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EXPERIMENTAL EVIDENCE ON ENGLISH AUCTIONS: ORAL OUTCRY VERSUS 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 oral 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. Although interesting and encouraging, the results clearly indicate that further research is necessary, particularly with a modified experimental design.

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I. INTRODUCTION

One of the most remarkable results in auction theory, the revenue equivalence theorem, first stated by Vickrey (1961), has been the object

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of substantial research over 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 auction, Dutch or descending bid auction, first-price and second-price sealed bid auctions) 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 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, which is continuously increasing, is posted on a screen. 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 by Levin *et al.* (1996) and Avery and Kagel (1997). But real world English auctions usually involve bidders stopping to bid and then restarting again later on, as well as 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; Cheng, 2004; Isaac *et al.*, 2007; David *et al.*, 2007; Gonçalves, 2008a) have shown theoretically that 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 that could emerge in independent private value English auctions.

[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, 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 (Milgrom and Weber, 1982).

In a common value setup, we test experimentally the clock auction and an oral outcry auction with discrete and endogenous bidding in a model based on the ‘wallet game’ (Klemperer (1998), which has been tested experimentally by Avery and Kagel (1997)). In such common value settings, a typical result 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 (see Kagel, 1995; Avery and Kagel, 1997). The purposes of this paper are twofold: (i) to test experimentally whether allowing for discrete bidding leads to significantly different outcomes 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 in the literature. Recent research has analysed the impact of such an assumption on the revenue equivalence theorem. In an independent private values auction, Fang and Morris (2006) assume that each bidder observes his private valuation and a noisy and private signal about his opponent’s valuation. Revenue equivalence breaks down, although there is no general price ranking between the first-price and the second-price auction. Also in an independent private value auction, Kim and Che (2004) assume that subgroups of bidders perfectly observe their own valuations. 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) suggests an extension to this type of model where each bidder’s noisy signals about their opponent’s valuations are common knowledge (instead of private information as in Fang and Morris, 2006). 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. In highway construction procurement auctions, a bidder’s capacity utilization can be a determinant of their costs (Jofre-Bonet and Pesendorfer, 2003); hence, rival firms may try to infer a bidder’s costs based on their capacity utilization levels (Fang and Morris, 2006). As we will see, our assumption that the signal ranking is common knowledge introduces in the experiments a particular form of Fang and Morris’s (2006) private and noisy signals about opponents’ signal realizations.

Gonçalves (2008a) 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, an equilibrium exists in which the high signal bidder always prefers to start the auction, and will choose his starting bid in a payoff maximizing way: he starts with either the lowest possible bid or the second lowest possible bid, thus choosing the bidding path that favours him the most. This result is similar in its nature to Avery (1998). From the starting bid onwards, 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). Knowledge of the signal ranking in a clock auction should not affect each bidder's equilibrium strategies: Klemperer (1998) and Gonçalves (2008b) highlight that once the symmetric equilibrium bidding limit is reached, the low signal bidder realizes that he is indeed 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 (EV) of their opponent's signal and then used it to compute their bidding limit. 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,[4] we also found significant overbidding compared to the Nash prediction and a strong presence of the winner's curse. Such overbidding led to 19 percent of bidders in the clock auction and 23 percent in the oral outcry auction receiving negative profits.

Although encouraging and interesting, our results are not conclusive and clearly indicate that further research is necessary, ideally with a slightly modified experimental design.[5] Briefly, the setup used in our experiment should (i) be extended with a new type of clock auction treatment which mimics more closely the bid structure of the oral outcry auction, (ii) include a larger number of treatments and subjects and

[4] See Kagel (1995).

[5] We thank an anonymous referee for pointing out and discussing in detail the need for further research with a modified experimental design.

(iii) abandon the ‘perfect stranger’ design which has the potential to introduce dependencies in the observations within each treatment.

We leave the discussion of our findings and a more thorough discussion of future research to Section VII. Section II presents the theoretical models and discusses their implications; Sections III and IV discuss some alternative bidding theories; Section V describes the experimental details and discusses its shortcomings; finally, Section VI contains an extensive analysis of the results.

II. 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 $[a, b]$.

II.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] None of the players has any 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, and in order 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, as Avery and Kagel (1997) suggest, there is no *ex post* regret in this equilibrium, in the sense that even after learning the other bidder’s signal, no bidder will regret having bid how they actually did. Another important property is that profits are always positive for the winner,

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

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 (Avery and Kagel, 1997, Theorem 2.5):

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

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

II.2 The oral outcry auction

The oral outcry auction is based on Gonçalves (2008a). We assume the auctioneer sets discrete bid levels (bid structure) $A = \{a_0, a_1, \ldots, a_L\}$, with $a_L > \cdots > a_1 > a_0$, L finite and $a_L \geq v(b, b)$, which are known to both bidders. Any of the two bidders can start the auction with an initial bid. Bidding is alternate, which implies that no bidder can increase his own previous bid. In each auction round, bidders are free to submit any bid, as long as it is above the minimum allowed bid in that round. Additionally, bidders know the impact that their bid will have on their opponent's minimum allowed bid in the next bidding round, which will be the lowest bid level in A above that round's bid. For example, if at a given bidding round a bidder places a bid of $y \in [a_k, a_{k+1})$, then his opponent will face a minimum bid of a_{k+1} in the next bidding round.[7]

If the signal ranking (i.e., the identity of the bidder holding the highest signal) is also common knowledge, Gonçalves (2008a) shows that the bid functions $b_i^*(x_i) = v(x_i, x_i) = 2x_i,\ i = 1, 2$, are a Bayesian equilibrium of this auction, provided there are no ties.[8] In this equilibrium, the high signal bidder 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 highest possible expected payoff. 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.

[7] The online auction site QXL, which closed down in May 2008, had very similar bidding rules.

[8] A tie occurs when signal realizations are such that the symmetric equilibrium bidding limits belong to the same interval within the bid structure A, i.e., when $v(x_i, x_i) \in [a_k, a_{k+1}),\ \forall i$, 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 that 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 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).

Avery (1998) obtains a jump bidding equilibrium in which a jump bid is a signalling mechanism for a particular bidder's high signal realization. Gonçalves' (2008a) model allows for jump bidding to occur, but because the signal ranking is common knowledge, there is no motivation to jump bid as a means of communicating a particularly high signal realization.[9]

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 oral outcry auction, Gonçalves (2008a) also shows that the knowledge of the signal ranking does not affect bidders' bidding limits. In fact, knowledge of the signal ranking is a form of noisy and private information about an opponent's signal, as suggested by Fang and Morris (2006). For example, if bidder 1, with signal x_1, knows he is the high signal bidder, then he also knows that $X_2 < x_1$. This is a noisy signal about bidder 2's private signal realization, because it tells bidder 1 that his opponent's signal belongs to the interval $[a, x_1)$, which is narrower than the support of the signal distribution $[a, b]$, but is still a noisy signal about his opponent's private signal. Moreover, these noisy signals are also private: even if bidder 2 knows that he is the low signal bidder, he does not know what bidder 1's noisy signal is because that signal depends on bidder 1's private information (his own signal realization, x_1). Fang and Morris (2006), in an independent private values model, show that such noisy signals about opponents do not affect bidding strategies in a second-price sealed bid auction (although they do affect bidding strategies in first-price sealed bid auctions). The *ex post* no regret property of the symmetric equilibrium strategies in clock auctions (see Avery and Kagel, 1997) indicates that such a result can be extended to common value clock auctions; Gonçalves (2008a) suggests that result would also hold in discrete bidding oral outcry common value auctions.

In equilibrium, the expected price for the auctioneer in the oral outcry auction depends on the bid levels contained in A. Therefore, the bid structure adopted for the experiment yields an expected price, which is approximately the same as in the clock auction:

$$E[P^{Oral} \mid A] \approx \frac{2(2a + b)}{3} \tag{2}$$

[9] We thank an anonymous referee for this observation.

To obtain this expected price, we have simulated a sequence of (1 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.[10] We have chosen A so that the average of all the final auction prices in the simulation (Equation (2)) was approximately the same as in the clock auction (Equation (1)).

II.3 Summary of the theoretical predictions

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

Prediction 1: In both types of auction, fully rational bidders should play the symmetric Nash equilibrium strategies.

Prediction 2: In both types of auction, the winning bidder should always make a positive profit in equilibrium.

Prediction 3: Bidding behaviour in the clock auction is expected to be similar to that in the oral outcry auction.

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 A in each bidding round.

III. ALTERNATIVE HYPOTHESES

The objective of this experiment was to test the theoretical predictions summarized in Section II.3. In this section, we outline alternative explanatory theories that may explain bidding behaviour in the experiment.

III.1 Expected value

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

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

[10] Under this bid structure, the expected price for the oral outcry auction is not very sensitive to the assumption that the high 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 lower than 1.

where $\bar{x} = (a + b)/2$ 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 $x_i < \bar{x}$ and more passive bidding if $x_i > \bar{x}$. The strategy is not an equilibrium. Assume $\bar{x} > x_1 > x_2$. If $b_2^{EV} = x_2 + \bar{x} > 2x_2$ is the current price, bidder 2 will drop out. Bidder 1 would win because his bidding limit was $b_1^{EV} = x_1 + \bar{x} > b_2^{EV}$. At this price, bidder 1's payoff is $\pi_1 = x_1 + x_2 - x_2 - \bar{x} = x_1 - \bar{x} < 0$. Hence, bidder 1 would not want to win this auction at this price and should deviate from this bidding strategy if he knew bidder 2 was using it.

III.2 Adjusted expected value

The adjusted expected value (AEV) bidding strategy is based on the previous one, 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

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

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

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

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

$$\hat{x}(x_1) = \frac{x_1 + b}{2} \tag{6}$$

Note that this bidding 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.

III.3 Best response to adjusted expected value

One further possibility of bidding behaviour is based on Milgrom's (1981) multiple asymmetric equilibria in common value English auctions.[11] Let $h(.)$ be an increasing and surjective function.[12] The following

[11] We thank an anonymous referee for making this suggestion.
[12] A function is surjective if its target coincides with its range.

strategies are equilibrium bid functions of the English auction (Milgrom, 1981):

$$\begin{aligned} b_1(x_1) &= v(x_1, h(x_1)) = x_1 + h(x_1) \\ b_2(x_2) &= v(h^{-1}(x_2), x_2) = h^{-1}(x_2) + x_2 \end{aligned} \quad (7)$$

Each asymmetric equilibrium departs from the symmetric equilibrium in the following way: if $h(x_1) > x_1,\ \forall x_1$, then bidder 1 will be playing a strategy which is more aggressive than the symmetric Nash equilibrium strategy whereas bidder 2 will be playing a less aggressive strategy than in the symmetric Nash equilibrium because $b_2(x_2) = h^{-1}(x_2) + x_2 < 2x_2$.[13,14]

Suppose bidders are told that $x_2 > x_1$, i.e., bidder 2 holds the highest signal. Also suppose that bidder 2 believes his opponent is behaving according to AEV. In that case, bidder 2 believes his opponent's bid function is $b_1(x_1) = \frac{3}{2}x_1 + \frac{1}{2}b$. Relating this bid function with Equation (7), we can see that $h(x_1) = \frac{1}{2}x_1 + \frac{1}{2}b$. Note that if bidder 2 believes bidder 1 is behaving in this way, then if he wins at a price p, he will find that $p = \frac{3}{2}x_1 + \frac{1}{2}b$ and hence infer that $x_1 = \frac{2}{3}p - \frac{1}{3}b$. His payoff will then be given by $\pi_2 = v(x_1, x_2) - p = \frac{2}{3}p - \frac{1}{3}b + x_2 - p$, which will only be positive when $p \leq 3x_2 - b$. Thus, bidder 2's best response to the fact that bidder 1 is bidding according to AEV is $b_2(x_2) = 3x_2 - b$. We could have obtained this bid function directly from Equation (7) because $h^{-1}(x_2) = 2x_2 - b$. Thus, if bidder 2 (high signal bidder) believes his opponent is following AEV, the following asymmetric equilibrium could be played: $b_1(x_1) = \frac{3}{2}x_1 + \frac{1}{2}b$ and $b_2(x_2) = 3x_2 - b$.

We can also extend this line of thought by looking at the possibility that it is the low signal bidder, bidder 1, who believes his opponent is bidding according to AEV. In that case, bidder 1 believes that bidder 2's bid function is given by $b_2(x_2) = \frac{3}{2}x_2 + \frac{1}{2}a$. Following Milgrom's (1981) equilibrium bid functions (Equation (7)), his best response is $b_1(x_1) = 3x_1 - a$.[15] Thus, if bidder 1 believes his opponent is following AEV, the following asymmetric equilibrium could be played: $b_1(x_1) = 3x_1 - a$ and $b_2(x_2) = \frac{3}{2}x_2 + \frac{1}{2}a$.

III.4 Cursed equilibrium

The concept of cursed equilibrium, put forward by Eyster and Rabin (2005), is another possible explanatory theory for bidding behaviour in our experiment.[16] The concept of cursed equilibrium relies on the

[13] Note that if $h(x) > x,\ \forall x$, this implies that $x > h^{-1}(x),\ \forall x$.
[14] For more details on asymmetric equilibria, see Milgrom (1981), Bikhchandani and Riley (1991) or Klemperer (1998).
[15] In this case, $h^{-1}(x_2) = \frac{1}{2}(a + x_2)$ and hence $h(x_1) = 2x_1 - a$.
[16] We thank anonymous referees for suggesting this as a possible explanatory theory.

possibility that bidders, with probability $\mathcal{X} \in [0, 1]$, behave as if their opponent's bid did not convey valuable information. In general, Eyster and Rabin's (2005) cursed equilibrium is related to an underappreciation of the extent to which other player's actions are correlated with their information. In the wallet game, the bid functions in a $\mathcal{X}$-cursed equilibrium are given by[17]

$$\begin{aligned} b_i(x_i) &= (1-\mathcal{X})v(x_i, x_i) + \mathcal{X}E[v(x_i, x_j) \mid X_i = x_i] \\ &= (1-\mathcal{X})2x_i + \mathcal{X}(x_i + \bar{x}) \\ &= (2-\mathcal{X})x_i + \mathcal{X}\bar{x} \end{aligned} \tag{8}$$

where $\bar{x} = (a+b)/2$ is the average of the signal distribution. When $\mathcal{X} = 0$, bidders are not cursed, i.e., they behave in a fully rational way, understanding that their opponent's bid function conveys valuable private information. In that case, Equation (8) shows that the equilibrium bid function is the symmetric Nash bid function. However, with positive probability $\mathcal{X}$ bidder i bids as if there was no informational content in winning and his bid function is merely the sum of his own private signal x_i and the expected value of his opponent's signal. In a fully cursed equilibrium ($\mathcal{X} = 1$), bid functions are similar to the EV hypothesis presented above. Although the EV bid functions are not a Nash equilibrium, they are a fully cursed equilibrium.

The $\mathcal{X}$-cursed equilibrium bid functions share some of the characteristics of the symmetric Nash bid functions, namely the *ex post* no regret property. Suppose $x_1 > x_2$. In the $\mathcal{X}$-virtual game,[18] bidder 1's payoff when he wins is

$$\begin{aligned} \pi_1 &= (1-\mathcal{X})(x_1 + x_2) + \mathcal{X}(x_1 + \bar{x}) - (2-\mathcal{X})x_2 - \mathcal{X}\bar{x} \\ &= x_1 - x_2 > 0 \end{aligned} \tag{9}$$

Thus, bidder 1 guarantees a positive payoff in a $\mathcal{X}$-cursed equilibrium. After learning the results of the auction, bidder 1 would not want to change his bid: raising it would have brought him no advantage and lowering it would not affect the price, which is set by his opponent. Similarly, bidder 2 would not benefit from increasing his bid, because the lowest price at which he could win the auction is $b_1(x_1) = (2-\mathcal{X})x_1 - \mathcal{X}\bar{x}$, which would leave him with a negative payoff equal to $x_2 - x_1 < 0$. In this respect, letting bidders know in advance who holds the highest and lowest signal realization does not affect their bidding behaviour in a $\mathcal{X}$-cursed equilibrium: this is information that bidders learn in equilibrium anyway.

[17] For more details, see Eyster and Rabin (2005).

[18] The $\mathcal{X}$-virtual game is the Bayesian game where each bidder fails to perceive with probability $\mathcal{X}$ that his opponent's actions are correlated with their private information. See Eyster and Rabin (2005) for more details.

IV. A CLOSER LOOK AT THE COMPETING THEORIES

Each of the theories described in Sections II (Nash), III.1 (EV), III.2 (AEV), III.3 (best response to AEV, which we will designate as 'BR to AEV') and III.4 (cursed equilibrium) 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 assumed for the experiment (independent uniform between 0 and 100), each theory predicts the following bid functions:

$$b_i^{\text{Nash}} = 2x_i \quad \forall x_i \tag{10}$$

$$b_i^{\text{EV}} = 50 + x_i \quad \forall x_i \tag{11}$$

$$b_i^{\text{AEV}} = \begin{cases} \frac{3}{2}x_i & \text{if } x_i > x_j \\ 50 + \frac{3}{2}x_i & \text{if } x_i < x_j \end{cases} \tag{12}$$

$$b_i^{\text{BR to AEV}} = \begin{cases} 3x_i - 100 & \text{if } x_i > x_j \\ 3x_i & \text{if } x_i < x_j \end{cases} \tag{13}$$

$$b_i^{\text{Cursed}} = (2 - \mathcal{X})x_i + 50\mathcal{X} \tag{14}$$

Figure 1 shows four of the competing bid functions, assuming $x_j = 50$.[19] Note that the EV bidding function is more aggressive than Nash for low signals ($x_i < 50$) but less aggressive for high signals ($x_i > 50$). The cursed equilibrium bid function (which is not represented in Figure 1) depends on $\mathcal{X}$: when $\mathcal{X} = 0$, it coincides with the Nash bid function; when $\mathcal{X} = 1$ it coincides with the EV bid function; for all other values, the cursed equilibrium bid function is a straight line with a higher intercept than the Nash bid function and a lower slope. AEV is somewhat similar to EV, but its bid 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 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. Finally, when the high signal bidder is playing BR to AEV, his bid function has a higher slope than under Nash but a lower intercept and is thus less aggressive than Nash for all signal realizations and less

[19] 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.

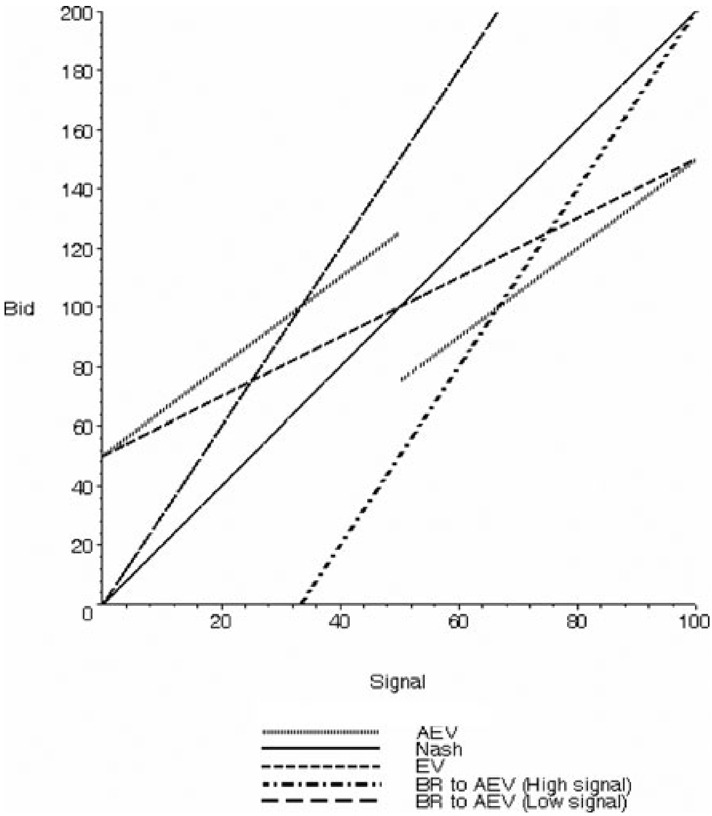

Fig. 1. Nash, EV, AEV and BR to AEV bid functions (assuming $x_j = 50$).

aggressive than AEV for signal realizations lower than $200/3$. When it is the low signal bidder who is playing BR to AEV, his bid function is always more aggressive than Nash and more aggressive than AEV for signal realizations above $100/3$.

We anticipated that bidders could play a combination of different strategies throughout the experiment. Thus, we have simulated a sequence of auctions,[20] and tested three of the theories (Nash, EV and AEV) against themselves and against the other theories.[21] Because the AEV bid function depends on who holds the highest signal, we have ordered each (random) pair of signals. Then, for each pair of signals,

[20] 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 1 million times.

[21] Note that the bid function associated with the cursed equilibrium theory is a hybrid between the Nash and the EV bid functions. For this reason, we have chosen to present only the simulation results for Nash and EV.

TABLE 1
Simulation results for competing theories (1 million random draws)

		High bidder		
		AEV	*EV*	*Nash*
Low bidder				
AEV	% auctions won by high signal bidder	44.45	66.63	74.97
	Average price	85.17	94.43	95.82
	Average 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
	Average price	77.77	83.33	81.24
	Average 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
	Average price	62.49	64.57	66.65
	Average profit (per player)	18.75	17.71	16.67
	% of auctions with negative profits for winner	0	0	0

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 for the clock auction. Simulations for the oral outcry auction yield similar results.[22]

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 percent of all auctions. When the high signal bidder plays Nash (the most aggressive strategy for him) and the low signal 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 high signal bidder plays AEV (the least aggressive strategy for him) and the low signal 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

[22] 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 lower than 1.

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 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 (Kagel, 1995; Charness and Levin, 2009). 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.

V. EXPERIMENTAL SETUP

V.1 Experimental setup

We have given all the participants an initial balance of £5.00 (their show-up fee),[23] to prevent early losses from affecting their bidding behaviour. The participants were divided into two 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 ('perfect stranger' design). 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 seven 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

[23] 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 two auction rounds left us with no choice but to increase this to £6.00 to compensate for the lost time.

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.[24,25]

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 s 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 s 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 his 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.[26] 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 $A = (0, 10, 20, \ldots, 190, 200)$, 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 his opponent. Bidders were given 20 s every time it 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,

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

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

[26] 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.

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.

V.2 Experimental design shortcomings

The setup used in our experiment has some shortcomings, which we now discuss in detail.[27] First, the two auction types – clock and oral outcry – are different in more than one way. In particular, not only do the dynamics of the auction change, but the increment size changes as well (equal to one in the clock auction and equal to ten in the oral outcry auction). Cox *et al.* (1982) point out two factors that may play an important role in clock auctions:[28] (i) the delay time between successive increments and (ii) the magnitude of the increment itself. The experimental design attempted to roughly equalize the increment per second between the two auction types. In the clock auction, the price would increase by 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 s to insert their bid); this implies a bid increment of 2 per second. Note, however, that if the active bidder inserted his bid before the 20 s 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., if 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. Therefore, our experimental design tried to ensure that time spent while bidding was approximately similar in both auctions, because as Isaac *et al.* (2005, 2007) note, impatience may be a relevant factor when choosing bidding strategies in discrete bidding oral outcry auctions.

However, it is clear that the strategy space in the clock auction is different from the strategy space in the oral outcry auction, because the minimum bidding increment in the latter (ten) is larger than the minimum bidding increment in the former (one) and this difference may affect bidding behaviour. In particular, if it is believed that the time delay between successive increments is important, then it would still be possible to roughly equalize the increment per second between the two auction types by introducing a longer delay in the clock auction's price increases under a minimum bidding increment of ten.

[27] We thank an anonymous referee for pointing out and discussing in detail the shortcomings of our experimental design.

[28] Cox *et al.* (1982) have referred to these factors when analysing behaviour in Dutch or decreasing bid auctions.

Second, each treatment has a relatively low number of observations (14 subjects and a total of 91 auctions in each treatment) and because of the 'perfect stranger' design, at the end of each treatment, each bidder will have interacted with each and every other bidder. Thus, the assumption of independence in the observations may have been compromised and this may be problematic when estimating the bid functions. The 'perfect stranger' design is a good choice to avoid super-game effects, such as any efforts by bidders to create reputations. In Avery and Kagel's (1997) experiment, subjects were told that they would be matched randomly according to a plan, which minimized the chances of repeated interactions. The matching plan itself, unknown to the bidders, paired the same two bidders at most three times in each session. Kagel *et al.* (1995) faced a similar problem because subsets of a common group of only 17 subjects participated in various experimental sessions. Whilst we have tested for and rejected the hypothesis of serial correlation in the data, an experimental design which did not rely on the 'perfect stranger' design would have been more appropriate.

VI. EXPERIMENTAL RESULTS

VI.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 percent of the winning bidders in the clock auction and 23 percent in the oral outcry auction); not all auctions were won by the high signal bidder (low signal bidders won 43 percent of all clock auctions and 40 percent of all oral outcry auctions); the final average price in each type of auction was significantly higher than predicted by the Nash bidding functions (22 percent higher in the clock auction and 31 percent higher in the oral outcry auction).

Tables 2 and 3 present the results of each auction divided into three groups: auctions where $x_i > 50,\ \forall i$ (both signal realizations above the average of the distribution); auctions where $x_i \leq 50,\ \forall i$ (both signal realizations below the average of the distribution); and finally auctions where $x_i > 50$ and $x_j \leq 50,\ i \neq j$ (one signal realization above the

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*
$x_i > 50, \forall i$	13	4	30.8	151.4	103.8	135.8	−23.6	47.6	15.5	306.4
$x_i \leq 50, \forall i$	29	8	27.6	53.1	50.9	36.0	41.3	2.2	17.1	13.1
$x_i \leq 50, x_j > 50$ $i \neq j$	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 3

Oral outcry 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*
$x_i > 50, \forall i$	19	6	31.6	147.6	129.2	130.5	−1.0	18.5	17.1	108.0
$x_i \leq 50, \forall i$	19	8	42.1	50.6	48.2	33.7	43.1	2.4	16.9	14.3
$x_i \leq 50, x_j > 50$ $i \neq j$	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

average and the other below).[29] The final price in clock (oral outcry) auctions where $x_i > 50,\ \forall i$, was 24 percent (1 percent) lower than 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 $x_i \leq 50,\ \forall i$, the final price was 41 percent (43 percent) higher in the clock (oral outcry) auction than expected under Nash bidding. Finally, when $x_i > 50$ and $x_j \leq 50,\ i \neq j$, the final price in the clock (oral outcry) auction was 46 percent (58 percent) higher than predicted by Nash bidding. This is also consistent with the AEV or EV models.

It is interesting to compare our results with those of Avery and Kagel (1997), especially our clock auction results.[30] There are two main differences between our experimental setup and that of Avery and Kagel (1997): (i) whilst we analyse English auctions (both clock and oral outcry), Avery and Kagel (1997) analyse second-price sealed bid auctions; and (ii) bidders know the signal ranking in our experiment. In addition, Avery and Kagel (1997) assume a uniform distribution on $[1, 4]$ whereas we assume a uniform distribution on $[0, 100]$.

Table 4 presents our experimental results and those of Avery and Kagel (1997) in a comparable format, which sets the expected price under Nash bidding to 100 in each of the experiments; observed average prices and average profits are presented as a proportion of that average price under Nash bidding. Note that in Avery and Kagel (1997) the observed deviation from expected prices under Nash (both for experienced and inexperienced bidders) is more pronounced than in our experiment: observed prices in our experiment are approximately 6 percent higher than expected under Nash bidding whereas in Avery and Kagel (1997) they are 15 percent higher.[31] Consequently, average profits were higher in our experiment and fewer auction winners received negative profits. Whilst these differences in the results could be explained by the differences in the experimental setup, what is common to both experiments is the fact that Nash bidding does not seem to emerge as a good explanatory bidding theory.

Looking in more detail at individual auction data, we have used a rule of thumb to try and understand how often each of the explanatory

[29] The division into these three groups is meant to highlight the fact that Nash bidding functions may not have been used by all bidders and to provide an early indication of what alternative theory (AEV or EV) could explain the data. In particular, for EV, a signal realization of 50 is the signal threshold above which EV is less aggressive than Nash bidding (whereas when the signal realization is lower than 50, EV is more aggressive than Nash bidding).

[30] We thank an anonymous referee for this suggestion.

[31] Earlier we had reported that observed prices in our experiment were 22 percent higher than under Nash bidding. That calculation was made with the signal realizations bidders received in the experiment (whose average is reported in Table 2), whereas the calculation in Table 4 relies on the prior distribution of signals, so as to compare with Avery and Kagel's results. The difference between the two is due to the fact that only 91 auctions were conducted and the average of the lowest signal in each auction (58; see Table 2) is lower than the expected value of the second-order statistic (200/3; see Equation (1)).

TABLE 4
Comparison with Avery and Kagel's (1997) results

	Type of results	*Subject experience*	*Number of auctions*	*Average price*	*Average profit*	*% auctions with negative profits for winner*
Clock auction	Observed	–	91	106.25	30.66	18.7
	Nash	–	–	100	50	0
	EV	–	–	125	25	25
Avery and Kagel (1997)	Observed	Inexperienced	299	115.50	9	39.8
Second-price	Observed	Experienced	308	115.75	11.50	29.2
sealed bid auction	Nash	–	–	100	25	0
	EV	–	–	112.50	12.50	25

TABLE 5
Individual bidding behaviour – clock auction

	Auctions won				Auctions lost			
	#	AEV	EV	Nash	#	AEV	EV	Nash
Bidder 1	5	100%	100%	80%	8	100%	63%	0%
Bidder 2	8	100%	88%	75%	5	40%	40%	0%
Bidder 3	8	100%	88%	75%	5	60%	60%	0%
Bidder 4	7	86%	71%	71%	6	100%	0%	50%
Bidder 5	6	100%	83%	67%	7	57%	29%	29%
Bidder 6	4	100%	75%	75%	9	44%	44%	0%
Bidder 7	4	100%	100%	75%	9	0%	22%	11%
Bidder 8	4	100%	100%	100%	9	89%	11%	0%
Bidder 9	10	100%	100%	80%	3	67%	0%	0%
Bidder 10	9	78%	67%	56%	4	25%	50%	25%
Bidder 11	7	86%	86%	86%	6	0%	17%	0%
Bidder 12	6	100%	100%	83%	7	57%	57%	0%
Bidder 13	8	63%	88%	63%	5	20%	0%	60%
Bidder 14	5	100%	80%	100%	8	63%	38%	0%
Total	91	92%	87%	76%	91	53%	32%	11%

theories could explain bidding behaviour. In order to do that, and for each signal realization, we have computed the bidding limits prescribed by Nash (Equation (10)), EV (Equation (11)) and AEV (Equation (12)). Under our rule of thumb, when a bidder wins an auction, a theory may explain bidding behaviour if it prescribes a bidding limit higher than the final price. Similarly, in the cases where a bidder loses the auction, a theory may explain bidding behaviour if the bidding limit it prescribes is 'sufficiently close' to the final price. We have defined 'sufficiently close' to be a difference lower than ten in absolute value.[32]

We present the results of our rule of thumb in Table 5 (clock) and Table 6 (oral outcry). In the clock auction, AEV appears to be the more likely strategy to have been played by bidders: under our rule of thumb, it appears to explain bidding behaviour of winning bidders in 92 percent of all auctions and of losing bidders in 53 percent of all auctions. Other theories are less convincing at explaining individual bidding behaviour in the clock auction. In the oral outcry auction, AEV also emerges as a convincing explanatory theory, but the results are not as clear-cut as in the clock auction. In particular, Nash bidding appears as a convincing explanatory theory for the bidding behaviour of particular bidders, such as bidder 2, 9 or bidder 13 (looking specifically at the auctions they lost).

[32] Therefore, this rule of thumb associates bidding behaviour with a given theory in cases where bidders may have overbid or underbid slightly compared to the prescribed bidding limit.

TABLE 6
Individual bidding behaviour – oral outcry auction

	Auctions won				*Auctions lost*			
	#	*AEV*	*EV*	*Nash*	#	*AEV*	*EV*	*Nash*
Bidder 1	7	86%	100%	100%	6	50%	17%	0%
Bidder 2	9	89%	89%	56%	4	25%	0%	50%
Bidder 3	5	60%	20%	60%	8	63%	25%	0%
Bidder 4	6	100%	83%	83%	7	57%	29%	29%
Bidder 5	4	100%	100%	100%	9	22%	56%	22%
Bidder 6	8	63%	88%	100%	5	20%	40%	20%
Bidder 7	8	100%	88%	75%	5	40%	0%	20%
Bidder 8	4	75%	75%	75%	8	38%	25%	13%
Bidder 9	5	100%	40%	60%	8	13%	25%	38%
Bidder 10	9	89%	78%	78%	4	50%	0%	0%
Bidder 11	6	100%	83%	67%	7	29%	57%	29%
Bidder 12	7	71%	57%	86%	6	33%	0%	17%
Bidder 13	4	100%	50%	50%	8	38%	38%	63%
Bidder 14	8	75%	88%	75%	5	80%	0%	0%
Total	90	86%	77%	77%	90	39%	26%	22%

As an illustration, Figure 2 contains a graphic of individual signal realizations and the final price for each auction of bidders 1 and 13 in the clock and oral outcry auctions respectively. Next to the price is an indication of whether each auction was won (W) or lost (L), as well as the bidding limits prescribed by AEV,[33] EV and Nash. Notice that bidder 1 in the clock auction is a good example of AEV bidding: in the auctions this bidder lost, the final price is very close to the AEV bidding limit; similarly, in the auctions this bidder won, the AEV bidding limit is always above the final price. Bidder 13 in the oral outcry auction exhibits a behaviour that is better explained by Nash bidding: in the auctions this bidder lost, the final price was always relatively close to the Nash bidding limit, and in the auctions this bidder won the Nash bidding limit is above or relatively close to the final auction price.

Overall, 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.

[33] As we have mentioned earlier, the AEV bidding limit depends on whether the bidder held the highest or lowest signal. Therefore, we present only the prescribed bidding limit for each signal realization (and not the bid function).

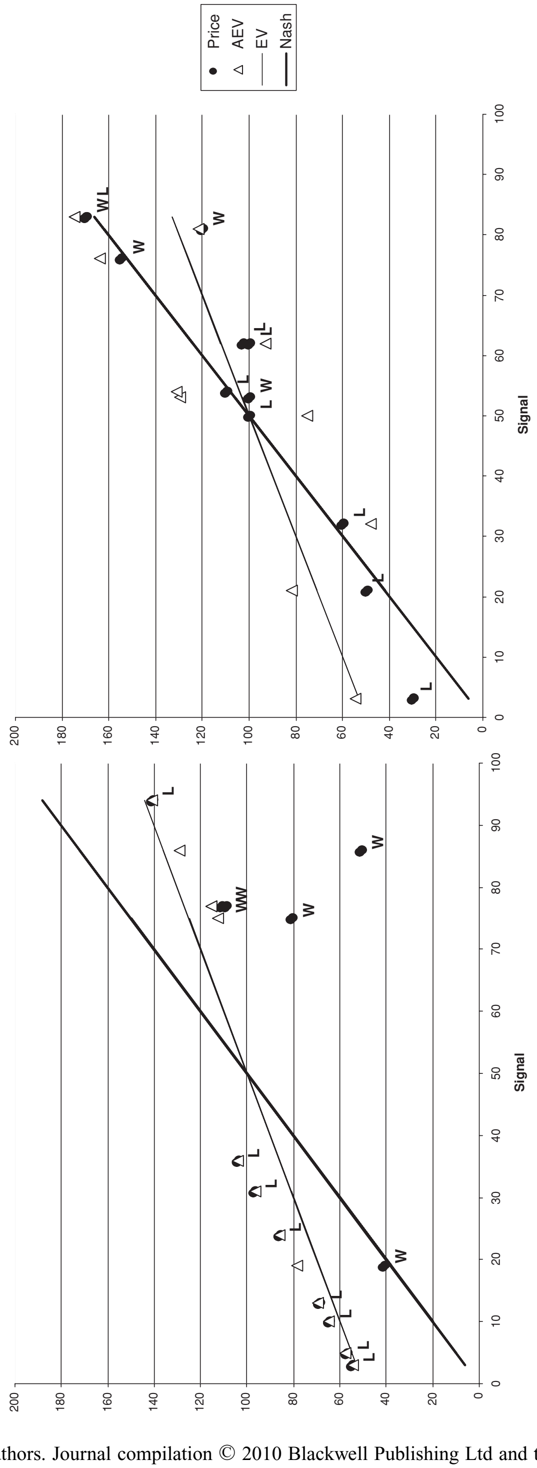

Fig. 2. Bidding behaviour by bidder 1 in the clock auction (left) and bidder 13 in the oral outcry auction (right).

We have estimated the bid functions of each type of bidder by separating them into high (regime 1) and low (regime 2) signal bidders:

$$\begin{cases} B_{1t} = \alpha_0 + \alpha_1 X_{1t} + \varepsilon_{1t} \\ B_{2t} = \beta_0 + \beta_1 X_{2t} + \varepsilon_{2t} \end{cases} \quad t = 1, \ldots, N \tag{15}$$

where regime 1 represents data for the high signal bidder and regime 2 for the low signal bidder, 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 assuming that they follow a bivariate normal with correlation ρ.[34]

The different theories imply different restrictions: AEV implies that $\alpha_0 = 0$, $\beta_0 = 50$, $\alpha_1 = \beta_1 = 1.5$; EV implies $\alpha_0 = \beta_0 = 50$, $\alpha_1 = \beta_1 = 1$; Nash implies $\alpha_0 = \beta_0 = 0$ and $\alpha_1 = \beta_1 = 2$; high signal bidders playing a BR to AEV imply $\alpha_0 = -100$, $\alpha_1 = 3$, $\beta_0 = 50$ and $\beta_1 = 1.5$; finally, low signal bidders playing a BR to AEV imply $\alpha_0 = 0$, $\alpha_1 = 1.5$, $\beta_0 = 0$ and $\beta_1 = 3$. Because high and low signal bidders may be using different bidding strategies, we test all the possible combinations using a likelihood ratio (LR) test. The cursed equilibrium bid function (Equation (8)) is symmetric and hence would entail the restrictions $\alpha_0 = \beta_0$ and $\alpha_1 = \beta_1$. However, the particular value of the coefficients depends on $\mathcal{X}$, i.e., it depends on how cursed bidders may be. Therefore, we first test the restriction that the bid function is symmetric (using an LR test) and only if the restriction is not rejected do we proceed to infer the value of $\mathcal{X}$ from the estimated coefficients.

VI.1.1 Clock auction. Table 7 contains the estimation results of Equation (15) for the clock auction. The estimated bid functions are quite similar to those predicted by AEV ($\alpha_0 = 0$, $\beta_0 = 50$, $\alpha_1 = \beta_1 = 1.5$). Some of the data in the experiment come 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 percent of all auctions were – see Table 2 – compared to our simulations' prediction of 44.5 percent – see Table 1) and some auction winners lost money (18.7 percent of all auctions yielded negative profits for the winner, and our simulations predicted 16.6 percent).

[34] Note that we have not made an allowance for subject-specific effects. Whilst it would certainly be possible to introduce such effects by creating a dummy variable for each individual bidder (in a way similar to the fixed effects model with panel data), this would most certainly significantly reduce our degrees of freedom in the estimation due to the large number of dummy variables. Nevertheless, we have estimated a model with such dummy variables (restricting them to have identical coefficients in regimes 1 and 2, i.e., assuming each bidder's individual effect is independent of him holding the highest or lowest signal) and tested the hypothesis that all the associated coefficients (the individual effects) were equal to 0 (using a likelihood ratio test). We could not reject this hypothesis at the 1 percent significance level for both the clock and oral outcry auctions.

TABLE 7

Switching regressions results for the clock auction – high/low signal bidders

	Variable	*Coefficient*	*SE*	*t-ratio*
High signal bidder	Constant	16.96	14.43	1.18
	X_{0t}	1.17	0.23	5.19**
Low signal bidder	Constant	40.87	4.39	9.31**
	X_{1t}	1.66	0.21	7.76**

Notes: $\rho = -0.1566$; $\mathrm{Var}(e_0) = 651.15$; $\mathrm{Var}(e_1) = 188.54$; $N = 91$.
**Significant at the 1% level.

TABLE 8

LR test results for the clock auction – high/low signal bidders

	High bidder			
LR $\sim \mathcal{X}^2_{(4)}$	*AEV*	*EV*	*Nash*	*BR to AEV*
Low bidder				
AEV	6.62	16.04**	25.51**	66.75**
EV	20.92**	27.95**	24.58**	–
Nash	108.88**	90.98**	101.5**	–
BR to AEV	71.17**	–	–	–

**Significant at the 1% level.

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.

Table 8 summarizes the results of imposing the restrictions of each theory (AEV, EV and Nash) against all others (AEV, EV and Nash), using an LR test. We also test the possibility that bidders were playing BR to AEV. For each combination of strategies, four restrictions are imposed. This implies that the test statistic has a $\mathcal{X}^2_{(4)}$ distribution. The only strategy combination that is not rejected is AEV versus AEV (for the high and low signal bidder, respectively). This suggests that AEV is the best explanatory theory in the clock auction.

We have also tested for cursed equilibrium by imposing the restriction that the bid function was symmetric, i.e., we have estimated Equation (15) under the restrictions $\alpha_0 = \beta_0$ and $\alpha_1 = \beta_1$. We have obtained the

TABLE 9

Switching regressions results for the oral outcry auction – high/low signal bidders

	Variable	*Coefficient*	*SE*	*t-ratio*
High signal bidder	Constant	−2.17	19.60	−0.11
	X_{0t}	1.89	0.35	5.37**
Low signal bidder	Constant	49.72	5.60	8.89**
	X_{1t}	1.44	0.24	6.12**

Notes: $\rho = -0.7945$; $\text{Var}(e_0) = 614.39$; $\text{Var}(e_1) = 557.85$; $N = 90$.
**Significant at the 1% level.

following results (standard errors in parentheses):

$$\hat{B}_t = \underset{(3.73)}{42.75} + \underset{(0.09)}{1.37} X_t \tag{16}$$

The LR test statistic associated with the hypothesis is 13.44, which is clearly rejected. Thus, bidders do not appear to have played symmetric cursed equilibrium bidding strategies.

VI.1.2 Oral outcry auction. For the oral outcry auction, we have also estimated the bid functions of Equation (15) using the data separated into high and low signal bidders for each auction t.[35] Table 9 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 percent) seem to agree with our simulation predictions of 96 and 74 percent, respectively, once we realize that high signal bidders were slightly less aggressive than predicted by Nash (see Table 9). 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.

We have tested each theory against the others using the LR test. The results are shown in Table 10. 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.

Similarly to the clock auction, we have also tested for cursed equilibrium by estimating Equation (15) under the restrictions $\alpha_0 = \beta_0$ and

[35] 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).

TABLE 10
LR test results for the oral outcry auction – high/low signal bidders

	High bidder			
LR $\sim \mathcal{X}^2_{(4)}$	*AEV*	*EV*	*Nash*	*BR to AEV*
Low bidder				
AEV	16.74**	19.97**	4.4	65.00**
EV	38.39**	48.35**	21.36**	–
Nash	96.77**	94.61**	85.21**	–
BR to AEV	57.87**	–	–	–

**Significant at the 1% level.

$\alpha_1 = \beta_1$. We have obtained the following results (standard errors in parentheses):

$$\hat{B}_t = \underset{(4.67)}{43.49} + \underset{(0.096)}{1.49}X_t \tag{17}$$

The LR test statistic associated with the hypothesis is 12.74, which is clearly rejected. Thus, bidders do not appear to have played symmetric cursed-equilibrium bidding strategies.

VI.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 percent in the clock auction and 31 percent in the oral outcry auction). In the clock auction, winning bidders received 62 percent of expected profits under Nash bidding, whilst in the oral outcry auction winning bidders received only 42 percent. Not all auctions generated positive profits, as expected under Nash bidding: only 81 percent of clock auctions and 77 percent of oral outcry auctions yielded positive profits for the winner.

The winner's curse occurs if a bidder fails to incorporate in his bid 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 percent higher than predicted whilst in the oral outcry auction they were 31 percent higher.

TABLE 11
Clock auction – price and profit statistics

	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 12
Oral outcry 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%

Tables 11 and 12 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 was more pronounced (43 percent in the clock auction and 61 percent in the oral outcry auction). This led to lower profits (54 percent of expected profits in the clock auction and 33 percent 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 percent higher than predicted in the clock auction and 5 percent 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 percent of clock auctions and 23 percent of oral outcry auctions. Low signal bidders were particularly affected by negative profits: 33 percent of all clock auctions they won yielded negative profits, as did 25 percent of all oral outcry auctions won.

VI.3 Result 3 – Are the clock and oral outcry auctions equivalent?

Result 3: The bid function in the two 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 same for both types of auction. This provides weak support to the equivalence claim between the two types of auction.

VI.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:

$$\begin{cases} B_{1t} = \alpha_0 + \alpha_1 X_{1t} + \alpha_2 D_t + \alpha_3 D_t.X_{1t} + \varepsilon_{1t} \\ B_{2t} = \beta_0 + \beta_1 X_{2t} + \beta_2 D_t + \beta_3 D_t.X_{2t} + \varepsilon_{2t} \end{cases} \quad t = 1, \ldots, 181 \quad (18)$$

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 VI.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 other two hypotheses.

Table 13 contains the estimation results of Equation (18) and the LR tests on the three hypotheses. Note that the coefficients of β_2 and β_3 (low signal bidder) are not significantly different from 0, providing an early hint that the low signal 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 percent 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 VI.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

TABLE 13
Switching regressions estimation results for the full dataset (high/low signal bidders)

	Variable	*Coefficient*	*SE*	*t-ratio*
High signal bidder	Constant	−4.04	19.67	−0.21
	X_{0t}	1.95	0.36	5.35**
	D_t	29.38	23.77	1.24
	$D_t.X_{0t}$	−0.89	0.41	−2.19*
Low signal bidder	Constant	49.73	4.43	11.22**
	X_{1t}	1.41	0.17	8.05**
	D_t	−7.53	7.73	−0.97
	$D_t.X_{1t}$	0.46	0.30	1.54
		All bidders ($\mathcal{X}^2_{(4)}$)	*High bidders* ($\mathcal{X}^2_{(2)}$)	*Low bidders* ($\mathcal{X}^2_{(2)}$)
LR test on restrictions		17.55**	13.39**	2.74

Notes: $\rho = -0.7249$; Var(e_0) = 705.2; Var(e_1) = 444.59; N = 181.
**Significant at the 1% level; *significant at the 5% level.

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.

VI.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,[36] we can isolate subject-specific disturbances, and obtain more efficient estimates than when using ordinary least squares.[37] We estimated the following equation with the random effects model[38] (174 observations):

$$B_{it} = \alpha_1 + \alpha_2 X_{it} + \alpha_3 H_{it} + \alpha_4 D_{it} + \alpha_5 D_{it}.X_{it} + \alpha_6 D_{it}.H_{it} + \varepsilon_{it}$$
$$i = 1, \ldots, N, \; t = 1, \ldots, T_i \qquad (19)$$

[36] 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.
[37] Note that ignoring subject-specific disturbances may also lead to bias, through the missing individual variables.
[38] We have excluded eight 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 three observations for the same reason and one observation because the auction was void.

TABLE 14

Random effects model estimation results for the full dataset

Variable	*Coefficient*	*SE*		*t-ratio*
Constant	45.34	3.65		12.43**
X_{it}	1.45	0.08		19.01**
H_{it}	−35.84	4.12		8.7**
D_{it}	−7.38	5.20		1.42
$D_{it}.X_{it}$	−0.05	0.11		0.47
$D_{it}.H_{it}$	2.50	5.76		0.43
			$W \sim \mathcal{X}^2_{(3)}$	
Wald test on restrictions			4.77	

Notes: $r^2 = 0.774$; Var(u) = 72.96; Var(e) = 207.14; $N = 174$.
**Significant at the 1% level.

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 value of 1 if bidder i at auction t held the highest signal, and 0 otherwise, and $\varepsilon_{it} = u_i + e_{it}$ is a combination of subject-specific and auction period error terms. These error terms are assumed to follow the standard assumptions ($u_i \sim \mathrm{IN}(0, \sigma_u^2)$ and $e_{it} \sim \mathrm{IN}(0, \sigma_e^2)$). 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 test this restriction using a Wald test. Table 14 shows the results.

First, each coefficient (α_4, α_5 and α_6) is not statistically different from 0. Second, the Wald 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.

There is an apparent inconsistency in our results which merits further exploration.[39] Low signal bidders win a significant number of auctions

[39] We thank an anonymous referee for pointing this out.

(43 percent of clock auctions and 40 percent of oral outcry auctions – see Tables 2 and 3) and we cannot reject the hypothesis that their bid functions were equivalent in both types of auction (see Table 13). However, the bid functions of high signal bidders are apparently different in both types of auction, approaching AEV in the clock auction and Nash in the oral outcry auction (see Tables 8 and 10). In spite of this, auction prices – set by the bid function of losing bidders – are approximately equivalent (see Table 14) when one would certainly expect that, if high signal bidders were bidding according to Nash in the oral outcry auction, their bidding behaviour should translate into higher auction prices when they lost (which happened in 40 percent of oral outcry auctions). In order to address this issue, we have estimated Equation (19) separately for the clock auction ($D_{it} = 1$) and for the oral outcry auction ($D_{it} = 0$) and obtained the following results (standard errors in parentheses):

$$\begin{aligned}\hat{B}_{it} &= \underset{(3.16)}{38.03} + \underset{(0.08)}{1.39}X_{it} - \underset{(3.51)}{33.35}H_{it} \text{ (clock auction)} \\ \hat{B}_{it} &= \underset{(4.12)}{45.32} + \underset{(0.08)}{1.45}X_{it} - \underset{(4.57)}{35.88}H_{it} \text{ (oral outcry auction)}\end{aligned} \qquad (20)$$

Note that the estimated bid function of losing bidders in the oral outcry auction is slightly more aggressive than in the clock auction and this is particularly true for high signal bidders. This helps to explain why auction prices in the oral outcry auction were higher than in the clock auction (see Tables 11 and 12). But also note that the oral outcry bid function does not resemble the Nash bid function at all; if anything, it appears much closer to the AEV bid function. Therefore, it must be the case that when high signal bidders were following the Nash bid function in the oral outcry auction, they must have won very frequently, which makes sense because the Nash bid function is more aggressive than the AEV bid function (see Figure 1). However, in the cases where they did not win, the (aggressive) Nash bid function may have translated into higher auction prices and this may explain the slightly more aggressive estimated bid function of the losing bidders in the oral outcry auction (Equation (20)). In fact, our earlier analysis of individual bidding behaviour (Tables 5 and 6) had shown that in the oral outcry auction losing bidders may have played Nash relatively more frequently and AEV relatively less frequently than in the clock auction. Nevertheless, and as we have seen in Table 14, we cannot reject the hypothesis that the bid function of losing bidders in both types of auction is similar, i.e., it is not possible to argue statistically that losing bidders in the oral outcry auction were more aggressive than in the clock auction.

Finally, given our ‘perfect stranger’ design, we have also tested for the existence of serial correlation in the data. As explained above, both in the clock and oral outcry auctions, we could only observe the bid function of the losing bidders. Therefore, we have estimated Equation (19) for the clock auction ($D_{it} = 1$) and for the oral outcry auction ($D_{it} = 0$) separately and tested for serial correlation in the errors (e_{it}) using the test suggested by Wooldridge (2002). In both the clock and oral outcry auctions, we cannot reject the hypothesis that there is no serial correlation in the data (although in the oral outcry auction the hypothesis is only rejected at the 5 percent significance level). This indicates that although not ideal, the 'perfect stranger' design did not introduce significant dependencies in the data within each treatment.

VI.4 Result 4 – Was there evidence of jump bidding in the oral outcry auction?

Result 4: 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 of Gonçalves (2008a), high signal bidders are expected to manipulate their starting bid in a way which maximizes their expected payoff, i.e., to choose the bidding path which favours them the most. Hence, in that equilibrium, high signal bidders should start either 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 exceeds 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 seem to contradict this. Figure 3 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 allowed bid (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 3 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 4 shows the bidding increments over time. Again, one would expect that over time bidders approached our theoretical prediction. The data seem 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. This behaviour lends some support to Isaac *et al.*

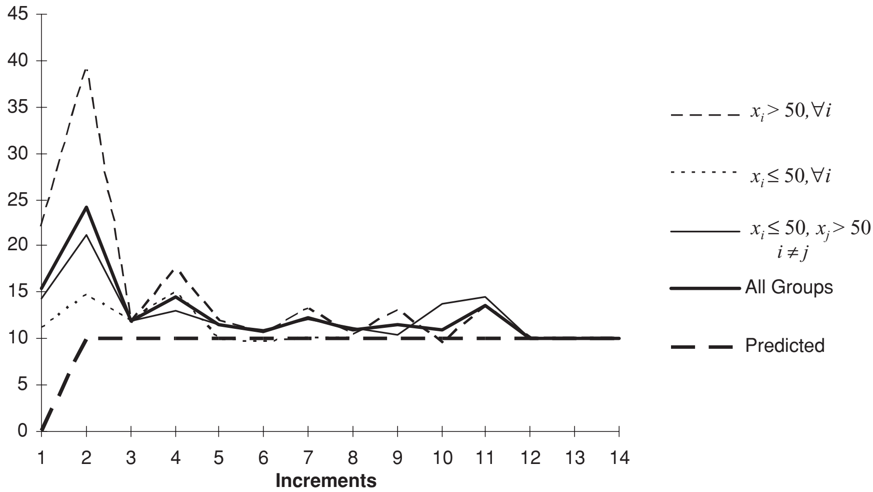

Fig. 3. Oral outcry auction bidding increments (between groups).

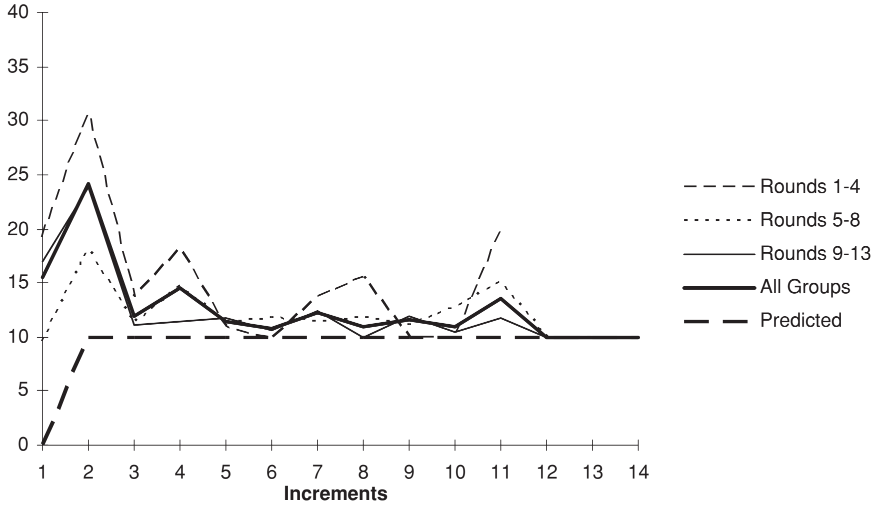

Fig. 4. Oral outcry auction bidding increments (over time).

(2005, 2007) who argue that impatience may be an important factor in the choice of bidding strategies in oral outcry auctions.

VII. 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*.[40] 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 percent in the clock and 31 percent 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.

Although encouraging and interesting, the results are not conclusive and clearly indicate that further research is necessary. In particular, as discussed in more detail in Section V.2, the experimental design should be modified so that it (i) includes a new type of clock auction treatment which mimics more closely the bid structure of the oral outcry auction, (ii) includes a larger number of treatments and subjects and (iii) abandons the 'perfect stranger' design which has the potential to introduce dependencies in the observations within each treatment.

From the results of our experiment, we would have to 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 did Kagel and Levin (1986)[41] and Levin *et al.* (1996)[42] 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. In particular, it should be noted that a more detailed investigation of asymmetric bidding strategies (Bikhchandani and Riley, 1991; Klemperer, 1998) was not carried out.[43]

[40] 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.

[41] Kagel and Levin (1986) test experimentally a common value first-price sealed bid auction with more than two bidders. Nash bidding is rejected, and the winner's curse seems to be present.

[42] Levin *et al.* (1996) have run a common value experiment of clock auctions with more than two 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.

[43] We thank an anonymous referee for making this observation.

Our experiment is probably the first so far where Nash bidding is clearly not rejected for a subset of bidders.[44] 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 compared to clock auctions.

Further (experimental) research will eventually prove our conjecture right or wrong. In particular, it would be worth pursuing an extension of our experiment with a modified design which addresses the shortcomings mentioned above. In addition, it would be 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; 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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