategies throughout the experiment. Thus, we have simulated a sequence of auctions[10], and tested each theory against itself and against the other theories. Because the AEV bidding function depends on who holds the highest signal, we have ordered each (random) pair of signals. Then, for each pair of signals, we have assumed the bidder holding the highest signal would play AEV, EV or Nash against an opponent (with the lowest signal realization) who could also play AEV, EV or Nash. Table 1 summarizes the results of our simulation.

As theoretically predicted, Nash vs. Nash and EV vs. EV result in all auctions being won by the high signal bidder; under AEV vs. AEV, the high signal bidder only wins 44% of all auctions. When the high bidder plays Nash (the most aggressive strategy for him) and the low bidder plays AEV (also the most aggressive for him), the final price is the highest, and the profit levels the lowest. By contrast, when the highest bidder plays AEV (the least aggressive strategy for him) and the lowest bidder plays Nash (also the least aggressive strategy for him), the corresponding final price is the lowest and the profit level the highest.

Generally, the profit levels of Nash vs. Nash are very close to the maximum profit levels in the simulation. This tells us that bidders cannot improve much on the Nash profit levels; but by following other strategies, they can end up with much lower profits. Additionally, Nash is the only strategy which, when played against itself, never leaves the winner with negative profits. For instance, AEV vs. Nash implies that in about half of all auctions, the winner receives negative

[10] We have used Maple to (randomly) generate a pair of signals. For each pair (and for each combination of possible bidding strategies), we have calculated the final price and the profit per player. We have repeated this process one million times.

			High Bidder		
			AEV	EV	Nash
Low Bidder	AEV	% auctions won by high signal bidder	44.45	66.63	74.97
		Av. Price	85.17	94.43	95.82
		Av. Profit (per player)	7.41	2.78	2.08
		% of auctions with negative profits for winner	16.63	37.5	50.02
	EV	% auctions won by high signal bidder	66.63	100	87.49
		Av. Price	77.77	83.33	81.24
		Av. Profit (per player)	11.11	8.33	9.37
		% of auctions with negative profits for winner	12.49	25.01	25.01
	Nash	% auctions won by high signal bidder	75.02	87.51	100
		Av. Price	62.49	64.57	66.65
		Av. Profit (per player)	18.75	17.71	16.67
		% of auctions with negative profits for winner	0	0	0

Table 1: Simulation results for the competing theories (one million random draws)

payoffs, because they are the most aggressive strategies available to each type of bidder.

Negative profits are an extreme consequence of the winner's curse, whereby a winner overestimates the value of the good and ends up overpaying. The winner's curse occurs in common value auctions when a bidder fails to take into account a critical future event (winning the auction) in his decision of how much to bid (Charness and Levin (2005), Kagel (1995)). In these auctions, the winner tends to be whoever had a higher estimate of the good's value; failure to consider this likely overestimation in the bid function results in overbidding and below normal or even negative payoffs - the winner's curse.

These results relate to simulations using the clock auction. Simulations for the oral outcry auction yield similar results[11].

5 Experimental setup

We have given all the participants an initial balance of £5.00 (their show-up fee)[12], to prevent early losses from affecting their bidding behaviour. The participants were divided into 2 treatments: the clock auction and the oral outcry auction. Both treatments took place on the same day, but at different times, and with different subjects. In both treatments, the 14 subjects were randomly paired in such a way that they never faced the same opponent twice (and were told this beforehand). This implied that the maximum number of auctions each bidder could participate in without meeting the same opponent twice was 13. In each auction round, the 14 bidders were allocated into

[11] For the oral outcry auction, we assumed either bidder could start the auction with some probability between 0 and 1 (we ran several simulations for different probabilities). The results are not significantly different from those in Table 1. For most starting probabilities, the difference between the average price in the clock auction (see Table 1) and the oral outcry auction is smaller than 1.

[12] In the oral outcry auction, the show-up fee was initially set at £5.00 (equal to the show-up fee in the clock auction). However, a crash in the computer software after 2 auction rounds left us with no choice but to increase this to £6.00 to compensate for the lost time.

7 simultaneous auctions. With 13 auction rounds, the total number of auctions (per treatment) was 91.

At the start of each treatment, participants were told they were about to take part in an auction for a good of unknown value. They were given their signal estimates, X_1 and X_2, independently drawn from a uniform distribution on $(0, 100)$, and told that the good was worth $V = X_1 + X_2$. We have stressed that their signals were part of the value of the good, and were extremely valuable information. Any profits realized would be added to their initial balance and any loss deducted. They would be paid, in cash, at the end of the experiment an amount corresponding to their show-up fee plus their profits, net of losses incurred. Before the auction started, they were also told who held the highest signal (in the form of "You" or "Your opponent").

The participants were mostly undergraduate students from the University of York, and the experiment took place at the Centre for Experimental Economics. Each participant in the room had a computer in front of him, and verbal communication during the session was forbidden. The instructions were given before each treatment started, and participants were asked whether they had any questions. The software used to run the experiment was Z-Tree[13,14].

In the clock auction, after receiving their signals, bidders were told that the number on their screen was the current price, that it would start at 0 and then increase in fixed increments of 1. They were given 40 seconds after receiving the signals and before each auction started to think about their strategy. To quit the auction all they had to do was to strike a key on their keyboard. The auction would then stop and the price on the screen at that time would become the final price. They would then be told the signal realizations (of both bidders), the value of the good, the final price and the identity of the winner (in the form of "You" or "Your opponent"), but neither his real identity nor the current balance of any of the bidders. They were then told that they would be re-matched and a new auction round would start.

For the oral outcry auction, bidders were also given 40 seconds after receiving their signals to think about their strategy. Once the auction started, the minimum price was 0 and any of the two bidders could place an initial bid. Whoever was faster would be the initial bidder and his bid would then be communicated to their opponent. Some restrictions were in place, though: at least one bid had to be submitted for the auction to be valid. If neither bidder submitted any bid, the auction would be void[15]. The bid structure was given in the instructions, and both bidders knew the effect of their bid on their opponent's minimum bid in the following bidding round.

The bid structure adopted was $\mathbf{a} = (0, 10, 20, ..., 190, 200)$, i.e. minimum bids had a constant absolute difference between them of 10. Bidding was alternate, so no bidder could increase his own previous bid without a response from their opponent. Bidders were given 20 seconds every time it

[13] Zurich Toolbox for Readymade Economic Experiments, programmed by Urs Fischbacher.

[14] The code used to run the experiment is available upon request.

[15] This would be equivalent to a real world auction, in which the auctioneer calls for a starting price but no bidder shows any interest. In those cases, the object goes unsold.

was their turn to insert a bid. Only a valid bid (above the minimum bid) would be accepted. Before actually bidding, the active bidder at that round would be asked whether he wanted to continue in the auction; if he dropped out, the final price would be the last submitted bid, and the signal realizations, value of the good and final price would be revealed, as would the winner's identity (in a way similar to the clock auction). Neither the real identity of the bidders nor their current balance was revealed. Bidders were then re-matched and a new auction round would start.

As Cox *et al* (1982) point out, two factors may play an important role in clock auctions: (i) the delay time between successive increments and (ii) the magnitude of the increment itself. The experiment design attempted to make sure that such factors did not influence bidding behavior differently across auction types. In the clock auction, the price would increase 1 (the fixed increment) every second. In the oral outcry auction, the price would increase by at least 10 (the minimum increment) in each auction round (where active bidders had 20 seconds to insert their bid); this implies a bid increment of 2 per second. Note, however, that if all active bidders inserted their bid before the 20 seconds elapsed, the price increment per second would be smaller and closer to the clock auction. Additionally, if an active bidder chose to place a bid which was higher than the next available minimum bid (i.e. the difference between the submitted bid and the minimum bid in that auction round was at least 10), the price increment per second would also be smaller and closer to the clock auction.

6 Experimental results

6.1 Result 1 - Which theory explains the data?

Result 1 In the clock auction, the estimated bid function of a typical bidder is most likely to have been as predicted by AEV. By contrast, in the oral outcry auction, the estimated bid function of high signal bidders is most likely to have been as predicted by the symmetric Nash equilibrium, whereas the low signal bidder's bid function is most likely to have been as predicted by AEV.

Several pieces of evidence indicate that the Nash bidding functions were not used in the experiment (or, at least, not by all bidders): some winning bidders received negative profits (19% of the winning bidders in the clock auction and 23% in the oral outcry auction); not all auctions were won by the highest signal holder (low signal bidders won 43% of all clock auctions and 40% of all oral outcry auctions); the final average price in each type of auction was significantly higher than that predicted by the Nash bidding functions (22% higher in the clock auction and 31% higher in the oral outcry auction).

Tables 2 and 3 present the results of each auction divided into 3 groups: auctions where $x_1 > 50$ and $x_2 > 50$ (both realizations above the average of the distribution); auctions where $x_1 \leq 50$ and $x_2 \leq 50$; and finally auctions where $x_1 > 50$ and $x_2 \leq 50$ or $x_1 \leq 50$ and $x_2 > 50$. The final price

	No. of auctions	Auctions won by highest signal bidder	Auctions won by highest signal bidder (% of total)	Average value	Average price	Average expected price (Nash)	Diff. between price and expected price (%)	Average profit	Average expected profit (Nash)	Profit as % of expected profit
x_1>50, x_2>50	13	4	30.8	151.4	103.8	135.8	-23.6	47.6	15.5	306.4
x_1 <=50, x_2 <=50	29	8	27.6	53.1	50.9	36.0	41.3	2.2	17.1	13.1
x_1>50, x_2 <=50 OR x_1 <=50, x_2>50	49	40	81.6	97.9	73.9	50.5	46.3	24.0	47.4	50.6
TOTALS	91	52	57.1	91.3	70.8	58.1	21.9	20.4	33.2	61.6

Table 2: Clock auction summary table

	No. of auctions	Auctions won by highest signal bidder	Auctions won by highest signal bidder (% of total)	Average value	Average price	Average expected price (Nash)	Diff. between price and expected price (%)	Average profit	Average expected profit (Nash)	Profit as % of expected profit
x_1>50, x_2>50	19	6	31.6	147.6	129.2	130.5	-1.0	18.5	17.1	108.0
x_1 <=50, x_2 <=50	19	8	42.1	50.6	48.2	33.7	43.1	2.4	16.9	14.3
x_1>50, x_2 <=50 OR x_1 <=50, x_2>50	52	40	76.9	102.6	84.5	53.7	57.5	18.2	49.0	37.1
TOTALS	90	54	60.0	101.2	86.3	65.7	31.4	14.9	35.5	42.0

Table 3: Oral outcry auction summary table

in clock (oral outcry) auctions where $x_1 > 50$ and $x_2 > 50$ was 24% (1%) lower than that predicted by the Nash hypothesis. This is more consistent with the AEV or EV models than with the Nash model (see Figure 1). In the case where $x_1 \leq 50$ and $x_2 \leq 50$, the final price was 41% (43%) higher in the clock (oral outcry) auction than that expected under Nash bidding. Finally, when $x_1 > 50$ and $x_2 \leq 50$ or $x_1 \leq 50$ and $x_2 > 50$, the final price in the clock (oral outcry) auction was 46% (58%) higher than that predicted by Nash bidding. This is also consistent with the AEV or EV models.

This seems to suggest that Nash bidding is not the best explanatory theory behind the data. In order to test this conjecture, we have estimated the bid function by maximum likelihood using switching regressions (see Maddala (1983)). Given a particular auction t, and the two bidders involved, 1 and 2, we observe B_{1t} if bidder 1 loses the auction. This also means that $B_{2t} \geq B_{1t}$ because in that case bidder 2 wins the auction. Hence, we observe $\min(B_{1t}, B_{2t})$ for each auction t. We have estimated the bid functions of each type of bidder by separating them into high (regime 1) and low signal bidders (regime 2):

$$\begin{cases} B_{1t} = \alpha_0 + \alpha_1 X_{1t} + \varepsilon_{1t} \\ B_{2t} = \beta_0 + \beta_1 X_{2t} + \varepsilon_{2t} \end{cases}, \ t = 1, ..., N \tag{10}$$

where regime 1 represents data for the high signal bidder and regime 2 for the low, and the observable dependent variable is $B_t = \min(B_{1t}, B_{2t})$, $\forall t$. The error terms are assumed to be normally distributed ($\varepsilon_1 \sim N(0, \sigma_1)$ and $\varepsilon_2 \sim N(0, \sigma_2)$), but we allow the two disturbances to be correlated. This amounts to assume that they follow a bivariate normal with correlation ρ. The different theories imply slightly different restrictions in this context: AEV implies that $\alpha_0 = 0$, $\alpha_1 = 1.5$, $\beta_0 = 50$ and $\beta_1 = 1.5$; EV implies $\alpha_0 = 50$, $\alpha_1 = 1$, $\beta_0 = 50$ and $\beta_1 = 1$; and Nash implies $\alpha_0 = 0$, $\alpha_1 = 2$, $\beta_0 = 0$ and $\beta_1 = 2$. Because high and low signal bidders may be using different bidding strategies, we test all the possible combinations using the Likelihood Ratio (LR) test.

Note that in the oral outcry auction there are measurement errors in the dependent variable. When we observe B_{lt} in a particular auction t (i.e. bidder l has lost this auction), it is not necessarily true that B_{lt}. is bidder l's true reservation price (which we denote by B^*_{lt}). Bidder w (who won the auction) may have bid $B_{lt} < B^*_{lt}$, and the next possible minimum bid could have been $a > B^*_{lt}$, in which case bidder l would have dropped out and the auction finished at a price of $B_{lt} < B^*_{lt}$. Conversely, bidder l could have bid $a < B^*_{lt}$, and bidder w increased the bid to $B_{lt} > B^*_{lt}$. In this case, bidder l would drop out at a price of $B_{lt} > B^*_{lt}$. Hence, in the oral outcry auction, we observe

$$B_{lt} = B^*_{lt} + v_t \tag{11}$$

Provided we assume the error term, v_t, has a 0 mean and a variance of σ^2_v, and is independent of B^*_{lt} and of all the independent variables, we can carry out our estimations using B_{lt} (the variable with the errors). In fact, under our assumptions (and in equilibrium), v_t should be uniformly distributed between $[-10, 10]$ and have a 0 mean.

6.1.1 Clock auction

Table 4 contains the estimation results of equation (10) for the clock auction. The estimated bid functions are quite similar to those predicted by AEV ($\alpha_0 = 0$, $\alpha_1 = 1.5$, $\beta_0 = 50$ and $\beta_1 = 1.5$). Some of the data in the experiment comes close to what our earlier simulations predicted: when AEV is played by both bidders, the auction is not always won by the highest signal bidder (only 57% of all auctions were - see Table 2- compared to our simulations' prediction of 44.5% - see Table 1) and some auction winners lost money (18.7% of all auctions yielded negative profits for the winner, and our simulations predicted 16.6%).

However, the average price was lower (71) than predicted by our simulations (85), and profits were consequently higher. The estimated bid functions suggest that high signal bidders were less aggressive than predicted by AEV. This asymmetry must account for the difference in the average price: whenever low signal bidders won the auction, (on average) they must have paid less than expected under AEV; and whenever high signal bidders won the auction, (on average) they must have paid approximately what was expected under AEV. The former effect might have introduced the downward bias on the prices.

	Variable	Coefficient	Std. Error	t-ratio
High signal bidder	Constant	16.9614	14.4341	1.175
	X_{0t}	1.1696	0.2253	5.19 (**)
Low signal bidder	Constant	40.8658	4.3908	9.307 (**)
	X_{1t}	1.6556	0.2132	7.764 (**)
Rho=-.1566; Var(e_0)=651.15; Var(e_1)=188.54; N=91				

Table 4: Switching regressions results for the clock auction - High/Low signal bidders

LR~$X^2_{(4)}$		High Bidder		
		AEV	EV	Nash
Low Bidder	AEV	6.62	16.04 (**)	25.51 (**)
	EV	20.92 (**)	27.95 (**)	24.58 (**)
	Nash	108.88 (**)	90.98 (**)	101.5 (**)

Table 5: LR test results for the clock auction - High/Low signal bidders

Table 5 summarizes the results of imposing the restrictions of each theory (AEV, EV and Nash) against all others (AEV, EV and Nash), using a LR test. For each combination of strategies, 4 restrictions are imposed. This implies that the test statistic has a $\mathcal{X}^2_{(4)}$ distribution. The only strategy combination which is not rejected is AEV vs. AEV (for the high and low signal bidder respectively). This suggests that AEV is the best explanatory theory in the clock auction.

6.1.2 Oral outcry auction

For the oral outcry auction, we have also estimated the bid functions of equation (10) using the data separated into high and low signal bidders for each auction t.[16] Table 6 contains the results of the estimation. The high signal bidder seems to have bid very close to the Nash prediction($\alpha_0 = 0$, $\alpha_1 = 2$), whereas the low signal bidder seems to have followed AEV ($\beta_0 = 50$ and $\beta_1 = 1.5$).

The average price (86) and the percentage of auctions won by high signal bidders (60%) seem to agree with our simulation predictions of of 96 and 74% respectively, once we realize that high signal bidders were slightly less aggressive than predicted by Nash (see Table 6). In fact, their bid function is somewhere in between that predicted by Nash and by AEV (see Figure 1). Therefore, high signal bidders won less often than predicted by our simulations and when they lost, the winning bidder must have paid a lower price than predicted by our simulations.

[16] Our experimental software would only consider the auction valid if there was at least one bidding round. Subject 13 in round 7 was considered the starting bidder because he was the fastest to submit the starting bid; however, on the previous screen, he had clicked "Yes" on the "Do you want to drop out at this stage?" question. Hence, his bid was considered void, but because of a software limitation, his opponent could no longer bid, and both received a 0 profit in this round (the auction was void). For this reason, only 90 oral outcry auctions were used in these estimations (compared to 91 in the clock auction).

	Variable	Coefficient	Std. Error	t-ratio
High signal bidder	Constant	-2.1720	19.5964	-0.111
	X_{0t}	1.8862	0.3515	5.366 (**)
Low signal bidder	Constant	49.7207	5.5961	8.885 (**)
	X_{1t}	1.4450	0.2361	6.119 (**)
Rho=-.7945; Var(e_0)=614.39; Var(e_1)=557.85; N=90				

Table 6: Switching regressions results for the oral outcry auction - High/Low signal bidders

$LR \sim X^2_{(4)}$		High Bidder AEV	High Bidder EV	High Bidder Nash
Low Bidder	AEV	16.74 (**)	19.97 (**)	4.4
	EV	38.39 (**)	48.35 (**)	21.36 (**)
	Nash	96.77 (**)	94.61 (**)	85.21 (**)

Table 7: LR test results for the oral outcry auction - High/Low signal bidders

We have tested each theory against the others using the LR test. The results are shown on Table 7. Nash vs. AEV (for the high and low signal bidder respectively) is in fact the most likely combination of strategies in the oral outcry auction.

6.2 Result 2 - Was there any evidence of the "winner's curse"?

Result 2 There was some strong evidence of the winner's curse in both types of auction. Final prices were higher than expected (22% in the clock auction and 31% in the oral outcry auction). In the clock auction, winning bidders received 62% of expected profits under Nash bidding, whilst in the oral outcry auction winning bidders received only 42%. Not all auctions generated positive profits, as expected under Nash bidding: only 81% of clock auctions and 77% of oral outcry auctions yielded positive profits for the winner.

The winner's curse occurs if a bidder fails to incorporate in his bidding function the information conveyed to him when he wins the auction; a bidder should realize that if he wins, in all likelihood he had the highest signal estimate, which, although unbiased, may have overestimated the common value. Failure to incorporate this information in the bidding function leads to overbidding and possibly to negative profits.

As we have seen earlier, the bid functions apparently used by bidders lead to overbidding compared to the Nash prediction. In fact, from Tables 2 and 3 we can see that prices in the clock auction were 22% higher than predicted whilst in the oral outcry auction they were 31% higher.

Tables 8 and 9 contain some detailed statistics for the clock and oral outcry auctions. We can see that whenever high signal bidders won, the deviation from the expected price under Nash is

	In auctions won by:		
	High signal bidder	Low signal bidder	Total
Average price/expected price	1.43	1.01	1.22
Average profit/expected profit	0.54	0.94	0.62
% of auctions where winning bidder receives negative profits	8%	33%	19%

Table 8: Clock auction - price and profit statistics

	In auctions won by:		
	High signal bidder	Low signal bidder	Total
Average price/expected price	1.61	1.05	1.31
Average profit/expected profit	0.33	0.76	0.42
% of auctions where winning bidder receives negative profits	22%	25%	23%

Table 9: Oral outcry auction - price and profit statistics

more pronounced (43% in the clock auction and 61% in the oral outcry auction). This led to lower profits (54% of expected profits in the clock auction and 33% in the oral outcry auction). This indicates that whenever high signal bidders won, low signal bidders were bidding more aggressively than predicted by the Nash strategies. By contrast, whenever low signal bidders won, the average price was relatively close to the Nash prediction: 1% higher than predicted in the clock auction and 5% higher in the oral outcry auction. Profits, however, were lower than predicted in those cases because low signal bidders, under Nash, should never win - the expected profits refer to the profit levels which high signal bidders would receive under Nash bidding.

Overbidding led to a significant number of auctions yielding negative profits for the winner: 19% of clock auctions and 23% of oral outcry auctions. Low signal bidders were particularly affected by negative profits: 33% of all clock auctions they won yielded negative profits, as did 25% of all oral outcry auctions won.

6.3 Result 3 - Are the clock and oral outcry auctions equivalent?

Result 3 The bid function in both types of auction does not appear to be the same: we reject the hypothesis that the estimated bid function of the clock auction is equal to the estimated bid function of the oral outcry auction. However, the estimated bid function of the auction losers (who determine the final auction price) and of the low signal bidders does appear to be the

	Variable	Coefficient	Std. Error	t-ratio
High signal bidder	Constant	-4.0367	19.6720	-0.205
	X_{0t}	1.9462	0.3639	5.349 (**)
	Dt	29.3792	23.7687	1.236
	$D_t.X_{0t}$	-0.8923	0.4072	-2.192 (*)
Low signal bidder	Constant	49.7337	4.4336	11.217 (**)
	X_{1t}	1.4070	0.1749	8.047 (**)
	D_t	-7.5251	7.7316	-0.973
	$D_t.X_{1t}$	0.4619	0.3004	1.538
Rho=-.7249; Var(e_0)=705.2; Var(e_1)=444.59; N=181				
		All bidders ($X^2_{(4)}$)	High bidders ($X^2_{(2)}$)	Low bidders ($X^2_{(2)}$)
LR test on restrictions		17.55 (**)	13.39 (**)	2.74

Table 10: Switching regressions estimation results for the full dataset (High/Low signal bidders)

same for both types of auction. This provides weak support to the equivalence claim between the two types of auction.

6.3.1 Bid function equivalence

Using switching regressions with the data for each auction t separated into regime 1 for the high signal bidder and regime 2 for the low signal bidder, we have estimated the following equation:

$$\begin{cases} B_{1t} = \alpha_0 + \alpha_1 X_{1t} + \alpha_2 D_t + \alpha_3 D_t.X_{1t} + \varepsilon_{1t} \\ B_{2t} = \beta_0 + \beta_1 X_{2t} + \beta_2 D_t + \beta_3 D_t.X_{2t} + \varepsilon_{2t} \end{cases}, \ t = 1, ..., 181 \tag{12}$$

where the observed dependent variable is $B_t = \min(B_{1t}, B_{2t})$. The dummy variable D_t is equal to 1 if auction t is a clock auction, and 0 otherwise. The error terms follow the same assumptions as in Section 6.1.

If the oral outcry and clock auctions are in fact equivalent, then the coefficients α_2, α_3, β_2 and β_3 should not be significantly different from 0. Hence, our first hypothesis is $H_0 : \alpha_2 = \alpha_3 = \beta_2 = \beta_3 = 0$. Our second hypothesis is that the high signal bidder's estimated bid function (regime 1) is not significantly different across auctions: $H_0 : \alpha_2 = \alpha_3 = 0$. Our third hypothesis is that the estimated bid function of the low signal bidders is not significantly different across auctions: $H_0 : \beta_2 = \beta_3 = 0$. The LR test statistic has a $\mathcal{X}^2_{(4)}$ distribution for the first hypothesis, and a $\mathcal{X}^2_{(2)}$ distribution for the two latter.

Table 10 contains the estimation results of equation (12) and the LR tests on the 3 hypotheses. Note that the t-ratios of β_2 and β_3 (low bidder) are not significantly different from 0, providing an early hint that the low bidders bidding behaviour may have been similar across auctions. The t-ratios of α_2 and α_3 (high bidder) are inconclusive: α_3 seems to be significantly different from 0 at the 5% significance level.

The LR test on the first hypothesis (high and low signal bidders bidding in the same way across auctions) is rejected. It turns out that this difference of behaviour across auctions is explained by the high signal bidder's bid function (the LR test rejects equivalence). The LR test on the low bidder's bid function did not reject the hypothesis of equivalence.

This leads us to conclude that there are significant differences between the bid functions in the clock and oral outcry auctions. Our tests indicate that this difference originates in the high signal bidder's bid function. This is not totally surprising: the results of Section 6.1 had suggested that low signal bidders were apparently following the AEV bid function in both types of auction. The difference between their bid functions in each auction is not statistically significant. On the other hand, high signal bidders were apparently following the Nash bid function in the oral outcry auction, and the AEV bid function in the clock auction; this difference turns out to be statistically significant.

6.3.2 Auction price equivalence

In order to test whether the final auction price is different across auctions, we have used the data of the losing bidders in each auction. Note that the price at which the latter dropped out should be equal to their reservation price. Using this information as an (unbalanced) panel[17], we can isolate subject-specific disturbances, and obtain more efficient estimates than when using OLS (Ordinary Least Squares)[18]. We estimated the following equation with the random effects model (REM)[19] (174 observations):

$$B_{it} = \alpha_1 + \alpha_2 X_{it} + \alpha_3 H_{it} + \alpha_4 D_{it} + \alpha_5 D_{it}.X_{it} + \alpha_6 D_{it}.H_{it} + \varepsilon_{it},$$
$$i = 1,..,N, \ t = 1,..,T_i \qquad (13)$$

with

$$D_{it} = \begin{cases} 1, & \text{if observation comes from the clock auction} \\ 0, & \text{otherwise} \end{cases}$$

and where $N = 28$ is the number of subjects, B_{it} is the drop out price of bidder i at auction t, X_{it} is bidder i's signal observation at auction t, H_{it} is a dummy variable which takes on the

[17] A panel is unbalanced if for each subject i there are T_i observations. In our auctions, each subject did not necessarily lose the same number of auctions.

[18] Note that ignoring subject-specific disturbances may also lead to bias, through the missing individual variables.

[19] We have excluded 4 observations from our analysis: in the clock auction, we have excluded four observations of bidders who dropped out at a price below their signals (which may indicate a failure to understand the auction rules); in the oral outcry auction, we have excluded 3 observations for the same reason and one observation because the auction was void.

Variable	Coefficient	Std. Error	t-ratio
Constant	45.3001	3.6221	12.507 (**)
X_{it}	1.4496	0.0738	19.64 (**)
H_{it}	-35.9005	3.9865	-9.006 (**)
D_{it}	-7.4004	5.1602	-1.434
$D_{it}.X_{it}$	-0.0549	0.1110	-0.495
$D_{it}.H_{it}$	2.5694	5.5768	0.461
r^2=.7742; Var(u)=85.43; Var(e)=208.86; N=174			
		F(3,168)	
F-Test on restrictions		0.2189	

Table 11: REM estimation results for the full dataset

value of 1 if bidder i at auction t held the highest signal, and 0 otherwise, $\varepsilon_{it} = u_i + e_{it}$ is a combination of subject specific and auction period error terms. These errors terms are assumed to follow the standard assumptions ($u_i \sim IN\left(0, \sigma_u^2\right)$ and $e_{it} \sim IN\left(0, \sigma_e^2\right)$). The coefficients α_4, α_5 and α_6 should represent changes in the estimated bid function caused by the different type of auction. If these coefficients are significantly different from 0, we must conclude that the estimated bid function of the losing bidders in the clock auction is significantly different from that of the oral outcry auction, which would indicate that the final auction prices were statistically different. Hence, our test hypothesis is $H_0 : \alpha_4 = \alpha_5 = \alpha_6 = 0$. We can use a standard F-test to test the validity of the joint restrictions, as well as the individual t-ratios of the regression. Table 11 shows the results.

Firstly, each coefficient (α_4, α_5 and α_6) is not statistically different from 0. Secondly, the F-test statistic did not reject the hypothesis that the coefficients are simultaneously equal to 0. Hence, we must conclude that the estimated bid function of the losing bidders in the clock auction, which effectively sets the auction price, is not statistically different from the oral outcry auction. This lends some support to the equivalence between these two types of auction.

6.4 Result 4 - Was the decision to start the oral outcry auction strategic?

Result 4 In the oral outcry auction, the high signal bidder did not always start the auction as expected.

Table 12 contains a summary of the data, both between groups of bidders and over time. It can be seen that the bidder holding the high signal started the auction 51% of the time. At a first glance, this seems to be consistent with some sort of randomization, and not strategic behaviour. This figure does not change much between groups of bidders, or even over time (one would expect

		Number of Auctions	High bidder starts the auction	In %	Starting bidder wins the auction	In %
Data between Groups	$x_1>50$, $x_2>50$	21	12	57	9	43
	$x_1<50$, $x_2<50$	19	8	42	9	47
	$x_1>50$, $x_2<50$ OR $x_1<50$, $x_2>50$	50	26	52	24	48
Data over time	Sessions 1-4	28	14	50	11	39
	Sessions 5-8	27	14	52	15	56
	Sessions 9-13	35	18	51	16	46
TOTAL		90	46	51	42	47

Table 12: Oral outcry auction summary table

more experienced bidders to realize the advantage of starting the auction). What this seems to suggest is one of the following: (i) high signal bidders did not realize the advantage of starting the auction, given the information on the bid structure, and hence randomized in order to decide; or (ii) high signal bidders were following some other strategy in which the choice of starting/not starting the auction was not relevant.

In order to understand which is more likely to be true, bear in mind that the decision of starting the auction is particularly advantageous to the high signal bidder if and only if he does win the auction. In the equilibrium we are testing, the high signal bidder is always expected to win. But given that high signal bidders seemed to be following Nash whereas low signal bidders seemed to be following AEV (see section 6.1), the high signal bidder is only expected to win 75% of the auctions (see our simulation results in Table 1). Under the alternative assumption that high signal bidders were playing AEV some times, they should win around 44% of the auctions.

In the oral outcry auction, 60% of the auctions were won by the high signal bidder (see Table 3). Note, also, that this value is exactly half way through the probability of winning when he is playing Nash (75%) and when he is playing AEV (44%). With the exception of the first group of bidders (with signals $x_1 > 50$ and $x_2 > 50$, in which case the high signal bidder started the auction 57% of the time), the decision to start the auction seems to have been the result of randomization rather than strategic thinking. In no other group or in fact over time did the percentage of auctions started by the high signal bidder come close to 60%.

6.5 Result 5 - Was there evidence of jump bidding in the oral outcry auction?

Result 5 In the oral outcry auction, the bidding increments from one round to the next were substantially higher than expected, particularly in the earlier rounds.

In the equilibrium we are testing, we expected the high signal bidder to manipulate his starting bid in a way which maximised his expected utility, i.e. a choice of the bidding path which led to

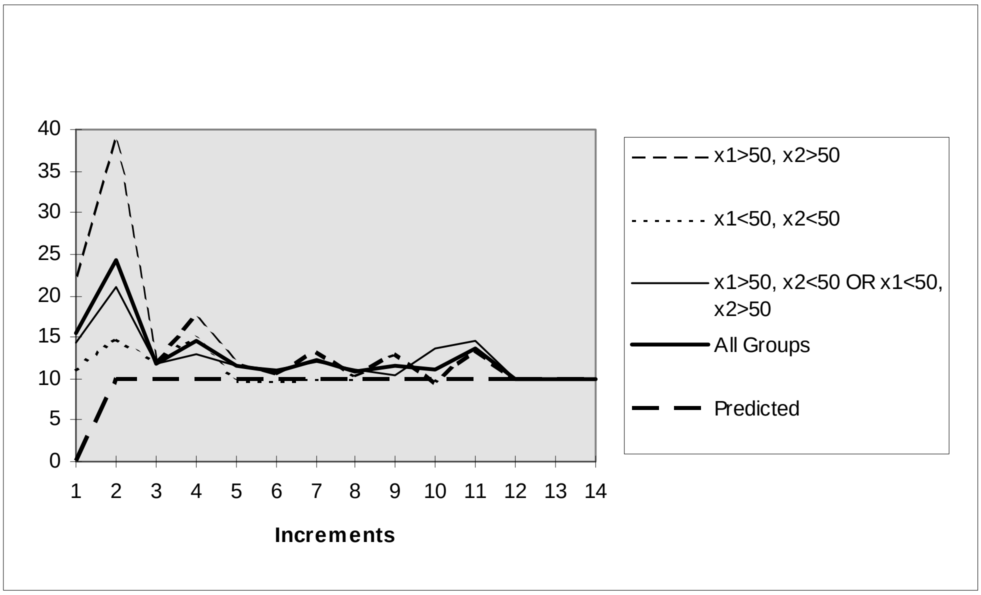

Figure 2: Oral outcry auction bidding increments (between groups)

the lowest expected price. Hence, in that equilibrium, he should either start with a bid of 0 or with a bid of 10, and after this initial bid, both bidders should raise the bid by the minimum amount possible until the current bid exceeded their reservation prices. Consequently, if that equilibrium was being played, we would expect an average first bid of at least 0 and at most 10; subsequent increments were expected to be at the minimum (10).

The data seems to contradict this: Figure 2 shows the average increment from one bidding round to the next. The first bidding increment is the difference between the first submitted bid and the minimum bid allowed (0); the second bidding increment is the difference between the second bid submitted and the first; and so on. It can be seen from Figure 2 that the first two bidding increments are significantly higher than expected for all bidder groups. It can also be seen that there is a significant correlation between the signals and the bidding increments (pairs of bidders with signals $x_i < 50$ jump bid less than pairs of bidders with at least one signal $x_i > 50$, who in turn jump bid less than pairs of bidders with signals $x_i > 50$). The average bidding increments tend to approach our expectation in later bidding rounds (for all bidder groups).

Figure 3 shows the bidding increments over time. Again, one would expect that over time bidders approached our theoretical prediction. The data seems to contradict this: there seem to be no signs of learning or equilibrium bidding in later auctions. What we do see are jump bids, in particular in the first two rounds, then followed by slightly higher than expected increments. Such bidding behaviour is inconsistent with all the bidding theories we have come across.

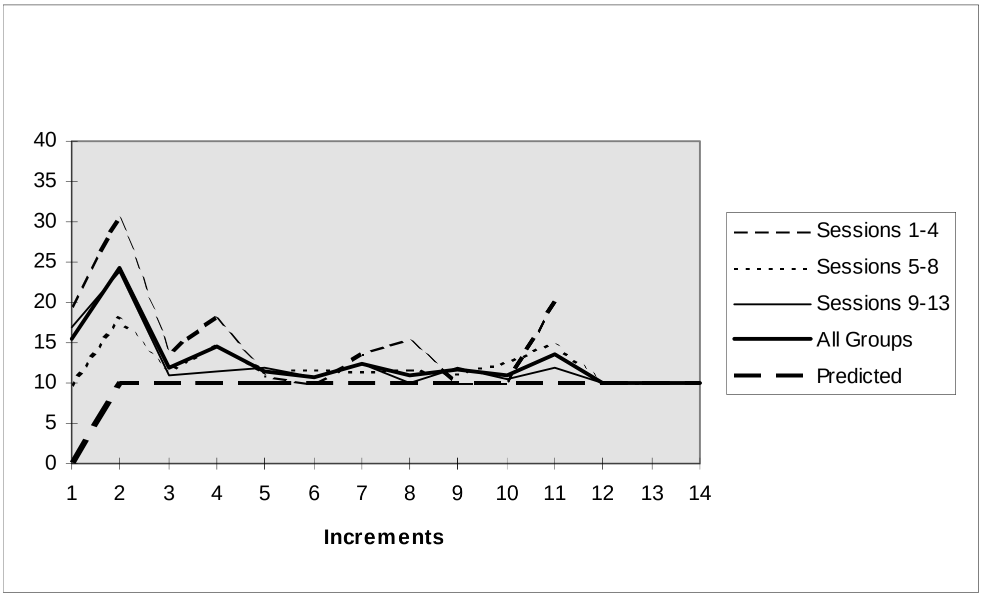

Figure 3: Oral outcry auction bidding increments (over time)

7 Discussion

The starting point of this paper was the claim that the clock auction is a good representation of an oral outcry auction. In this experimental test of equivalence between these auction types, we have reached the main conclusion that they are *not* strategically equivalent. The theory predicts that all bidders in both auctions should follow the (same) Nash bidding function; in reality, not only did most players *not* play Nash, but they also diverged from the theory in *different ways*[20]. In the context of this comparison, we must conclude that the clock auction is *not* a good representation of an oral outcry auction.

If both auctions were indeed strategically equivalent, the expected price in each of them should be the same. In the experiment, the final price in each type of auction was higher than predicted by Nash bidding (22% in the clock and 31% in the oral outcry auctions) but we have shown that losing bidders in each type of auction departed from Nash bidding *in the same direction*: the difference between the losing bidders' bid function in the clock and oral outcry auctions is not statistically significant. Hence, we must conclude that the final prices in both auctions are not significantly different from one another.

We must conclude that Nash bidding is simply not observed in real auctions (or, at least, not in experimental auctions, or by all bidders). Avery and Kagel (1997) reached the same conclusion, as

[20] In the clock auction, AEV was the most likely bidding strategy played by all bidders (high and low signal bidders); in the oral outcry auction, AEV was the most likely strategy used by low signal bidders, whereas Nash was the most likely strategy used by high signal bidders.

did Kagel and Levin (1986) [21] and Levin, Kagel and Richard (1996) [22] in different experiments. Is this an indication that symmetric Nash bidding is nonsensical in real auctions? Or is it an indication that other factors may play an important role in these auctions (e.g. asymmetric bidding strategies, irrational bidding, etc.)? Maybe both.

Our experiment is probably the first so far where Nash bidding is clearly not rejected for a subset of bidders[23]. However, note that this bidding behaviour appeared in the oral outcry auction, *not* in the clock auction. From the results of our experiment, we conjecture that Nash bidding is more likely to be played in "real" English auctions. And because the only difference between the clock and oral outcry auctions was the bid structure and endogenous bidding, we conjecture that this is the missing feature in most experimental tests of English auctions. And because most real world English auctions have those two features, it does not come as a surprise that this type of auction is so popular when compared to clock auctions.

Further (experimental) research will eventually prove our conjecture right or wrong. In particular, one extension of our work is worth pursuing. It would be extremely interesting to test our model (clock and oral outcry auctions) without revealing the ranking of signals. Such an experiment, and especially the clock auction results, would be directly comparable to the other experiments we have mentioned (Levin *et al* (1996) and Avery and Kagel (1997)). And we could compare the oral outcry auction results to those experiments, which have repeatedly reported the "winner's curse" and non-Nash bidding. If, under that model, Nash bidding does emerge, we can unambiguously conclude that the oral outcry auction gives rise to "rational" bidding.

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[21] They test experimentally a common value first-price sealed bid auction with more than 2 bidders. Nash bidding is rejected, and the "winner's curse" seems to be present.

[22] They have run a common value experiment of clock auctions with more than 2 bidders (with publicly revealed drop out prices), very similar to Milgrom and Weber's (1982) model. Symmetric Nash bidding seems to be rejected for the vast majority of bidders. A signal averaging rule (resembling our AEV hypothesis) seems to be the best explanatory theory.

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