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# An experimental analysis of auctions with interdependent valuations

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February 11, 2000

**Abstract**

We study experiments in an auction setting with interdependent valuation. Groups of three players receive private signals and then bid for a single, indivisible item. Valuations for the item differ within groups and depend asymmetrically on a bidder's own and other bidders' signals. Theoretically, the English auction yields efficient allocations, while other standard auction formats fail to do so.

Consistent with equilibrium predictions, we find that an English auction yields significantly more efficiency than a second-price sealed-bid auction.

We also study the seller's expected revenue and the bidders expected payoff, and find that the experimental results are close to the theoretical predictions. (JEL C92, D44)

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# An experimental analysis of auctions with interdependent valuations

September 24, 2000


**Abstract**

We study experiments in an auction setting with interdependent valuation. Groups of three players receive private signals and then bid for a single, indivisible item. Valuations for the item differ within groups and depend asymmetrically on a bidder's own and other bidders' signals. Theoretically, the English auction yields efficient allocations, while other standard auction formats fail to do so.

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# 1 Introduction

Most of the experimental literature on auctions and bidding[1] considers symmetric settings where valuations are private (i.e., bidder *i*'s value depends only on a signal available to *i*) or purely common (i.e., all bidders have the same value but they receive different signals about that value).

In the purely common value case efficiency is trivial (since all bidders have the same true value) and is attained by all standard auctions (Dutch, English, first price sealed bid, second-price sealed-bid auction). In a symmetric private value context all standard auctions are efficient (they are also equivalent in terms of revenue).

In this paper we focus on an experimental setting with asymmetric, interdependent valuations: There is one object for sale, and there are three bidders (imagine them sitting at a round table). Each bidder receives a signal, and her valuation for the object is equal to her signal plus a constant weight multiplied by the (unobserved) signal of that bidder's right neighbour. General settings with interdependent valuations are studied in Maskin [Mas92], Dasgupta and Maskin [DM99] and in Jehiel and Moldovanu [JM98].

Due to the asymmetric nature of the interdependencies, in our model it is not the case that the agent with the highest signal has also the highest value. Hence, the task of aggregating the private information, such that the efficient buyer gets the object, is not easy. Besides forming correct estimates about valuations, our agents also have to solve a non-trivial bidding problem where "winner's curse" considerations play a role.

In a remarkable result, Maskin [Mas92] shows that the English auction yields an efficient allocation (even in very asymmetric settings) as long as a bidder's signal has a higher impact on that bidder's value than on the opponents' values. It is easy to show that a second-price sealed-bid auction is not necessarily efficient (Note that first-price sealed-bid or Dutch auctions may be inefficient already in asymmetric private values settings).

The English auction achieves efficiency because relevant private information is gradually

[1] See Kagel [Kag95] for an excellent survey of this literature.

revealed during the auction process. In contrast, in sealed-bid (or Dutch) auctions a bidder must bid without any specific information about the realisations of competitors' signals (which affect here that bidder's value). Since the English auction is efficient while the other auction formats are not, the standard auctions are not necessarily revenue equivalent in our framework.

Given the above remarks, it is clear that the asymmetric interdependent valuations setting provides an excellent framework to test efficiency and revenue properties of standard auctions.

The paper is organised as follows: In section 2 we describe the experimental setup. In section 3 we compute equilibria for an English auction and for a second-price sealed-bid auction. In the English auction bidding can be divided into two stages: The first stage ends when the first bidder drops out of the auction. Then the remaining two bidders try to infer the first dropper's signal from her bid and compete by bidding in the second stage. Since only two bidders are left, and since the auction ends before any new inference can be made, the second stage is equivalent to a second-price sealed-bid auction with two bidders. Bids are driven by the fact that one bidder is to the left of the first dropper (hence the first dropper's signal directly affects that bidder's valuation), while the other bidder is to the right (hence her valuation is influenced by the signal of the other remaining bidder). We show that the English auction yields efficient allocations, while the second-price sealed-bid auction yields efficient allocations only if the agent with the highest signal has also the highest valuation for the object. Finally, we compute ex-ante expected revenues for the seller and the bidders. We find that the seller's expected revenue is the same in the English auction as in the second-price sealed-bid auction. The bidders expect higher revenues in the English auction. Hence, the loss due to the inefficiency of the second-price sealed-bid auction is fully born by the bidders.

In section 4 we describe the experimental results and compare them to the theoretical predictions. In section 4.1 we compare the bids in the first stage of the English auction with the bids in the second-price sealed-bid auction (since these bids are based on the same information, i.e., on initial beliefs about signals of competitors). The experimental results agree very well with the theoretical predictions. In particular, we find that agents with higher signals bid more (note that this monotonicity is crucial for correct inferences during the second stage of the English auction). In section 4.2 we describe how the experimental second-stage bids in the English auction depend on the bidders' own signals and on the bid of the first dropper. The left bidder's behaviour and the comparative sensitivities among left and right bidders are as predicted by theory. But right bidders (who have a quite complex, indirect inference problem) react much less than in equilibrium to their own and to the first dropper's signal. Such a deviation from equilibrium behaviour, however, has no substantial influence on efficiency and payoffs. In section 4.4 we compare the efficiency attained in the experiment by the two types of auctions. For 'simple' realisations of signals, where the bidder with the highest signal has also the highest value, both auction types achieve similar high measures of efficiency. In contrast, for 'hard' realisations of signals, where the above property does not hold, the English auction achieves significantly higher measures of efficiency. These findings agree well with the theoretical predictions. They are also consistent with the right bidder's deviation from equilibrium behaviour. In sections 4.5 we describe the experimental results concerning expected revenues for the seller. While the experimental seller's revenues are higher than the theoretically predicted ones (which can be attributed to a small amount of over-bidding), we find that there is no significant difference among the two types of auctions. Again, this last finding agrees very well with the theoretical prediction. Finally, in section 4.6 we look at the bidders' expected revenues in the experiment, and we find, as predicted by theory, that bidders are significantly better off in the English auction.

Several concluding comments are gathered in section 5.

# 2 The Experimental Setup

The setup we study is as follows:

Three bidders, $i = 1,2,3$, bid for one unit of an indivisible object. Each bidder receives a private signal $s_i$. From the point of view of bidder $i$, bidder $i+1$ modulo three is the bidder to the 'right' of $i$, and bidder $i-1$ modulo three is the bidder to the left of bidder $i$.

If bidder $i$ bids successfully for the object and pays a price $p$ then her payoff is given by $s_i + \alpha \cdot s_{i+1} - p$ where $s_i$ is bidder $i$'s private signal, $s_{i+1}$ is the right neighbour's signal, and the weight $\alpha$ is a parameter that is varied during the experiment (see appendix A). Note that $\alpha = 0$ yields the independent private values case. The signal $s_i$ is a uniformly distributed integer from $[0, 100]$, independent of $s_{i+1}$ and $s_{i-1}$.

We compare two auction formats: An English auction and a second-price sealed-bid auction.

In the English auction there are three clocks, one for each bidder. They simultaneously start at a bid of -10 and synchronously move upwards every 2 seconds in equal steps ranging from 2 to 5 units of currency. Each bidder may stop her clock at any time by pushing a button. If a bidder stops her clock, then, at the next price increase, the other bidders observe that the respective clock has been stopped. When a unique clock is left active, the remaining bidder obtains the object at the price shown by the clock of the agent that stopped last. After each auction, the winner's identity, all signals, bids, and gains are communicated to the subjects. Information about past auctions within the same round is also visible on the screen.

In the second-price sealed-bid auction bidder $i$'s clock shows a permanently increasing price. The clock stops when the bidder pushes a button. In contrast to the English auction, the stopping is not observable by the other bidders. When two clocks have stopped, the remaining bidder obtains the item at the price shown by the clock of the agent that stopped last, and the winner's identity, all signals, bids, and gains are communicated to the subjects. Information about past auctions within the same round is also visible on the screen

In both the English auction and the second-price sealed-bid auction groups are allocated randomly for rounds of 8 or 10 auctions each. The parameter $\alpha$ and the type of the auction does not change within rounds. During one experiment, however, participants experience different $\alpha$s and both auctions formats. We conducted 6 experiments, involving 96 participants and including 395 different rounds with 2069 auctions.

# 3 Equilibrium Predictions

In this section we compute symmetric equilibria for both auctions formats. For simplicity of notation we assume that signals are distributed uniformly between 0 and 1, and not, as in the experiment, between 0 and 100.

## 3.1 English auction

### 3.1.1 Bids in the English auction

In the English auction with 3 bidders we distinguish 2 stages: a first stage where all bidders are still active in the auction, and a second stage where there are only two bidders left. The bidding strategy during the first stage may only depend on a bidder's own signal $s$. During the second stage a bidding strategy may further depend on the price $\hat{b}_0$ where the first bidder dropped out, and on the first dropper's position (i.e. whether the bidder is to the left or to the right of the first dropper). Since only two bidders are left, the second stage ends before any other update of beliefs can be made. Hence, the second stage is equivalent to a second-price sealed-bid auction. In a symmetric equilibrium strategies are described by a triple $(b_0(s), b_{\mathrm{L}}(s, \hat{b}_0), b_{\mathrm{R}}(s, \hat{b}_0))$ where $b_0(\cdot)$ describes the initial bidding function, provided that no other bidder has left the auction. $\hat{b}_0$ is the price where the first bidder dropped out. $b_{\mathrm{L}}(\cdot)$ describes the second stage bidding function of a bidder to the left of the first dropper. $b_{\mathrm{R}}(\cdot)$ describes the second-stage bidding function of a bidder to the right of the first dropper.

**The optimal first-stage bid** The bid $b_0(\cdot)$ determines a lower boundary for $b_{\mathrm{L}}(\cdot)$ and $b_{\mathrm{R}}(\cdot)$. We first assume that this lower boundary is not binding, and then check that the assumption is fulfilled in the computed strategies.

Assume that a bidder receives signal $s$ and initially bids up to $B$, while the other bidders (with signals $s_{\mathrm{L}}$ and $s_{\mathrm{R}}$) bid according to $b_0(\cdot)$, which is assumed to be strictly monotonically increasing. Denote by $b_0^{-1}$ the inverse of $b_0(\cdot)$. Note that our bidder wins the auction with the initial bid $B$ if and only if $s_{\mathrm{L}} = s_{\mathrm{R}} < b_0^{-1}(B)$. Her expected payoff is given by

$$U_0(B) = \int_0^{b_0^{-1}(B)} (s + \alpha \cdot s_{\mathrm{L}} - b_0(s_{\mathrm{L}}))\, ds_{\mathrm{L}} \tag{1}$$

The first derivative is

$$\frac{\partial U_0}{\partial B} = (s + \alpha \cdot b_0^{-1}(B) - B) b_0^{-1\prime}(b_0(s)) \tag{2}$$

which is zero for $B = s \cdot (1+\alpha)$. The second derivative $\partial^2 U_0 / \partial B^2$ is $-1/(1+\alpha) < 0$. Hence we have found a maximum, and the candidate equilibrium bidding function is

$$b_0(s) = s \cdot (1+\alpha) \tag{3}$$

**The left bidder's strategy during the second stage** Given that $b_0(\cdot)$ is strictly monotonically increasing, the signal $s_0$ of the first dropper can be perfectly inferred from her bid $\hat{b}_0$. Hence, it is possible to write strategies during the second stage as functions of own signals and the first dropper's signal. After the first dropper has left the auction, the left bidder can infer her valuation for the good which is $s_{\mathrm{L}} + s_0 \cdot \alpha$. Since the second stage is equivalent to a second-price sealed-bid auction, the left bidder, who now knows her valuation, has a dominant action: remain in the auction till the price exceeds valuation. Hence, the candidate equilibrium bidding function for the left bidder is

$$b_{\mathrm{L}}(s_{\mathrm{L}}, s_0) = s_{\mathrm{L}} + s_0 \cdot \alpha \tag{4}$$

With the help of equation 3 the equilibrium bidding function can be expressed as a function of the own signal and the observed first bid.

$$b_{\mathrm{L}} = s_{\mathrm{L}} + \frac{\alpha}{1+\alpha} \hat{b}_0 \tag{5}$$

Note that $\forall s_0 < s_{\mathrm{L}} : b_{\mathrm{L}}(s_{\mathrm{L}}, s_0) > b_0(s_{\mathrm{L}})$. Hence, for all possible signals, the candidate equilibrium bid in the first stage does not restrict the second-stage bid of the left bidder.

**The right bidder's strategy during the second stage** Here we consider the case $\alpha < 1$ separately from $\alpha \geq 1$.

- Let us start with $\alpha < 1$.

  Again we use the fact that the signal $s_0$ of the first dropper can be perfectly inferred from her bid $\hat{b}_0$ . As above, we write strategies as a triple $(b_0(s), b_{\mathrm{L}}(s,s_0), b_{\mathrm{R}}(s,s_0))$

  Let $B$ be the bid of the right bidder, and let $b_{\mathrm{L}}(s_{\mathrm{L}}, s_0)$ be the bidding function of the left bidder which is strictly monotonic increasing in $s_{\mathrm{L}}$. The inverse with respect to $s_{\mathrm{L}}$ is called $b_{\mathrm{L}}^{-1}(s_{\mathrm{L}}, s_0)$. The right bidder will obtain the object as long as the signal $s_{\mathrm{L}}$ of the left bidder is lower than $b_{\mathrm{L}}^{-1}(B, s_0)$. The expected payoff of the right bidder is

$$U_{\mathrm{R}}(B) = \int_0^{b_{\mathrm{L}}^{-1}(B,s_0)} (s_{\mathrm{R}} + \alpha \cdot s_{\mathrm{L}} - b_{\mathrm{L}}(s_{\mathrm{L}}, s_0))\, ds_{\mathrm{L}} \tag{6}$$

  which has the derivative

$$\frac{\partial U_{\mathrm{R}}}{\partial B} = s_{\mathrm{R}} - B \cdot (1-\alpha) - s_0 \cdot \alpha^2 \tag{7}$$

  Since $\partial^2 U_{\mathrm{R}}/\partial B^2 = \alpha - 1$, the second order condition is fulfilled by assumption.

  Solving the first order condition, $\partial U_{\mathrm{R}}/\partial B = 0$, yields $B = (s_{\mathrm{R}} - s_0 \cdot \alpha^2)/(1-\alpha)$. Hence, the candidate equilibrium bidding function for the right bidder is given by

$$b_{\mathrm{R}}(s_{\mathrm{R}}, s_0) = \frac{s_{\mathrm{R}} - s_0 \cdot \alpha^2}{1-\alpha} \qquad \text{if } \alpha < 1 \tag{8}$$

  With the help of equation 3 the equilibrium bidding function can be expressed as a function of the own signal and the observed first bid.

$$b_{\mathrm{R}} = \frac{1}{1-\alpha} s_{\mathrm{R}} - \frac{\alpha^2}{1-\alpha^2} \hat{b}_0 \qquad \text{if } \alpha < 1 \tag{9}$$

  It is interesting to note that for $\alpha < 1$ the right bidder's bid $b_{\mathrm{R}}(s_{\mathrm{R}}, s_0)$ is decreasing in the first dropper's signal $s_0$. The intuition is as follows: The higher the price reached in the first stage of an auction, the lower the expected payoff of the right bidder. Relevant for the right bidder's payoff is the left bidder's signal whose high bid may be motivated only by the presumably high signal of the first dropper (which is relevant for the left bidder's payoff).

- Let us next consider the case $\alpha \geq 1$.

  In this case the right bidder's valuation is always higher than the left bidder's valuation and, since the left bidder bids the true valuation in equilibrium, the right bidder should always bid more than the left bidder.

  We have to show that

  $$(s_{\mathrm{R}} + \alpha s_{\mathrm{L}}) \geq (s_{\mathrm{L}} + \alpha s_0) \tag{10}$$

  Rearranging expression 10 yields

  $$(s_{\mathrm{R}} - s_0) \geq (\alpha - 1) \cdot (s_0 - s_{\mathrm{L}}) \tag{11}$$

  Given that the first dropper already left the auction we know that $s_{\mathrm{R}} \geq s_0$ and $s_{\mathrm{L}} \geq s_0$. Hence, the left hand side of the inequality is always positive and the right hand side is always negative. $\square$

  There are many ways to describe a bidding function of a right bidder who always bids more than the left bidder. Below we will use

  $$b_{\mathrm{R}} = (1 + \alpha) \tag{12}$$

  which is always higher than $b_{\mathrm{L}}$.

Note that $\forall s_0 < s_{\mathrm{R}} : b_{\mathrm{R}}(s_{\mathrm{R}}, s_0) > b_0(s_{\mathrm{R}})$, hence, for all signals, the first-stage candidate equilibrium bid does not restrict the second-stage bid of the right bidder.

One can easily check that the above determined strategies form indeed an equilibrium. Moreover, it is straightforward to show that the above strategies form an equilibrium no matter what the signals' distribution functions are (this is an *ex-post* equilibrium).

### 3.1.2 Efficiency in the English auction

We can now formulate the following proposition:

**Proposition 1** *Assume that* $0 \leq \alpha \leq 1$ . *Then the English auction yields an efficient allocation for any realisation of signals.*

**Proof** We first show that it is not efficient to allocate the good to the first dropper (who has the lowest signal). It is sufficient to show that $s_0 + \alpha \cdot s_R \leq s_R + \alpha \cdot s_L$. Rearranging yields $s_0 \leq (1-\alpha)s_R + \alpha \cdot s_L$, which follows immediately from $s_0 \leq \min\{s_R, s_L\}$.

We now show that when the right bidder bids more than the left then it is indeed efficient to allocate the object to the right bidder, and vice versa. What we have to show is the following:

$$\underbrace{s_L + \alpha \cdot s_0}_{\text{left bid}} \lesseqgtr \underbrace{\frac{s_R - s_0 \cdot \alpha^2}{1-\alpha}}_{\text{right bid}} \quad \Rightarrow \quad \underbrace{s_L + \alpha \cdot s_0}_{\text{left value}} \lesseqgtr \underbrace{s_R + s_L \cdot \alpha}_{\text{right value}} \tag{13}$$

Multiplying the left inequality with $1-\alpha$ and adding $\alpha s_L - \alpha^2 \cdot s_0$ on both sides yields the inequality on the right hand. $\square$

Note that for weights $\alpha > 1$ the efficient allocation rule is not monotonically increasing in signals, i.e., increasing the signal of a certain bidder may cause the object to be efficiently allocated to another bidder. As a consequence, the efficient allocation rule cannot be implemented. There exists no mechanism such that, in equilibrium, the object is always efficiently allocated.

### 3.1.3 Expected Revenues in the English auction

Assume without loss of generality that bidder 2 determines the price. This means that either 1 or 3 have the lowest signal.

- If 1 has the lowest signal, then 2 determines the price only if 3 wins. Player 3 can only win if 3's signal is larger than the critical signal $s_3^c$ which is defined by the condition

$b_{\mathrm{R}}(s_2, s_1) = b_{\mathrm{L}}(s_3, s_1)$, which yields

$$s_3^c = \frac{s_2 - \alpha \cdot s_1}{1 - \alpha} \tag{14}$$

However, if 1 has the lowest signal and $s_3^c > 1$ then 3 can never win. Also if $\alpha > 1$ then 3 will never win. Hence, player 2 will not determine the price iff $s_2 > s_2^c$ where $s_2^c$ is defined as follows:

$$s_2^c = \begin{cases} 1 - \alpha + \alpha \cdot s_1 & \text{if } \alpha < 1 \\ s_1 & \text{if } \alpha \geq 1 \end{cases} \tag{15}$$

- If 3 has the lowest signal, then 1 will win if bidder 1 has more than the critical signal $s_1^c$ which is defined through $b_{\mathrm{L}}(s_2, s_3) = b_{\mathrm{R}}(s_1, s_3)$. Solving for $s_1^c$ yields the following:

$$s_1^c = \begin{cases} (1 - \alpha)s_2 + \alpha \cdot s_3 & \text{if } \alpha < 1 \\ s_3 & \text{if } \alpha \geq 1 \end{cases} \tag{16}$$

Then the expected revenue of the seller in the English auction is

$$\begin{aligned} R_{\mathrm{e}} \;&=\; 3\left(\int_0^1 \int_{s_3}^1 \int_{s_1^c}^1 b_{\mathrm{L}}(s_2, s_3)\, ds_1\, ds_2\, ds_3 + \right. \\ &\left. \int_0^1 \int_{s_1}^{s_2^c} \int_{s_3^c}^1 b_{\mathrm{R}}(s_2, s_1)\, ds_3\, ds_2\, ds_1 \right) = \begin{cases} \frac{1}{8}(4 + 3\alpha) & \text{if } \alpha < 1 \\ \frac{1}{8}(5 + 2\alpha) & \text{if } \alpha \geq 1 \end{cases} \end{aligned} \tag{17}$$

Similarly the ex-ante (i.e., before signals are revealed) sum of expected payoff $G_{\mathrm{e}}$ of the three bidders can be calculated.

$$\begin{aligned} G_{\mathrm{e}} \;&=\; 3 \cdot \left(\int_0^1 \int_{s_3}^1 \int_{s_1^c}^1 s_1 + \alpha \cdot s_2 - b_{\mathrm{L}}(s_2, s_3)\, ds_1\, ds_2\, ds_3 + \right. \\ &\left. \int_0^1 \int_{s_1}^{s_2^c} \int_{s_3^c}^1 s_3 + \alpha \cdot s_1 - b_{\mathrm{R}}(s_2, s_1)\, ds_3\, ds_2\, ds_1 \right) = \begin{cases} \frac{2+\alpha^2}{8} & \text{if } \alpha < 1 \\ \frac{3\alpha}{8} & \text{if } \alpha \geq 1 \end{cases} \end{aligned} \tag{18}$$

## 3.2 Second-price sealed-bid auction

### 3.2.1 Bids in the second-price sealed-bid auction

In a second-price sealed-bid auction a bidding strategy, $b_{\mathrm{S}}(\cdot)$, can only depend on an agent's own signal. We consider below symmetric equilibria. Take one of the bidders, and assume that her two neighbours, L and R, bid according to $b_S(\cdot)$, which is strictly monotonically increasing and has inverse $b_S^{-1}(B)$. Assume that our bidder bids $B$. Then she will obtain the object as long as $\max(s_L, s_R) < b_S^{-1}(B)$. The value of the object is always $s + \alpha \cdot s_R$ (where $s$ is the own signal and $s_R$ the right neighbour's signal).

The expected payoff of this bidder is given by

$$U(B) = \int_0^{b_S^{-1}(B)} \left( \int_0^{s_R} (s + \alpha \cdot s_R - b_S(s_R))\, ds_L + \int_{s_R}^{b_S^{-1}(B)} (s + \alpha \cdot s_R - b_S(s_L))\, ds_L \right) ds_R \quad (19)$$

The derivative with respect to $B$ is

$$\frac{\partial U}{\partial B} = \frac{1}{2} b_S^{-1}(B) \left( 3\alpha \cdot b_S^{-1}(B) + 4(s - B) \right) \frac{\partial b_S^{-1}(B)}{\partial B} \quad (20)$$

The first order condition $\partial U / \partial B = 0$ yields $B = s \cdot (4 + 3\alpha)/4$. Hence, the equilibrium candidate bidding function in the second-price sealed-bid auction is

$$b_S(s) = s \cdot \left( 1 + \frac{3}{4}\alpha \right) \quad (21)$$

The second order condition is

$$\frac{\partial^2 U}{\partial B^2} = -\frac{32s}{(4 + 3\alpha)^2} < 0 \quad (22)$$

which is always fulfilled.

It is straightforward to show that the above computed strategies form a symmetric equilibrium for the assumed uniform distribution of signals.

### 3.2.2 Efficiency in the second-price sealed-bid auction

In contrast to the English auction, the allocation with the second-price sealed-bid auction is not always efficient even for $\alpha < 1$. For illustration, consider the following example: Assume $\alpha = 1/2$ and signals $(s_1, s_2, s_3) = (24, 0, 16)$. Then valuations are $(v_1, v_2, v_3) = (24, 8, 28)$. Hence, the efficient allocation is to give the object to bidder 3. Indeed, in equilibrium in the English auction bidder 2 drops at a price of zero, bidder 1 drops at a price of 24, and bidder 3 obtains the object (she would stay in the auction till a price of 56). In the second-price sealed-bid auction the ordering of equilibrium bids follows the ordering of signals: $(b_1^S, b_2^S, b_3^S) = (33, 0, 22)$. Hence, in the second-price sealed-bid auction bidder 1 obtains the object, which is not efficient.

### 3.2.3 Expected Revenues in the second-price sealed-bid auction

To calculate the seller's expected revenue we assume without loss of generality that bidder 2 determines prices. Then either bidder 1 has the lowest signal and bidder 3 the highest signal, or vice versa. The seller's expected revenue is

$$R_s = 3\left(\int_0^1\int_{s_1}^1\int_{s_2}^1 b(s_2)\,ds_3\,ds_2\,ds_1 + \int_0^1\int_{s_3}^1\int_{s_2}^1 b(s_2)\,ds_1\,ds_2\,ds_3\right) = \frac{1}{8}(4+3\alpha) \tag{23}$$

Note that for $\alpha \leq 1$ the seller expects the same revenue as in the English auction! Since the respective allocation functions are not the same, the equality of expected revenues is not a corollary of the revenue equivalence theorem but a coincidence that occurs for the specific parameters used here.

Similarly the ex-ante sum of the three bidder's expected gain $G_s$ can be calculated.

$$\begin{aligned} G_s \quad = \quad & 3\cdot\left(\int_0^1\int_{s_1}^1\int_{s_2}^1 s_3+\alpha\cdot s_1 - b_S(s_2)\,ds_3\,ds_2\,ds_1 + \right. \\ & \left. \int_0^1\int_{s_3}^1\int_{s_2}^1 s_1+\alpha\cdot s_2 - b_S(s_2)\,ds_1\,ds_2\,ds_3\right) = \frac{1}{4} \end{aligned} \tag{24}$$

Note that, while the expected revenues of the seller are the same under the English auction and the second-price sealed-bid auction, the bidders' expected payoffs differ. The efficiency loss occurring in the second-price sealed-bid auction is fully born by the bidders.

# 4 Experimental Results

As described in section 2 both the English auction and the second-price sealed-bid auction are implemented as ascending clock auctions. In the English auction participants observe during the course of the auction at which bid which bidders leave the auction. In the second-price sealed-bid auction this information is not available. In both cases the clock stops when only one bidder remains in the auction. Hence, in both cases we observe the bids of the first and the second dropper.

In sections 4.1 and 4.2 we will analyse the empirical bidding behaviour. We will find bidding functions in most situations to be in line with equilibrium recommendations, except the bids of the right bidder in the English auction. This motivates the introduction of a second reference case (in addition to the equilibrium strategies) in section 4.3. In section 4.4 we will then study empirical efficiency. Even if the right bidder does not follow equilibrium recommendations the English auction is still more efficient than the second-price sealed-bid auction. We will give a theoretical argument supporting this fact. In sections 4.5 and 4.6 we will study sellers' gains and bidder's payoffs. In line with equilibrium recommendations bidders are better of with the English auction than the second-price sealed-bid auction. Sellers are indifferent among the two auctions formats.

## 4.1 Initial bids

In section 4.1.1 we will have a brief look at the raw bids in the first stage. In section 4.1.2 we will then estimate bidding functions with the help of a censored normal regression.

### 4.1.1 Raw data

In order to study the relation between initial bids and signals we show in figure 1 bids that are normalised to compensate for different weights $\alpha$: The left graph shows $\hat{b}_0/(1+\alpha)$ for the English auction and the right graph shows $\hat{b}_0/(1+\frac{3}{4}\alpha)$ for the second-price sealed-bid auction. Each dot represents one initial bid.

[Figure 1 about here.]

Both for the English auction and the second-price sealed-bid auction smoothed median bids of the first dropper are monotonically increasing in $s_0$. In the English auction this monotonicity is crucial, since it allows bidders in the second stage to infer the first dropper's signal from her bid.

We also observe some inertia: When signals are low subjects bid slightly more than the equilibrium value, while, when signals are high, subjects bid slightly less.[2]

### 4.1.2 Estimating the bidding function

We explain the bid of the first dropper as a linear function of this person's signal:

$$b_0 = \beta \cdot s \tag{25}$$

In the second-price sealed-bid auction we observe bids for the first two droppers. The winning bid is only known to be higher than the two observed bids.

In the English auction we observe the initial bid $\hat{b}_0$ for a unique bidder (the first dropper). For the remaining two bidders we only know that their unobserved initial bids $\hat{b}_{0,\mathrm{L}}$ and $\hat{b}_{0,\mathrm{R}}$ must have been larger then $\hat{b}_0$.

We estimate equation 25 with the help of a censored-normal regression. In the English auction one realisation of the dependent variable is known and the other two are right censored. In the second-price sealed-bid auction, two realisations are known, and the remaining one is right-censored. Calling the lowest bid $\hat{b}_0$ and the second-lowest bid $\hat{b}''$, bids enter the censored-normal regression as shown in the following table:

| | | first bidder | second bidder | winner |
|---|---|---|---|---|
| English auction | $b_0$ | $= \hat{b}_0$ | $\geq \hat{b}_0$ | $\geq \hat{b}_0$ |
| Second-price sealed-bid auction | $b_0$ | $= \hat{b}_0$ | $= \hat{b}''$ | $\geq \hat{b}''$ |

[2] Kagel et al. [KHL87] and other researchers report bidding above the level determined by the dominant strategy in a second-price auction with private values (where winner's curse does not play a role). For English auctions they observe quick convergence to the bids consistent with the dominant strategies. Over-bidding by low signal bidders in English auctions with pure common values is reported in Kagel and Levin [KL92].

We estimate equation 25 separately for each weight. Figure 2 shows the dependence of $\beta$ on $\alpha$ and on the type of the auction.

[Figure 2 about here.]

The figure qualitatively confirms equilibrium predictions. Initial bids in the English auction are higher than bids in the second-price sealed-bid auction. However, bids are significantly below equilibrium in the second-price sealed-bid auction which they are not in the English auction. We relate this finding to the fact that over-bidding in the second-price sealed-bid auction is immediately punished and, hence, soon avoided. Over-bidding in the first stage of the English auction, however, has often no effect at all. The strategy is only relevant when the two other bidders leave the auction simultaneously at a lower price — an event that does not occur very often and therefore possibly does not receive much strategic consideration.

## 4.2 Bids in the second stage of the English auction

Following the equilibrium bidding functions given in equations 5 and 9 we explain bids in the second stage as a linear function of the first bid, the second dropper's own signal, and a constant.

As in the estimation of the initial bid, we do not observe all realisations of the dependent variable. Hence, we use the censored-normal regression approach again. Calling the lowest bid $\hat{b}_0$ and the second-lowest bid $\hat{b}''$, bids enter the censored-normal regression as shown in the following table:

| | first bidder | second bidder | | winner | |
|---|---|---|---|---|---|
| | | left of 1st | right of 1st | left of 1st | right of 1st |
| $b_L$ | $\geq \hat{b}_0$ | $= \hat{b}''$ | $\geq \hat{b}_0$ | $\geq \hat{b}''$ | $\geq \hat{b}_0$ |
| $b_R$ | $\geq \hat{b}_0$ | $\geq \hat{b}_0$ | $= \hat{b}''$ | $\geq \hat{b}_0$ | $\geq \hat{b}''$ |

We normalise coefficients to disentangle the influence of $\alpha$ from the other effects and estimate bidding functions for $\alpha < 1$ as follows:

$$b_L = \beta_1^i s_L + \beta_2^i \frac{\alpha}{1+\alpha} b_0 + 100 \cdot (1+\alpha) \beta_3^i \tag{26}$$

$$b_R = \beta_1^i \frac{1}{1-\alpha} s_R + \beta_2^i \frac{-\alpha^2}{1-\alpha^2} b_0 + 100 \cdot (1+\alpha)\beta_3^i \tag{27}$$

The normalisation of the coefficients that describe linear influence of own signal and the bid of the first dropper follows the equilibrium prediction (see equations 5 and 9) such that in equilibrium coefficients $\beta_1 = \beta_2 = 1$. Normalising the constant part of the estimation cannot be based on the equilibrium bidding strategies, since these do not include a constant. As we will see in figure 4 below, a constant that increases with $\alpha$ can explain a substantial part of the actual bidding behaviour. We normalise, hence, the constant as $100 \cdot (1+\alpha)$, which is the maximal valuation of an object.

The result of estimating equations 26 and 27 for $\alpha < 1$ and for each individual separately (again with a censored regression) is shown in figure 3.

[Figure 3 about here.]

The figure confirms that most left bidders (shown as '$\circ$' in the graphs) are indeed relatively close to the equilibrium behaviour (point 'A' in both graphs). Left bidders are a little less sensitive to their own signal which is compensated by an increased sensitivity to the first dropper's signal and a small constant part.

Right bidders (shown as '+'), however, do not follow the equilibrium prediction when $\alpha < 1$. They are closer to point 'B' in the graph, i.e. they do not react much to the signal of the first dropper and also react much too little to their own signal. This is compensated by a substantial constant part of the bidding function.[3] Right bidders are, however, not completely insensitive to their own signal. Figure 4 shows estimates of absolute sensitivities to signals and bids following equations 28 and 29.

[Figure 4 about here.]

[3] Kagel et al. [KLR96] report experimental results about information processing in English pure common value auctions. They find that the signal of the first dropper is correctly inferred, but that bidders follow a simple strategy where bids are based on an average of own signal and the first dropper's signal

$$b_{\mathrm{L}} = \beta_1 s_{\mathrm{L}} + \beta_2 b_0 + 100 \cdot (1+\alpha)\beta_3 \quad (28)$$

$$b_{\mathrm{R}} = \beta_1 s_{\mathrm{R}} + \beta_2 b_0 + 100 \cdot (1+\alpha)\beta_3 \quad (29)$$

We see that in absolute terms right bidders are even slightly more sensitive to their own signal than left bidders are. Right bidders are far away from the equilibrium bidding function which would require them to have a sensitivity $\beta_1$ as high as 10 for $\alpha = 0.9$.

In the case of $\alpha \geq 1$ right bidders do not follow the equilibrium recommendation either. In equilibrium they should always wait until the left bidder has left the auction. Figure 5 shows the relative fraction of auctions where the bidder to the right of the first dropper wins.

[Figure 5 about here.]

The fraction of right winners for $\alpha \geq 1$ is only marginally larger than for $\alpha < 1$.

## 4.3 A second reference case: The naive right bidder

Given that the right bidder in the English auction strongly deviates from the equilibrium recommendation we consider, in addition to the equilibrium, a second reference case: The first dropper and the bidder left to the first dropper follow their equilibrium bidding functions as described in equations 3 and 4. The bidder right to the first dropper, however, bids according to

$$\tilde{b}_{\mathrm{R}} = (1+\alpha)\,. \quad (30)$$

This bidding strategy corresponds to point 'B' in figure 3. We will call this second reference case the 'case of a naive right bidder'. Notice that, given a naive right bidder the equilibrium strategies in the first stage and of the left bidder are still best replies.

## 4.4 Efficiency

In this section we study the efficiency properties of the English auction and the second-price sealed-bid auction, i.e. we inquire whether the object is allocated to the bidder with the highest valuation.

We know that the equilibrium of the English auction yields an efficient allocation for all realisations of signals as long as $\alpha < 1$, whereas the second-price sealed-bid auction is not always efficient (even for $\alpha < 1$, see the example given in section 3.2.2 above).

[Figure 6 about here.]

Even in the case of a naive right bidder the English auction is more efficient than the equilibrium allocation for sufficiently large $\alpha$.

For the analysis of the experimental results we measure efficiency in two different ways.

[Figure 7 about here.]

The upper part of figure 7 shows relative frequency of efficient allocations. On the left we show the results for all auctions. As in equilibrium, efficiency is higher in the English auction. The middle and right part of figure 7 distinguish between ‘simple’ and ‘hard’ cases in an attempt to better understand where the additional efficiency in the English auction is gained. ‘Simple’ auctions correspond to realisations of signals where the bidder with the highest signal has also the highest valuation. In such settings monotonicity of bids alone is sufficient for efficiency, and both auctions types are theoretically efficient. This seems to be supported by our data. ‘Hard’ auctions correspond to realisations of signals where the bidder with the highest valuation is not the bidder with the highest signal. In these cases the English auction theoretically achieves full efficiency (as long as $\alpha < 1$) while the second-price sealed-bid auction is never efficient. While in our experiment the English auction does not reach full efficiency, the relative frequency of efficient allocations is considerably higher than in the second-price sealed-bid auction. To conclude, efficiency is higher in hard cases, where it is supposed to be higher and approximately the same in simple cases, where it is supposed to be the same.

Figure 7 also shows that efficiency decreases in $\alpha$, i.e., the more complex the situation becomes, the harder it is for participants to find the efficient allocation. Moreover, both auction formats yield more efficiency in simple cases.

Measuring relative frequency of efficient allocations does not distinguish between missing the efficient allocation by a substantial amount or only slightly. A second approach is shown in the lower part of figure 7. Let $v_1$, $v_2$, $v_3$ be the valuations of the three players. Let $v^*$ be the valuation of the winner, let $v_{\text{rand}} := (v_1+v_2+v_3)/3$ be the average value, and let $v_{\max} := \max_i v_i$ be the maximal value. Then $(v^* - v_{\text{rand}})/(v_{\max} - v_{\text{rand}})$ measures the degree of efficiency. Note that both measures are 1 if allocations were always efficient (e.g., for $\alpha < 1$ in the equilibrium of the English auction). This measure of efficiency confirms the results obtained above.

To summarise this section, we have found that efficiency properties of the two auction schemes are in line with equilibrium predictions. At first glance this may be surprising since at least one of the bidders in the English auction, the right bidder, does not seem to follow the equilibrium recommendation. However, as we have seen at the beginning of this section, even with an extremely 'naive' right bidder the English auction still has superior efficiency properties. Having said that, the next step will be to find out who bears the efficiency loss in the second-price sealed-bid auction — the seller or the bidders. We investigate this question in the next section.

## 4.5 The seller's expected revenue

We now focus on the revenue to the seller. From equations 17 and 23 we know that the equilibrium expected seller's revenue in the English auction is the same as in the second-price sealed-bid auction.

[Figure 8 about here.]

Even in the extreme case of a naive right bidder in the English auction expected sellers' revenues are similar to expected equilibrium revenues in the second-price sealed-bid auction (see the left part of figure 8).

[Figure 9 about here.]

This property can also be found in our experimental data. The left part of figure 9 shows the seller's expected revenues. These revenues are very similar for both types of auctions. To confirm that, we estimate the following equation:

$$R = 100 \cdot \begin{cases} \beta_e \cdot \frac{1}{8}(4+3\alpha) & \text{English auction, if } \alpha < 1 \\ \beta'_e \cdot \frac{1}{8}(5+2\alpha) & \text{English auction, if } \alpha \geq 1 \\ \beta_s \cdot \frac{1}{8}(4+3\alpha) & \text{second-price sealed-bid auction} \end{cases} \tag{31}$$

$\beta_e$ measures sensitivity to $\alpha$ in the English auction, $\beta_s$ measures sensitivity to $\alpha$ in the second-price sealed-bid auction, and $\beta'_e$ takes care of the kink in the seller's revenue in the English auction at $\alpha = 1$. All coefficients should be 1 in equilibrium.

[Table 1 about here.]

The results of a robust regression (allowing for correlated observations within each of our six experiments) shown in table 1 are in line with the equilibrium prediction. In particular we find that $\beta_e$ and $\beta_s$ are not significantly different[4].

## 4.6 Bidders' expected payoffs

As we have seen above in equations 18 and 24 bidders should be better off in the equilibrium of the English auction than in the equilibrium of the second-price sealed-bid auction. This holds also for the case of a naive right bidder as we see in the right part of figure 8. Naive bidding has only a relatively small cost which is for sufficiently large $\alpha$ compensated by the remaining efficiency gains of the English auction.

The superiority of the English auction also holds in the experiment: The right part of figure 9 shows that, for each $\alpha$, bidders' gain is higher in the English auction than in the second-price sealed-bid auction.

[4] An F-Test shows that $F(1,5) = 0.44$.

To confirm that, we estimate the following robust regression (allowing for correlated observations within experiments)[5]:

$$G = 100 \cdot \begin{cases} \beta_E \cdot \frac{2+\alpha^2}{8} + c \cdot \frac{1}{4} & \text{English auction, if } \alpha < 1 \\ \beta_E \cdot \frac{3\alpha-2}{8} + c \cdot \frac{1}{4} & \text{English auction, if } \alpha \geq 1 \\ \beta_S \cdot \frac{2+\alpha^2}{8} + c \cdot \frac{1}{4} & \text{second-price sealed-bid auction, if } \alpha < 1 \\ \beta_S \cdot \frac{3\alpha-2}{8} + c \cdot \frac{1}{4} & \text{second-price sealed-bid auction, if } \alpha \geq 1 \end{cases} \tag{32}$$

[Table 2 about here.]

By equations 18 and 24 we should expect $\beta_E = 1$, $\beta_S = 0$, and $c = 1$. Indeed $\beta_S$ is significantly smaller than $\beta_E$ — bidders' revenue is higher under the English auction than under the second-price sealed-bid auction. However, all coefficients are smaller than the equilibrium prediction. Again we attribute this finding to a some over-bidding that results in smaller payoffs for bidders.

# 5 Conclusion

We have experimentally compared an English auction with a second-price sealed-bid auction in a setting where bidders' valuations are asymmetric and interdependent. In our setting the logic governing equilibrium behaviour is relatively complex. Nevertheless, we generally find that the experimental results are well aligned with theoretical predictions.

In the English auction we find that participants do not always correctly use the information that is revealed during the bidding process if the inference problem is too complex (i.e., for the right bidders). Still, bidders' information processing is sufficient in order to achieve significantly more efficiency in the English auction. The additional efficiency of the English auction is obtained only in 'hard' cases, i.e. in cases where the English auction is theoretically efficient while the second-price sealed-bid auction is not. In 'simple' cases where both auction types are

[5] The equilibrium of the second-price sealed-bid auction does not tell us how to normalise $\beta_S$ since in equilibrium $\beta_S = 0$. Therefore we take the same normalisation for $\beta_S$ that we also take for $\beta_E$.

theoretically efficient, we find that both auction types are equally efficient in the experiment, and that the measures of efficiency are indeed quite high.

We also find that the seller's expected revenue is close to the theoretically predicted value and, as predicted by theory, this revenue is not affected by the type of the auction.

Finally, we find that bidders are better off in the English auction than in the second-price sealed-bid auction. This finding agrees well with the theoretical observation that the efficiency loss in the second-price sealed-bid auction is fully born by the bidders.

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# A List of experiments

| | Experiment | # Participants | # Auctions | α | sealed bid | Euro/Taler |
|---|---|---|---|---|---|---|
| 1. | 1 | 15 | 10 | .5 | 0 | .05 |
| 2. | 1 | 15 | 10 | .5 | 1 | .05 |
| 3. | 1 | 15 | 10 | .5 | 0 | .05 |
| 4. | 1 | 15 | 10 | .9 | 0 | .05 |
| 5. | 1 | 15 | 10 | .9 | 1 | .05 |
| 6. | 1 | 15 | 10 | .9 | 0 | .05 |
| 7. | 1 | 15 | 10 | 1.5 | 0 | .05 |
| 8. | 2 | 12 | 8 | .5 | 0 | .0375 |
| 9. | 2 | 12 | 8 | .5 | 1 | .0375 |
| 10. | 2 | 12 | 8 | .5 | 0 | .0375 |
| 11. | 2 | 12 | 8 | .8 | 0 | .0375 |
| 12. | 2 | 12 | 8 | .8 | 1 | .0375 |
| 13. | 2 | 12 | 8 | .8 | 0 | .0375 |
| 14. | 2 | 12 | 8 | 1.2 | 0 | .0375 |
| 15. | 2 | 12 | 8 | 1.2 | 1 | .0375 |
| 16. | 2 | 12 | 8 | 1.2 | 0 | .0375 |
| 17. | 2 | 12 | 8 | .5 | 0 | .0375 |
| 18. | 3 | 18 | 8 | .5 | 0 | .0425 |
| 19. | 3 | 18 | 8 | .5 | 1 | .0425 |
| 20. | 3 | 18 | 8 | .5 | 0 | .0425 |
| 21. | 3 | 18 | 8 | .9 | 0 | .0425 |
| 22. | 3 | 18 | 9 | .9 | 1 | .0425 |
| 23. | 3 | 18 | 8 | .9 | 0 | .0425 |
| 24. | 3 | 18 | 8 | 2 | 0 | .0425 |
| 25. | 4 | 15 | 8 | .5 | 0 | .0425 |
| 26. | 4 | 15 | 8 | .5 | 1 | .0425 |
| 27. | 4 | 15 | 8 | .5 | 0 | .0425 |
| 28. | 4 | 15 | 8 | .9 | 0 | .0425 |
| 29. | 4 | 15 | 8 | .9 | 1 | .0425 |
| 30. | 4 | 15 | 8 | .9 | 0 | .0425 |
| 31. | 4 | 15 | 8 | 1.7 | 0 | .0425 |
| 32. | 4 | 15 | 4 | 1.7 | 1 | .0425 |
| 33. | 5 | 18 | 8 | .5 | 0 | .0425 |
| 34. | 5 | 18 | 8 | .5 | 1 | .0425 |
| 35. | 5 | 18 | 8 | .5 | 0 | .0425 |
| 36. | 5 | 18 | 8 | .7 | 0 | .0425 |
| 37. | 5 | 18 | 8 | .7 | 1 | .0425 |
| 38. | 5 | 18 | 8 | .7 | 0 | .0425 |
| 39. | 5 | 18 | 8 | 1 | 0 | .0425 |
| 40. | 6 | 18 | 8 | .5 | 0 | .0425 |
| 41. | 6 | 18 | 8 | .5 | 1 | .0425 |
| 42. | 6 | 18 | 8 | 1.1 | 0 | .0425 |
| 43. | 6 | 18 | 8 | 1.1 | 0 | .0425 |
| 44. | 6 | 18 | 8 | 1.1 | 1 | .0425 |
| 45. | 6 | 18 | 8 | .3 | 1 | .0425 |
| 46. | 6 | 18 | 8 | .3 | 0 | .0425 |
| 47. | 6 | 18 | 8 | .3 | 0 | .0425 |
| 48. | 6 | 18 | 8 | .5 | 0 | .0425 |

# B Instructions

## Welcome to a strategy experiment

*This strategy experiment is financed by the Deutsche Forschungsgemeinschaft. The instructions are simple. If you take them into account carefully, decide sensibly, and also take into account the reasoning of the other players, you will gain a serious amount of money payed to you in cash at the end of the game.*

*Your payoff depends on your success. For each "Taler" that you obtain in the experiment you receive 0.05 Euro. We have already carried out similar experiments. From the experience that we have gained there, we expect that, depending on your strategy, you will today obtain between 15 Euro and 35 Euro.*

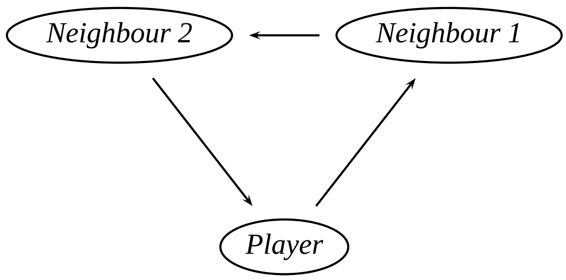
*Please note that we do not want to pay you less money than what you deserve. All the money that we do not give to participants, must be returned to the Deutsche Forschungsgemeinschaft.*

## Rules of the game

*Please note that we do not cheat during this experiment. Everything that you read in these instructions is true. This may sound trivial, but, sometimes psychologists do experiments where participants are deceived about parts of the experiment. This is not the case with economic experiments, like this one. We will explain the rules of the game and we will stick to them!*

*The game will be played in groups of 3 persons each. Allocation to groups will be determined by a random process. During the experiment groups will be reallocated repeatedly, again using a random mechanism.*

*Each group will play several auctions. Each member of a group has two neighbours, neighbour one and neighbour two. Imagine that the members of a group are sitting around a table.*




*Neighbour one is always the right neighbour. Neighbour two is, in turn, to the right of neighbour one. Also neighbour one has two neighbours. His or her right neighbour is the person that is, for you, neighbour two. His or her left neighbour is you. Finally also neighbour two has two neighbours. His neighbour one is you. His neighbour two is the person that is your right neighbour.*

*If this sounds complicated to you, please recall that in a sense all members of a group are sitting around a round table, and neighbour one for each player is always the person sitting to the right.*

Auction 10

Your Signal is **37**. The Value of the object for you is **37** plus 0.5 times **the signal of your right neighbour**

| Your Value | | Signal of your right neighbour | Value for your right neighbour depending on the signal of your left neighbour | | | Signal of your left neighbour | Value for your left neighbour depending on the signal of yourself | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 0 | 50 | 100 | | 0 | 50 | 100 |
| 87 | $= 37 + 0.5 \cdot 100$ | 100 | 100 | 125 | 150 | 100 | 100 | 125 | 150 |
| 74.5 | $= 37 + 0.5 \cdot 75$ | 75 | 100 | 125 | 150 | 75 | 100 | 125 | 150 |
| 62 | $= 37 + 0.5 \cdot 50$ | 50 | 100 | 125 | 150 | 50 | 100 | 125 | 150 |
| 49.5 | $= 37 + 0.5 \cdot 25$ | 25 | 100 | 125 | 150 | 25 | 100 | 125 | 150 |
| 37 | $= 37 + 0.5 \cdot 0$ | 0 | 100 | 125 | 150 | 0 | 100 | 125 | 150 |

In each auction each person receives a signal. This signal is a number drawn randomly between 0 and 100. All numbers between 0 and 100 are equally likely. The signal of a person in the current auction is only known to the person itself. Signals are shown at the top border of each individual screen.

When all members of a group of 3 persons have received their signal, an object will be auctioned. The person that manages to obtain the object receives a certain amount of “Taler” on his or her account. This amount is determined as the person’s own signal plus 0.5 times the signal of the person’s right neighbour. The signal of the person’s left neighbour is of no influence on the value.

To make this relationship more clear, the screen (left part of the table) shows a table that represents the value of the object depending on the signal of your right neighbour. Since the same relation also holds for your right neighbour we also show (middle part of the table) how the value of the object for your right neighbour depends on the signal of his right neighbour (your left neighbour). The right part of the table also shows this relation for the value of the object for your left neighbour. Notice that the middle part of the table and the right part of the table are identical and do not change during the course of the game. The left column, however, is different in each auction. It changes always with your signal.

You always know your own signal. You can deduce the signal of your right neighbour from the behaviour of the other players in the auction.

**Middle part of the screen: Bids**

| Your Bid | Right Neighbour | Left Neighbour |
|---|---|---|
| 54 | 54 | 22 |

In the middle of the screen, on the left you see a button that shows your bid slowly counting upwards like a clock. When you push this button, you leave the auction. When only one person remains in the auction, this person leaves automatically and obtains the object at the price that is currently indicated, i.e. the price where the previous bidder left the auction.

The bids of your left and right neighbour will be visible on the screen in some rounds. As long as they have not yet left the auction their bid is also counting upwards and shown on a red background. As soon as they leave the auction their clock stops and is shown on a blue background.

We will play some auctions, where you will not receive this information. In this case you see question marks in place of your neighbours' bids. Please note that in this case also your neighbours do not receive any information about your bids.

**Lower part of the screen: Past**

| Round 3 | Your data (gain=8.16 Euro) | | | Right neighbour | | | Left neighbour | | |
|---|---|---|---|---|---|---|---|---|---|
| Auction... | Signal | Bid | Payoff | Signal | Bid | Payoff | Signal | Bid | Payoff |
| 9 | 60 | 80 | (-10) | 20 | 20 | (-10) | 100 | 80 | **50** |
| 8 | ... | ... | ... | ... | ... | ... | ... | ... | ... |

In the lower part of the screen we give you an overview about the past auctions.

The first line in the table shows your total gain in Euro.

The following lines show for you as well as for your neighbours the signal, bid and the payoff. The payoff of the person that has obtained the object is shown on red background. We show a (hypothetical) payoff also for the other persons. This is the (hypothetical) amount that the person had obtained if the person had not left the auction until its end.

Let us consider auction 9 from the example. Your signal is 60, the signal of your right neighbour is 20. The value of the object for you is, hence, $60 + 0.5 \cdot 20 = 70$. The highest bid is 80. Were you to obtain the object at this price your payoff would be $70 - 80 = -10$.

Let us now consider your left neighbour. This person has signal 100. Your signal was 60. The value of the object for your left neighbour is, hence, $100 + 0.5 \cdot 60 = 130$. The price payed by your left neighbour was 80. His payoff is $130 - 80 = 50$. Since the object is indeed obtained by your left neighbour, the payoff of 50 is shown on red background.

If you have questions, you have now the opportunity to ask them. You can always ask questions during the experiment.

We will first play some auctions to get used to the game. Then we will make a little break to give you the opportunity to ask questions.

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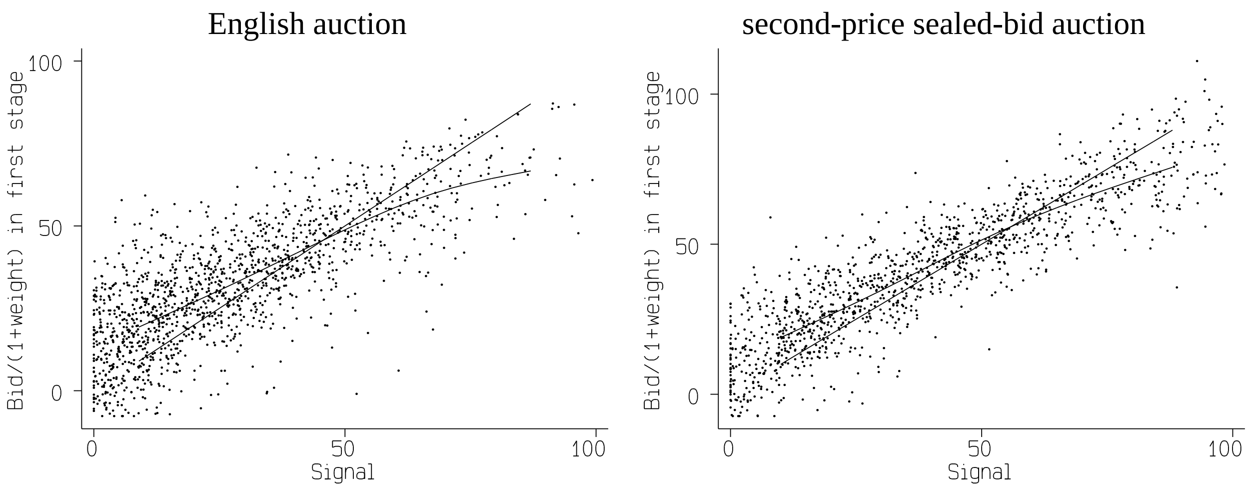
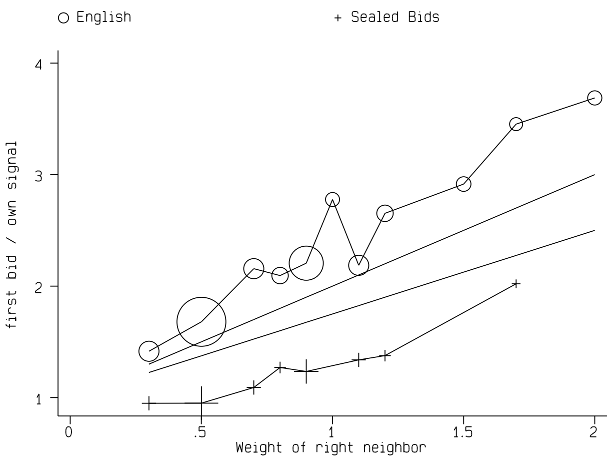


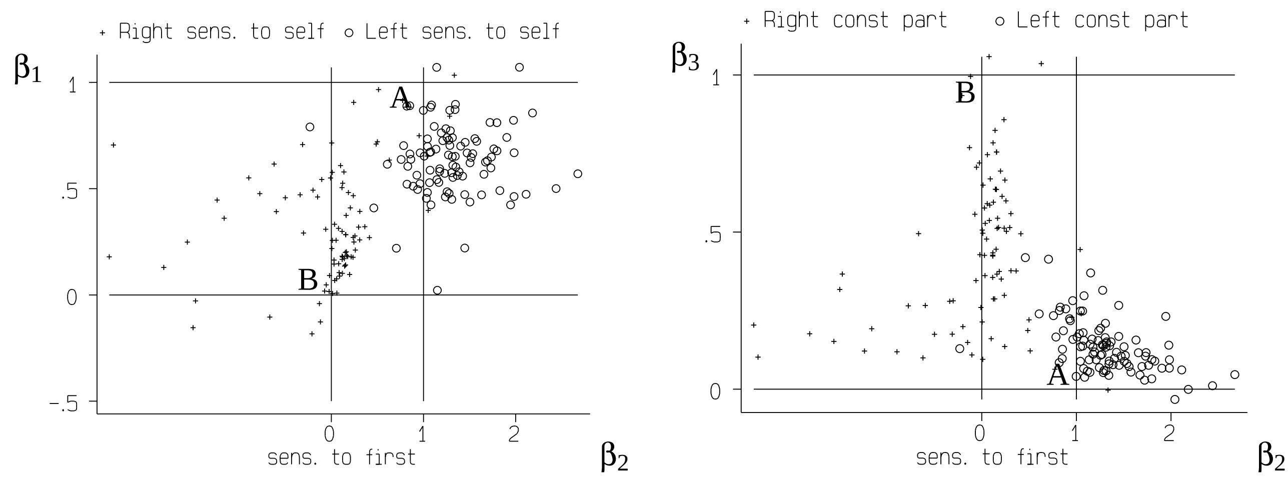

Dots show $\hat{b}_0/(1+\alpha)$ for the English auction and $\hat{b}_0/(1+\frac{3}{4}\alpha)$ for the second-price sealed-bid auction. Curves are splines through five median bands. The diagonal line shows the equilibrium values.

Figure 1: Monotonicity of first bid




The vertical axis shows $\beta$ as estimated (for each $\alpha$ separately) from $\hat{b}_0 = \beta \cdot s$. Straight lines show $s \cdot (1+\alpha)$ and $s \cdot (1+3\alpha/4)$ which are the equilibrium bids in the English auction and second-price sealed-bid auction respectively.

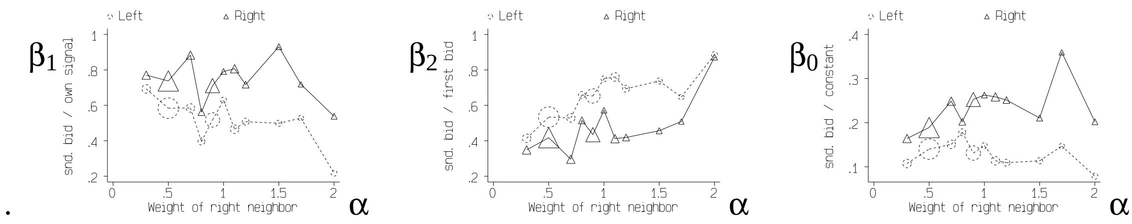
Figure 2: Bidding of the first dropper




The figure shows normalised estimations of the individual censored bidding functions from equation 26 and 27 for all auctions with $\alpha < 1$.

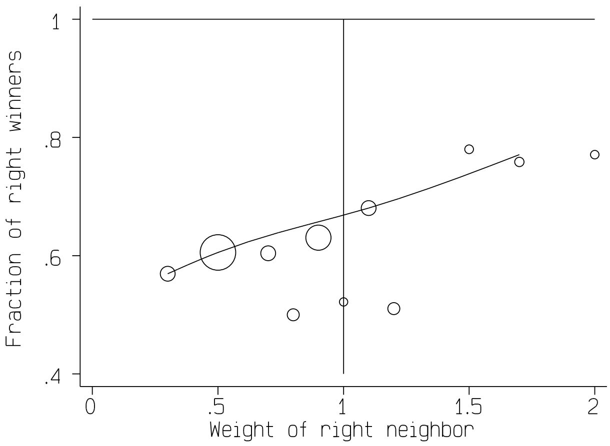
In equilibrium we have both for the left ($\circ$) and the right ($+$) bidder that $\beta_1 = 1$, $\beta_2 = 1$, and $\beta_3 = 0$ (point ‘A’ in both graphs). The case of a naive right bidder (see section 4.3) is located at point ‘B’.

Figure 3: Individual estimates for normalised bidding functions of the second stage



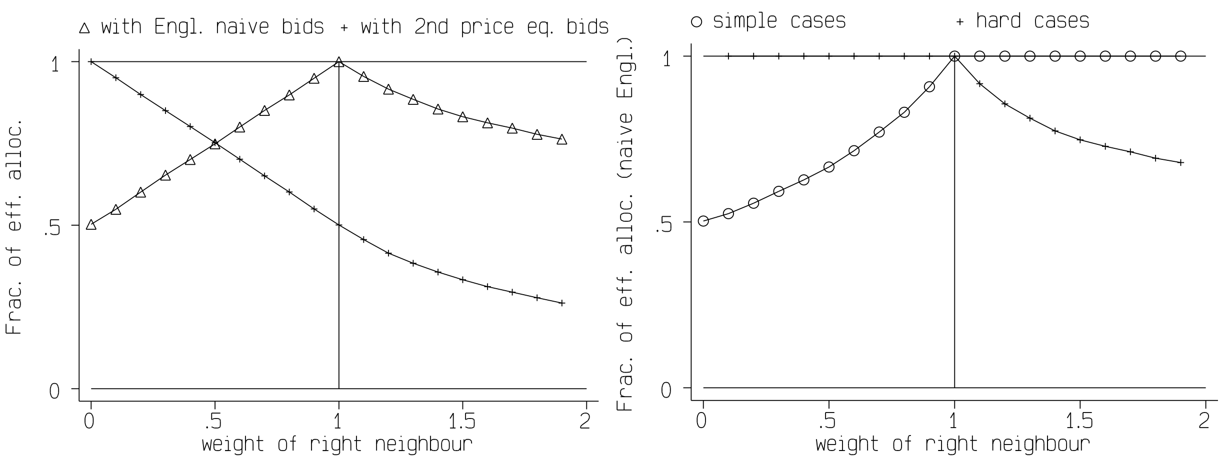

The figure shows absolute estimates of coefficients of the bidding functions 28 and 29. The estimation was done using a censored normal regression approach for each $\alpha$ separately.

Figure 4: Estimates of absolute bidding functions in the second stage




The figure shows the relative fraction of auctions where the bidder to the right of the first dropper wins. The curved line shows a median spline through four bands. Sizes of symbols are proportional to the number of observations.

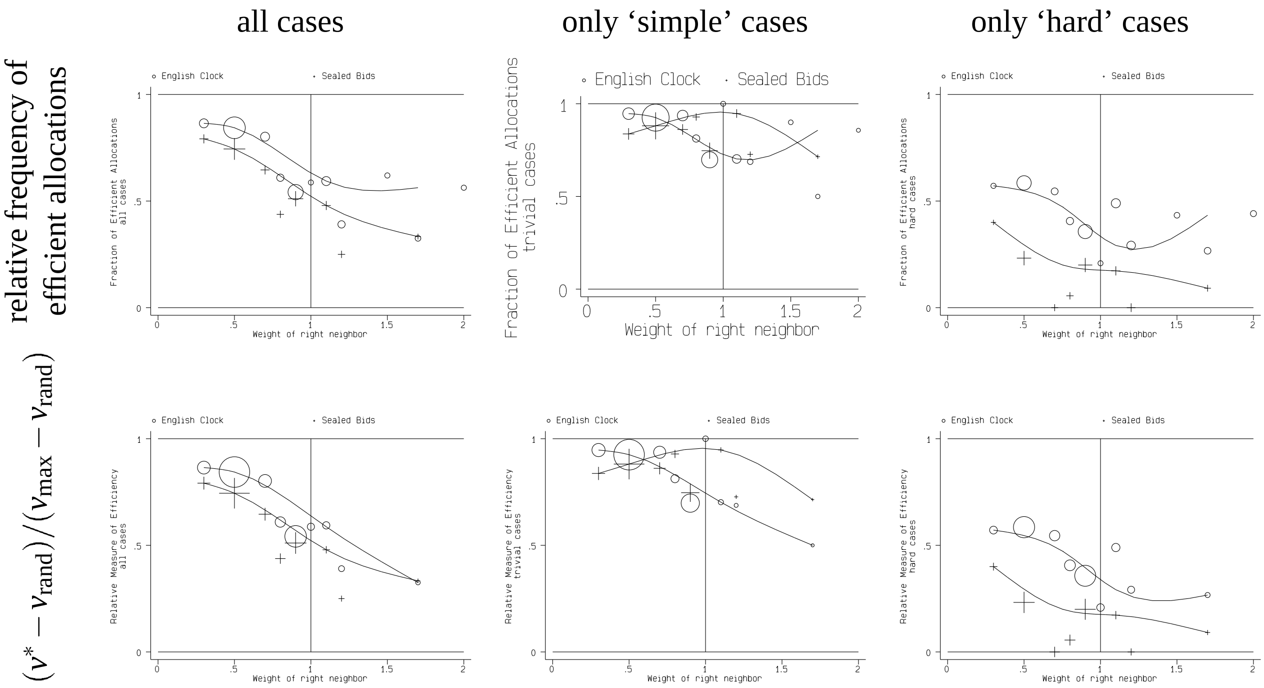
Figure 5: Relative fraction of right winners




The left graph compares the expected relative fraction of efficient allocations in two cases. The symbol $+$ marks the second-price sealed-bid auction, provided that participants follow equilibrium bidding functions. The symbol $\triangle$ marks the English auction, provided that participants are in the case of a naive right bidder.

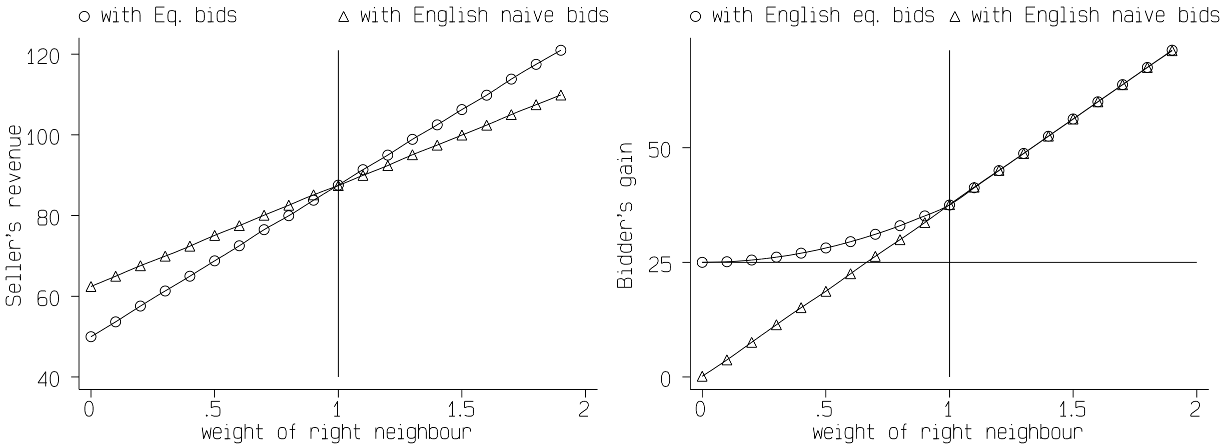
The right graph shows only for the English auction the expected fractions of efficient allocations for 'simple' and 'hard' cases (as defined in section 4.4) for the case of a naive right bidder.

Figure 6: Expected efficiency in the case of a naive right bidder in the English auction




Sizes of the symbols are proportional to the number of observations. Splines connect four median bands. The figure shows that the higher efficiency of the English auction is obtained primarily in ‘hard’ cases.

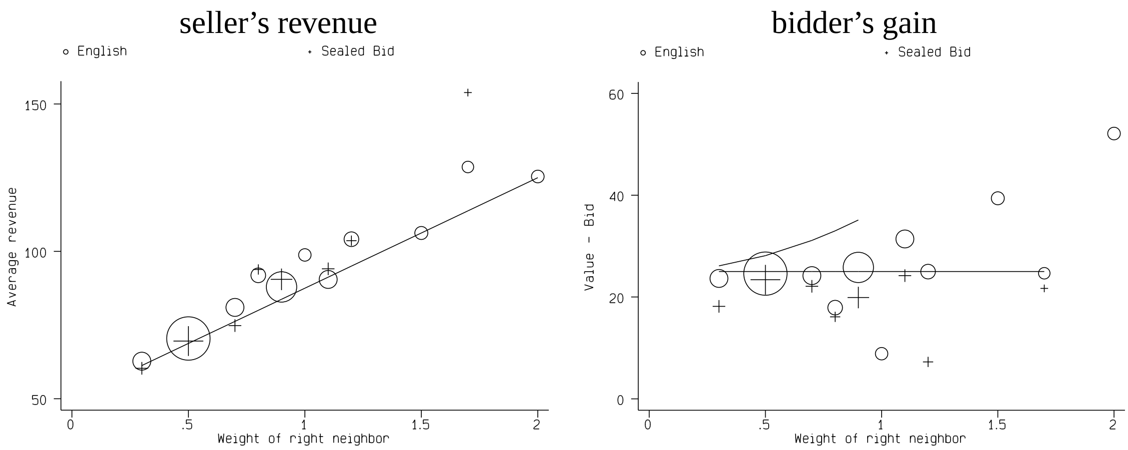
Figure 7: Empirical efficiency




The left part of the figure compares expected seller's revenue in the second-price sealed-bid auction in equilibrium (∘) with the English auction for the case of a naive right bidder(△). The seller's revenue in equilibrium of the English auction is the minimum of these two.

The right part of the figure shows expected bidder's gain for the English auction in equilibrium and the case of a naive right bidder.

Figure 8: Expected seller's revenue and bidder's gain with a naive right bidder




The left part of the figure shows average revenue for English auction and second-price sealed-bid auction. The straight line shows revenue in equilibrium (for $\alpha \geq 1$ only for the second-price sealed-bid auction).

The right part of the figure shows total bidders' gain (value$-$price). The curved line shows the equilibrium gain for the English auction, the straight line shows the equilibrium gain for the second-price sealed-bid auction.

Figure 9: Empirical revenue and gain

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| $R$ | $\beta$ | $\sigma_\beta$ | $t$ | $P > \lvert t \rvert$ | 95% conf. interval | |
|---|---|---|---|---|---|---|
| $\beta_e$ | 1.044862 | .0098444 | 106.137 | 0.000 | 1.019556 | 1.070168 |
| $\beta_s$ | 1.063437 | .0317715 | 33.471 | 0.000 | .9817656 | 1.145108 |
| $\beta'_e$ | 1.098719 | .03249 | 33.817 | 0.000 | 1.015201 | 1.182238 |

Robust regression estimate of equation 31. Following equations 17 and 23 we should expect $\beta_e = 1$, $\beta_s = 1$, and $\beta'_e = 1$.

Table 1: Estimation of revenue (equation 31)

| $G$ | $\beta$ | $\sigma_\beta$ | $t$ | $P > \|t\|$ | 95% conf. interval | |
|---|---|---|---|---|---|---|
| $\beta_E$ | .3981413 | .1276308 | 3.119 | 0.026 | .070056 | .7262267 |
| $\beta_S$ | -.1479799 | .1480071 | -1.000 | 0.363 | -.5284443 | .2324845 |
| $c$ | .8753965 | .0267222 | 32.759 | 0.000 | .8067049 | .944088 |

Robust regression estimate of equation 32. By equations 18 and 24 we should expect $\beta_E = 1$, $\beta_S = 0$, and $c = 1$.

Testing $\beta_E = \beta_S$ finds them significantly different ($F(1,5) = 6.78$).

Table 2: Estimation of bidders' expected payoff (equation 32)

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