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Could we overcome the Winner's Curse by (behavioral) Auction Design?

PRELIMINARY AND INCOMPLETE VERSION

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Abstract

The Winner's Curse (WC) is a non-equilibrium behavior in common-value auctions involving systematic and persistent overbidding that often results in significant losses. It is one of the most robust findings in laboratory experiments. We developed an auction mechanism with a payment rule that internalizes the adverse selection by inducing a simple strategy, sincere bidding, as *no-regret* equilibrium. Other less efficient payment rules, that use more than the *minimal* information needed, may also induce sincere bidding as equilibrium. However, given concerns with the WC, we study whether such less minimal rules can help bidders find their way to equilibrium bidding. Our main experimental findings are that the no-regret minimal payment rule results in more WC than the English auction. Yet, a less efficient but more intuitive payment rule addresses overbidding better than the minimal payment rule and, remarkably for a static, sealed-bid design, matches the performance of the English auction.

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1 Introduction

The Winner’s Curse (WC) - systematic overbidding that often results in losses - is a robust finding in experimental auction research. Bazerman and Samuelson (1983) and Kagel and Levin (1986) reported it for first-price auctions in common-value environments and it has been replicated widely, e.g., Lind and Plott (1991).¹ It has also been observed in other auctions formats such as second-price and English auctions, and in a wide range of common-value environments.²

Recently Eyster and Rabin (2005) and Crawford and Iriberri (2007) suggested behavioral explanations that allow for inconsistent belief formation while maintaining best-response behavior given beliefs. However, these models do not explain all deviations from equilibrium bidding.³ In particular overbidding relative to the equilibrium leading to the WC, seem to arise due to cognitive limitations as suggested by Charness and Levin (2009) studying individual choice and Charness, Levin, and Schmeidler (2012) studying the relation between the complexity of public information, estimation dispersion, and the adverse selection problem.

In this paper we attempt to overcome, at least mitigate, the WC by behavioral auction design aimed at simplifying bidders’ task of finding their way to the equilibrium bid strategy. We propose a direct mechanism that induces sincere (truthful) bidding, where each bidder bids her signal, as a simple and easier rule to follow. In the symmetric equilibrium of first-price, or second price, common-value auctions where each bidder possesses an *ex-ante* unbiased signal the bidder ought to bid, (often well), below her signal in order to correct for the adverse selection conditional in winning and avoid the WC. However, a commonly observed finding in experimental studies involving such auctions is that bidders bid lower but close to their signals and thus fall prey to the WC. Thus, our proposed mechanism caters to this behavioral tendency as it makes bidding one’s signal the correct bidding behavior.

The paper is organized as follows. In section 2 we present our theoretical framework and introduce auction formats that induce sincere bidding. In section 3 we describe our experimental design and in section 4 we report the results. Section 5 concludes with a short summary of our main findings.

2 Theoretical Considerations

The principle of our behavioral auction design is the simplicity of bidding from a bidder’s point of view. Since there seems nothing simpler for a bidder in a common-value auction than the submission of the observed signal as a bid, we first introduce an auction mechanism where sincere bidding is a *no-regret* equilibrium in a general common-value framework. Second, we demonstrate how this generally characterized auction mechanism can be applied to two prominent common-value models, the mineral-rights model and the signal-average model. Depending on the specific common-value model there can exist other auction mechanisms where sincere

¹Additional references can be found in Kagel and Levin (2002).

²For example, see Goeree and Offerman (2002), Levin, Kagel, and Richard (1996), Charness and Levin (2009), Ivanov, Levin, and Niederle (2010). For a study challenging it, see Hansen and Lott (1991).

³See Charness and Levin (2009) and Ivanov, Levin, and Niederle (2010) for common-value models and Kirchkamp and Reiß (2011) for the first-price private-value auction.

bidding is a Bayesian Nash equilibrium (BNE) but not a *no-regret* equilibrium.

2.1 Common-Value Framework and Ex-post Equilibrium Auction

Consider a general common-value framework where $(V, X) =: (V, X_1, \dots, X_n)$ denotes a vector of $(n + 1)$ random variables that are drawn from a joint distribution function and where, without loss of generality, we order the X_i 's such that $X =: \{X_1 \geq X_2 \geq \dots, \geq X_n\}$ and $X_{-i} =: \{X_1 \geq X_2, \dots, X_{i-1} \geq X_{i+1}, \dots, \geq X_n\}$ with x and x_{-i} , respectively, denoting the vectors of realizations. Assume that there exists a finite expected value conditional on realizations $E[V|x] =: h(x)$ with $\partial h(x)/\partial x_i \geq 0$, for all $i = 1, 2, \dots, n$. Consider a common-value auction with V denoting the common-value and with $n \geq 2$ risk-neutral bidders where each bidder i privately observes signal X_i . Let the common-value auction be a direct auction where bidder i reports her signal \tilde{x}_i with $\tilde{x} =: (\tilde{x}_1, \tilde{x}_2, \tilde{x}_3, \dots, \tilde{x}_n)$ and let the replacement mapping $\phi(\cdot)$ replace the highest reported signal by the second-highest reported signal, $\phi(\tilde{x}) =: (\tilde{x}_2, \tilde{x}_2, \tilde{x}_3, \dots, \tilde{x}_n)$.

Proposition 1 states that it is possible to induce sincere bidding in this general framework with a direct auction that allocates the object to the highest bidder for a price equal to the expected common-value conditional on the highest reported signal replaced by the second-highest one, $p = h(\phi(\tilde{x}))$. Specifically, this direct auction induces sincere bidding as an *ex-post* equilibrium.

Proposition 1 *The direct auction where the highest bidder wins and pays $h(\phi(\tilde{x}))$ induces sincere bidding, this is $\tilde{x} = x$, as no-regret BNE.*⁴

Proof. Consider a deviation by bidder $k = 1, 2, \dots, n$ assuming that all other bidders report their true signal. Bidder 1 wins by reporting truthfully and her expected payoffs are:

$$\begin{aligned} E[\pi_w(x)] &= E_{x_{-1}}\{[E[V|x] - h(\phi(x))]|x_1\} \\ &= E_{x_{-1}}\{[h(x) - h(\phi(x))]|x_1\} \\ &= E_{x_{-1}}\left\{\left[\int_{x_1}^{x_2} \frac{\partial h(x)}{\partial X_1} dX_1\right]|x_1\right\} \geq 0. \end{aligned}$$

Bidding higher will neither affect the outcome nor the price and bidding lower when it matters will result in zero payoffs rather than nonnegative. Any bidder $k \geq 2$ loses by bidding truthfully and earns zero. Bidding lower does not matter so consider a deviation up that matters this is $\tilde{x}_k > x_1$. Note that in such a case $\tilde{x} =: (\tilde{x}_k, x_{-k})$ and $\phi(\tilde{x}) =: (x_1, x_{-k}) > (x_1, x_{-1})$, so that $[h(x) - h(\phi(\tilde{x}))] < 0$. By deviating and winning bidder k earns expected payoffs of:

$$\begin{aligned} E[\pi_{k \geq 2}(x)] &= E_{x_{-k}}\{[E[V|x] - h(\phi(\tilde{x}))]|x_k\} \\ &= E_{x_{-k}}\{[h(x) - h(\phi(\tilde{x}))]|x_k\} \leq 0. \end{aligned}$$

Thus, a loser also does not wish to deviate. ■

⁴We use ex-post equilibrium with no regret vis a vis realization of others bidders private signals. There may be regret on the part of the winner or losers vis a vis realization of the common value V .

The equilibrium of this payment rule (that we refer to as Sophi from here on) “asks” bidders to simply bid their signals and thus allows unsophisticated bidders, who typically ignore the adverse selection, to avoid the WC. This contrasts with the more complex equilibrium strategies for common-value such as in first-price and English and auctions where generally bidders do not bid, or drop, at their signal. In the symmetric equilibrium of a first-price auction each bidder ought to behave as if holding the highest signal, then use quite complicated Bayesian calculation to correct her estimation for the value and finally decide on the proper shading for profits. In English auction each bidder typically (with the lowest signal holder as a possible an exception) drops at a lower clock price than their own signal while remaining bidders continuously correcting for the adverse selection inferred after each drop out. It is important to note that in either auction, Sophi or English, the winner is the bidder with the highest signal who receives the object and pays $p(\tilde{x}) = h(\phi(\tilde{x})) = E[V|\tilde{x}_2, \tilde{x}_2, \tilde{x}_3, \dots, \tilde{x}_n]$ as recorded in the corollary.

Corollary 2 *The Sophi auction and the English auction are allocation and price equivalent.*

Proof. In the English auction the highest signal holder wins the object and the price is set by the second-highest signal holder who, following Milgrom and Weber (1982), drops at precisely $h(\phi(\tilde{x}))$. ■

2.2 Two Common-Value Models

We show how sincere bidding can be induced with the Sophi auction in two common-value models that differ in the specification of the common value. The information structure of signals is the same in either model and follows the setup in Kagel and Levin (1986) and Levin, Kagel, and Richard (1996). Specifically let the random variable C be distributed uniformly on interval $[a, b]$ and denote its realization by c . Assume that conditional on $C = c$ the private signals X_i ($i = 1, \dots, n$) are i.i.d. with the uniform distribution on $[c - \varepsilon, c + \varepsilon]$.

2.2.1 Mineral-Rights Model

In the mineral-rights model we denote the common-value by V and assume that $V \equiv C$, so that signals are symmetrically distributed around the common value. The specification of the Sophi auction reduces to identifying the price rule that gives the common-value’s expected value conditional on the reported signals where the highest reported signal is replaced by the second-highest reported signal. For this case and given that the signals have a uniform distribution the average of the highest signal and the lowest signal form a sufficient statistic for the common-value V in our mineral-rights model. With replacing the highest reported signal by the second-highest reported signal, the price that a winner pays in the Sophi auction is,

$$\begin{aligned} p^{\text{Sophi}} &= h(\phi(\tilde{x})) = E[V|\phi(\tilde{x})] \\ &= \frac{\tilde{x}_2 + \tilde{x}_n}{2} \end{aligned}$$

2.2.2 Sincere Bidding with a Non-Minimal Payment Rule

Proposition 3 *The average pricing rule $p(x) = \frac{x_2+x_2+x_3+x_4}{4}$ induces sincere bidding as a BNE in the mineral-rights model.*

Proof. Assume that all but the k^{th} bidder ($k = 1, 2, \dots, n$) bid sincerely their signal and consider a deviation by the k^{th} bidder. For the winner, $k = 1$, in equilibrium, the expected payoff is

$$\begin{aligned}\pi_W &= E_{x_{-1}} \left\{ \left[V|x \right] - \frac{x_2 + x_2 + x_3 + x_4}{4} \middle| X_1 = x_1 \right\} \\ &= E_{x_{-1}} \left\{ \left[\frac{x_1 + x_4}{2} \right] - \left[\frac{x_2 + x_2 + x_3 + x_4}{4} \right] \middle| X_1 = x_1 \right\} \\ &= E_{x_{-1}} \left\{ \frac{2(x_1 - x_2) - (x_3 - x_4)}{4} \middle| X_1 = x_1 \right\} > 0\end{aligned}$$

as we show below in (*). Bidding higher (i.e. $b_1(x_1) > x_1$) will neither affect the outcome nor the price. Bidding lower (i.e. $b_1(x_1) < x_1$) either does not matter or results in zero profits rather than positive profits. For any loser, $k > 1$, bidding lower than their signals (i.e. $b_k(x_k) < x_k$) does not matter and bidding higher when it matters means $b_{k>1}(x_k) > x_1$ and results in the expected payoff

$$\begin{aligned}\pi_k &= E_{x_{-k}} \left\{ \frac{x_1 + x_4}{2} - \frac{x_1 + x_1 + (x_2 + x_3 + x_4 - x_k)}{4} \middle| X_k = x_k \right\} \\ &= E_{x_{-k}} \left\{ \frac{(x_k + x_4) - (x_2 + x_3)}{4} \middle| X_k = x_k \right\} \leq E_{x_{-k}} \left\{ \frac{(x_4 - x_3)}{4} \middle| X_k = x_k \right\} < 0.\end{aligned}$$

(*) It remains to show that $E_{x_{-1}} \left\{ \frac{2(x_1 - x_2) - (x_3 - x_4)}{4} \middle| X_1 = x_1 \right\} > 0$. Given that $X_1 = x_1 := x$, the random variable $V \in [x - \epsilon, x + \epsilon]$. Consider the case of a given $V = v$, we compute $E_{x_{-1}} \left\{ \frac{2(x_1 - x_2) - (x_3 - x_4)}{4} \middle| X_1 = x_1, V = v \right\}$. $E_{x_{-1}} \{x_1 | X_1 = x, V = v\} = x$. $E_{x_{-1}} \{X_2 | X_1 = x, V = v\} = \int_{v-\epsilon}^x (n-1)t \frac{f(t)}{F(x)} \left(\frac{F(t)}{F(x)}\right)^{n-2} dt = x - \int_{v-\epsilon}^x \left(\frac{F(t)}{F(x)}\right)^{n-1} dt = x - \frac{1}{n} \frac{[t-(v-\epsilon)]^n \Big|_{v-\epsilon}^x}{[x-(v-\epsilon)]^{n-1}} = x - \frac{[x-(v-\epsilon)]}{n}$. $E_{x_{-1}} \{X_3 | X_1 = x, V = v\} = \int_{v-\epsilon}^x (n-1)(n-2)t \frac{f(t)}{F(x)} \left[\frac{F(x)-F(t)}{F(x)}\right] \left(\frac{F(t)}{F(x)}\right)^{n-3} dt = \dots = x - \frac{2[x-(v-\epsilon)]}{n}$. $E_{x_{-1}} \{X_4 | X_1 = x, V = v\} = \int_{v-\epsilon}^x \frac{(n-1)(n-2)(n-3)}{2} t \frac{f(t)}{F(x)} \left[\frac{F(x)-F(t)}{F(x)}\right]^2 \left(\frac{F(t)}{F(x)}\right)^{n-4} dt = \dots = x - \frac{3[x-(v-\epsilon)]}{n}$. Collecting terms: $E_{x_{-1}} \left\{ \frac{2(x_1 - x_2) - (x_3 - x_4)}{4} \middle| X_1 = x, V = v \right\} = \frac{1}{4} \left[\frac{2[x-(v-\epsilon)]}{n} - \frac{[x-(v-\epsilon)]}{n} \right] = \frac{[x-(v-\epsilon)]}{16} > 0$. Since the last result holds for all $V = v$, by integration $E_{x_{-1}} \left\{ \frac{2(x_1 - x_2) - (x_3 - x_4)}{4} \middle| X_1 = x_1 \right\} > 0$. ■

2.2.3 Signal-Average Model

In the signal-average model we denote the common-value by W and assume that it is given by the average of signals, $W \equiv \frac{1}{n} \sum_{j=1}^n X_j$. In this model, there is no uncertainty about the common value if signals are reported sincerely since the realized common-value is simply the average of realized signals. It follows that the common-value's expected value conditional on reported signals after signal replacement is trivially given by

$$\begin{aligned}p^{\text{SigAv}} &= h(\phi(\tilde{x})) = E[V | \phi(\tilde{x})] \\ &= \sum_{j=1}^n \frac{\tilde{x}_j}{n} - \frac{\tilde{x}_1 - \tilde{x}_2}{n}\end{aligned}$$

3 Experimental Design

The main treatment variable in the experiment is varying the payment rule that induces sincere bidding studying whether and how well it mitigates the WC. We also vary the common-value model across treatments and study how an increase in the number of competing bidders (after twenty market periods) affects the results.

3.1 Treatments

Table 1 summarizes our treatment conditions. In our four main treatments 1-4 we implement the mineral-rights model and in treatments 5-6 we look at the signal-average model. In both common-value models we use the English auction as a basis for comparison. Using the English auction as the benchmark auction instead of the first-price auction is compelling since the English auction substantially mitigates the WC relative to the first-price auction (Levin, Kagel, and Richard, 1996). Thus, comparing the performance of our behaviorally motivated auction designs to that of the English auction provides a stronger test of overcoming the Winner’s Curse. To have the possibility of studying the mitigation of the WC we intended to create an abundance of WC situations in our benchmark treatment. For that we selected a relatively large signal range parameter of $\varepsilon = 18$ so that the common value given the unbiased signal x falls into the interval of $[x - 18, x + 18]$.

Treatment	CV model	Auction price rule ($n = 4$)	Signal range parameter ε	Number of sessions (subjects)
1) English-MR	mineral-rights	second-highest bid (clock at last drop-out)	18	5 (85)
2) Sophi-MR	mineral-rights	$\frac{b_{(2)}+b_{(4)}}{2}$	18	5 (75)
3) Sophi-All-MR	mineral-rights	$\frac{b_{(2)}+b_{(2)}+b_{(3)}+b_{(4)}}{4}$	18	5 (77)
4) Sophi-All-MR2	mineral-rights	$\frac{b_{(2)}+b_{(2)}+b_{(3)}+b_{(4)}}{4}$	36	4 (61)
5) English-AV	signal-average	second-highest bid (clock at last drop-out)	18	1 (9)
6) Sophi-AV	signal-average	$\frac{b_{(2)}+b_{(2)}+b_{(3)}+b_{(4)}}{4}$	18	1 (15)

Table 1: Treatment Conditions

Treatment ‘Sophi-MR’ implements the Sophi auction in the mineral-rights model where the winner’s payment is the average of the second-highest report and the lowest report. This auction is efficient since its payment rule uses the minimal sufficient statistic in of bidders’ reports. To see if minimal use matters, treatments 3 and 4 employ a modified Sophi auction that uses all reports for setting the price. In both of the modified Sophi auction treatments, ‘Sophi-All-MR’, with $\varepsilon = 18$, and ‘Sophi-All-MR2’, with $\varepsilon = 36$, the price is given by the average of all reported signals, after replacing the highest report by the second-highest one, which also induces sincere bidding (Proposition 3).

A comparison of the payment rules used in treatments ‘Sophi-MR’ and ‘Sophi-All-MR’ and displayed in table 1 shows that the price set in the modified Sophi auction of treatment ‘Sophi-

All-MR', with the same set of reports, is always higher than that in the Sophi auction used in 'Sophi-MR' due to the inclusion of higher reports in the former. With the same parametrization of the common-value model this puts bidders in treatment 'Sophi-All-MR' at a disadvantage and biases comparisons of bidders' payoffs and the frequencies of the WC. To address this bias treatment 'Sophi-All-MR2' implements a slightly modified parameterization of the common-value model such that in equilibrium the expected earnings of bidders in this treatment are equal to those in treatments 'English-MR' and 'Sophi-MR'.

The treatment 'Sophi-All-MR' that implements the basic parametrization of the common-value information structure used in all other treatments allows us to study if equilibrium deviations, particularly overbidding, are affected by the minimal use of bidders' reporting. Likewise, a comparison of equilibrium deviations in 'Sophi-All-MR' to those in 'Sophi-All-MR2' allows us to evaluate if the modification of the information structure's parameterization affects bidding behavior in a substantial way. Moreover, the comparison allows to test the comparative-statics prediction that the seller revenue is higher under the Sophi-All auction.

3.2 Basic Setup and Procedures

To facilitate comparisons to the literature on common-value auctions our experimental design closely follows the setup of Kagel and Levin (1986) and Levin, Kagel, and Richard (1996) that implemented the mineral-rights model and studied the first-price and the English auctions. In each of our treatments subjects were randomly matched into auction groups and bid for a fictitious object with a pure common-value. If the number of participants did not allow all bidders to be matched for an auction group, then some participants were assigned the status of inactive bidders. We employed a rotation rule to minimize the frequency of any subject's inactivities. There were four bidders in each auction group in market periods 1-20. If there were sufficiently many non-bankrupt subjects left at the end of market period 20, there were up to 10 more market periods in groups of seven bidders as in Kagel and Levin (1986) and Levin, Kagel, and Richard (1996).

In all of our treatments except for treatment 'Sophi-All-MR2' the random variable C is uniformly distributed on interval $[50, 250]$ and, conditional on $C = c$, private signals are i.i.d uniformly on $[c - 18, c + 18]$. In treatment 'Sophi-All-MR2' the domain of private signals was extended to $[c - 36, c + 36]$ to correct the earnings bias and C was uniformly drawn from $[25, 275]$ to avoid an excessive amount of boundary data. Before the experiment we randomly generated all common-values and private signals that were used in the experiment. We used different series of the information structure in each session of a treatment, but used the same set of series across treatments to improve comparisons across treatments.

The average number of subjects per session was fifteen and varied between twelve and seventeen due to variation in the show-up rates across sessions and admitted all shown-up subjects to the experiment. Note that the possibility of bankruptcies in our experiment does result in changes in the number of subjects participating in a given experimental session so that different sessions may have different number of bidders over the course of the experiment even when they start with the same number.

Subjects were randomly allocated to their cubicles and received written instructions at the

beginning of any experimental session. After all subjects in a session finished reading instructions they participated in two trial rounds to make themselves more familiar with the auction situation and the computer interface. The common-values and private signals used in both trial periods were the same in each session; in the treatment 'Sophi-All-MR2' we used appropriately scaled parameters to account for the modification of the information structure. After the conclusion of the trial periods, there were twenty market periods in groups of four bidders and then up to another ten market periods in groups of seven bidders if possible.

Subjects were randomly allocated to their cubicles and received written instructions at the beginning of any experimental session. After all subjects in a session finished reading instructions they participated in two trial ("dry") rounds to make themselves more familiar with the auction situation and the computer interface. The common-values and private signals used in both trial periods were the same in each session; in the treatment 'Sophi-All-MR2' we used appropriately scaled parameters to account for the modification of the information structure. After the conclusion of the trial periods, there were twenty market periods in groups of four bidders and then up to another ten market periods in groups of seven bidders whenever possible.

All experimental sessions were conducted in the Behavioral and Experimental Laboratory (BEElab) at Maastricht University. In total, there were 322 participants in the experiment. The sessions lasted between 60 and 90 minutes of time. The appendix provides the translated instruction and sketches of the input and feedback screens. In each session, a show-up fee of 4 EUR was paid and subjects were given a starting balance of 10 EUR to cover possible losses except for treatment 'Sophi-All-MR2' where the starting balance was increased to 20 EUR to account for the larger domain of signals that can imply larger losses in equilibrium. At the end of each market period, subjects' winnings and losses were added to their starting balances. If the a subject's balance became negative during the experiment, that subject was excluded from the experiment and paid the show-up fee. Subjects with a non-negative balance were paid in cash their balance at the end of the experiment where 1 Experimental Currency Unit was worth 1 EUR. The experiment was fully computerized and programmed and conducted with the software z-Tree (Fischbacher, 2007).

3.3 Equilibrium Bid Predictions

All treatments of Sophi auctions induce sincere bidding. In the English auction equilibrium bidding is more complicated: Bidder i drops out of the auction at a clock price equal to the expected common value conditional on all signals that are inferred from the observed dropping prices and on other active bidders having the same signal as bidder i . For our design, equilibrium drop out strategy is simplified since the lowest and highest signals of the sample form a sufficient statistic. Specifically, in the region where $a + \varepsilon < x_n < x_1 < b - \varepsilon$ (with $a \in \{25, 50\}$, $b \in \{250, 275\}$, and $\varepsilon \in \{18, 36\}$ depending on the treatment) equilibrium dropping prices are given by:

$$d_n(x_n) = x_n$$

for bidder n with the lowest signal dropping first and

$$d_i(x_i) = \frac{d_n + x_i}{2}, i = 1, \dots, (n - 1)$$

for any other bidder.

4 Experimental Results

We present the analysis of our laboratory data as follows. We begin with an overview of the aggregated WC data and then we proceed to explore differences between treatments in more detail. For the data analysis we have discarded all auction data where the signal of at least one of the bidders in any auction is sufficiently close to the boundaries of the common-value's support such that the signal's vicinity to the boundary allows to update the expected common-value.⁵ The number of auctions remaining for data analysis is reported in parentheses below the treatments' names in Table 2.

4.1 Overview of Winner's Curse Data

Statistic (4 bidders)	English-MR (252)	Sophi-MR (177)	Sophi-All-MR (186)	Sophi-All-MR2 (111)	English-AV (29)	Sophi-AV (57)
Actual profits	1.81	-0.17	-0.31	2.24	2.49	-1.18
Equilibrium profits	2.48	2.96	1.16	2.08	1.49	1.39
Auction share with negative exp.profits	0.36	0.49	0.54	0.36	0.41	0.65
Share: bid > $E[V x]$ (winning bid)	0.43 (0.99)	0.64 (0.99)	0.57 (0.99)	0.52 (0.98)	0.47 (1.00)	0.60 (1.00)
(lowest bid)	(0.12)	(0.12)	(0.07)	(0.04)	(0.10)	(0.04)
Bankruptcy share	0.27	0.41	0.40	0.28	0.22	0.27
Share periods 'out'	0.12	0.26	0.22	0.21	0.14	0.12
Auction share won with high signal	0.58	0.62	0.63	0.63	0.41	0.65
Average bid	-	149.8	146.7	148.1	-	135.1
Equilibrium bid	-	144.6	144.2	146.5	-	131.8

Table 2: Winner's Curse Aggregate Statistics

Table 2 reports various WC statistics. Since we want to study the mitigation of the WC it is essential to establish a benchmark treatment, English-MR. Note that by choosing the English auction as a benchmark, we raise the bar quite high, as, e.g., the first-price auction leads to the WC roughly twice as often as the English Auction.⁶ The third row of the table shows the share of auctions where the auction price exceeds the expected common value conditional on the signals' realization resulting in negative expected payoffs. As expected for the English auction, observed bidding behavior leads to negative expected bidder profits in 36% of the auctions in

⁵Specifically we discard the data for any auction where for at least one signal x_i satisfies $x_i < 50 + \varepsilon$ or $x_i > 250 - \varepsilon$. In treatment Sophi- All-MR2 the common-value boundaries of 50 and 250 are replaced by 25 and 275.

⁶See Levin, Kagel, and Richards (1996).

the mineral-rights model (English-MR) and in 41% of the auctions in the average-signals model (English-AV). Similarly the actual profits accruing to an auction winner on average (first row) in the English auction falls short of the equilibrium predictions in the mineral rights model (second row). The abundance of the WC in terms of negative profits also reflects in our bankruptcy data. The seventh row displays the share of bidders that went bankrupt over the course of the major part of the experiment, periods 1-20, with four bidders. In both common-value models around a quarter of subjects went bankrupt in the English auction and the share of periods that bankrupt subjects could not participate in due to their exclusion from the experiment was 12% in the mineral-rights model and 14% in the average-model as shown in the eight row.

Looking at the corresponding statistics for the Sophi auction (Sophi-MR and Sophi-AV) shows that the WC is alive and well there, too; in fact, it is much stronger than expected. Comparing the statistics obtained for the Sophi auction to these of the English auction in either common-value model shows that the English auction fares better in overcoming the WC. E.g., the share of auctions with negative expected bidder profits is 36% in English-MR but 49% in Sophi-MR and 41% in English-AV as compared to 65% in Sophi-AV.

The aggregate statistics on bidding behavior suggest that the reason why the Sophi auction does worse than the English auction in overcoming the WC may be due to larger bids relative to the expected common value under the Sophi auction. Specifically, the share of bids exceeding the expected common value, displayed in the fourth row of the table, is larger in the Sophi auction, 64% in Sophi-MR and 60% in Sophi-AV, than in the English auction where it is 43% in English-MR and 47% in English-AV. When moving from the Sophi auction to the Sophi-All auction the share of bids exceeding the expected common values drops somewhat. The small improvement (from 64% to 60%) suggests that bidding may be improving with a price payment rule that uses the average of all bids in the treatments Sophi-All-MR and Sophi-All-MR2. Below we further explore overbidding relative to equilibrium bidding in more detail.

The ninth row of the table shows the share of auctions won by the highest signal holder as it ought to be in equilibrium. This share is higher in any of the Sophi auctions as compared to the corresponding English auction treatment. This is one sense in which Sophi auctions are closer to equilibrium bids than bids in the English auction.

The second line of the table shows the average equilibrium profits of the winner for the realized signals. As theory predicts, moving from Sophi-MR to the Sophi-All reduces the winner's profits (increases seller's revenues) and also the actual winner's profits. So at least qualitatively (there are losses in both cases) this prediction is satisfied. Similarly, as theory predicts, moving from Sophi-All-MR to Sophi-All-MR2 increases bidder's profits (decreases seller's revenues) and also the actual winner's profits. Interestingly however, the average bidder's profit in Sophi-All-MR2 exceeds equilibrium prediction although it is lower for any other auction format in the mineral rights model.

Next we formally test for treatment differences regarding the WC. We use the expected winner's profit conditional on actual bidding to quantify the strength of the WC. For the mineral rights model with four bidders, it is given by:

$$\pi^W(\tilde{x}, x) =: E[CV|x] - (\tilde{x}_{(2)} + \tilde{x}_{(4)})/2.$$

To see if there are any treatment differences we estimate a mixed effects model that account for dependency of observations within sessions where the expected winner profit $\pi_{k\tau}^W$ in auction trial τ of session k is regressed on treatment dummies. We use the English auction as the benchmark auction in the regression. The regression equation is

$$\pi_{k\tau}^W = \beta_o + \beta_1 I_{k\tau}^{\text{Sophi-MR}} + \beta_2 I_{k\tau}^{\text{Sophi-All-MR}} + \beta_3 I_{k\tau}^{\text{Sophi-All-MR2}} + \nu_k + u_{k\tau} \quad (1)$$

where ν_k is the random effect of session k and $u_{k\tau}$ is the residual. Table 3 provides the regression results.

Explanatory variable	coefficient $\hat{\beta}$	σ_β	p -value	[95% conf. interval]
Intercept	2.515	0.808	0.002	0.932 4.097
Sophi-MR	-2.558	1.189	0.031	-4.887 -0.228
Sophi-All-MR	-2.575	1.180	0.029	-4.888 -0.261
Sophi-All-MR2	0.767	1.311	0.558	-1.802 3.336

Table 3: Mixed Effects Estimation Results of Equation (1)

As can be seen from the table, bidders' expected profits per auction conditional on actual bidding are significantly smaller in treatments Sophi-MR and Sophi-All-MR than in the English auction. Further we do not find any significant difference in bidders' profits between treatments English auction and Sophi-All-MR2.

4.2 English-MR vs Sophi-MR

The Sophi auction intends to allow bidders who fail to correct the adverse selection to overcome the WC through simple sincere bidding. The WC statistics given in Table 2 show the opposite. The Sophi auction fares worse than the English auction in both common-value models as bidders in the treatment English-MR earned on average 1.81 EUR per auction as compared to -0.17 EUR in Sophi-MR. This pronounced difference in winner earnings is particularly striking since theoretically both auction formats are price (and allocation) equivalent for each realization of signals. We expected that the Sophi auction will have the opposite effect by having bidders bid closer to equilibrium. To better understand why it did not happen we explore the determination of prices in both of these auctions and we begin with the mineral-rights model.

Recall that, for the MR model, the equilibrium price under either auction format, English or Sophi, is the average of the second-highest signal and the lowest signal. The Sophi auction's payment rule computes this average directly and the rule induces sincere bidding. In the English auction the determination of the equilibrium price is more involved as discussed before. In it the lowest signal holder ought to drop at her signal and every other bidder ought to drop at the average of the lowest observed bid, being the lowest signal, and their own signal value. In equilibrium, the second-highest signal holder drops at the average of her signal and the lowest signal and thus setting the same price as in the Sophi auction. As a result we can use deviations from equilibrium bidding to trace back the differences in earnings to differences in bidding behavior while controlling for differences in common-value realizations.

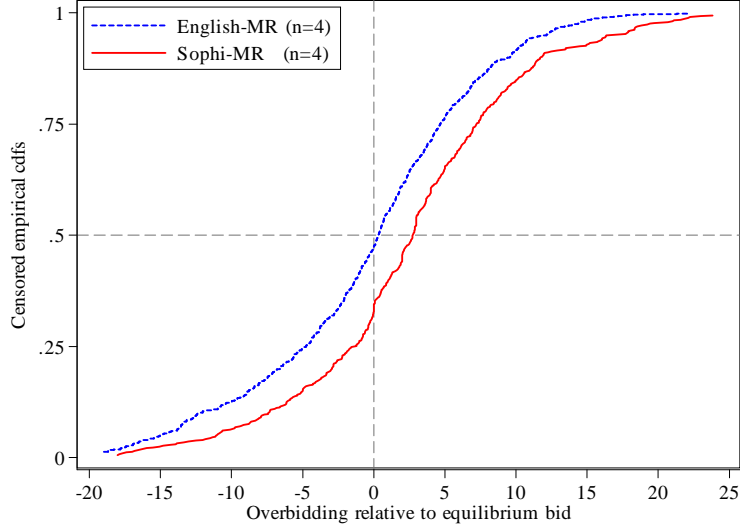


Figure 1: Censored overbidding distributions in treatments English-MR and Sophi-MR ($n = 4$)

Ideally we would compare the distributions of equilibrium bid deviations observed in either treatment but unfortunately this is not possible since the English auction ends when the next to the last bidder drops out and thus we cannot observe the bid (drop) of the last active bidder. Instead we compare the censored distributions of equilibrium deviations where we obtain the one for the Sophi-MR by dropping the high bid in each auction. We call “overbidding” when bids exceed the equilibrium predictions. Figure 1 depicts the censored distributions of both treatments. The comparison of distributions clearly shows that there is much more overbidding in the Sophi-Auction as its cdf first-order stochastically dominates that of English-MR. A comparison with the Kolmogorov-Smirnov test indicates that the difference is highly significant, $p < 0.001$. The average (censored) overbid is -0.50 EUR in English-MR and 2.47 EUR in Sophi-MR where the difference is significant (t -test, $p < 0.001$; Mann-Whitney- U test, $p < 0.001$; two-tailed).

4.3 Overbidding with the Sophi Payment Rules

The above reported increase in overbidding is consistent with the explanation for overbidding in second-price private-value auctions: Subjects may have the erroneous impression that bidding above signal increases the probability of winning at little cost since the payment rule is the average of two bids, the lowest one and the second-highest one. The average rule partly addresses this problem by basing the price on the average of all (“replaced”) signals i.e., including more higher bids than only the lowest bid which increases the predicted price and could close the gap between actual and predicted bids, mitigating the overbidding bias. Here we compare overbidding data across Sophi treatments and test this overbidding-reduction hypothesis

To facilitate the comparison of overbidding data across Sophi treatments we normalize overbidding relative to the signal range since the signal range parameter varies across treatments,

$\varepsilon \in \{18, 36\}$. The normalized overbid of bidder i in auction trial τ is given by,

$$d_{i\tau} =: \frac{b_{i\tau} - x_{i\tau}}{2\varepsilon_t}.$$

Figure 2 shows the time paths of the quartiles of normalized overbidding in the experiment over the course of the experiment for the Sophi treatments.⁷ Clearly the large majority of bidders in the Sophi-MR treatment repeatedly submitted bids exceeding the signal value. In comparison, the less efficient payment rules of Sophi-All-MR and Sophi-All-MR2 seem to induce less overbidding. Furthermore, equilibrium deviations seem to disappear in the last five rounds of the experiment in the treatments Sophi-All-MR and Sophi-All-MR2.

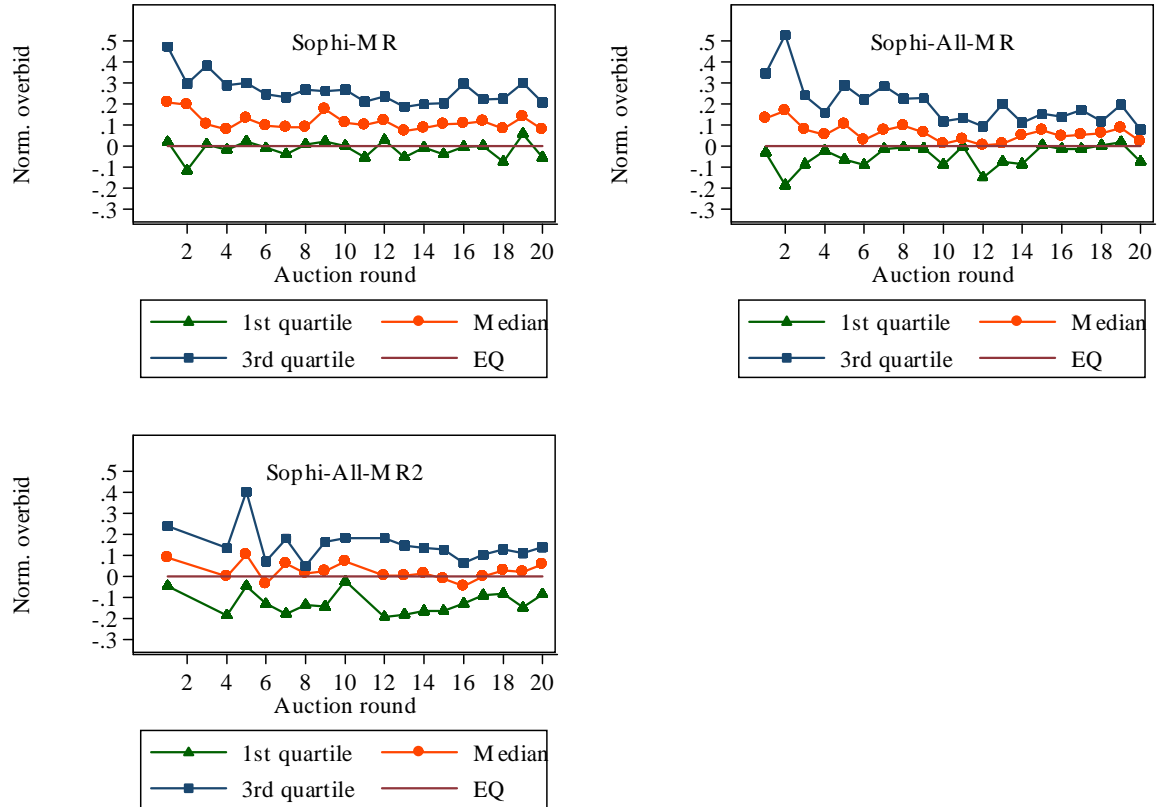


Figure 2: Normalized overbidding quartiles in the Sophi treatments.

To formally confirm that non-minimal payment rules reduces overbidding relative to the Sophi auction, we regress normalized overbids on a dummy variable that indicates if the observation was generated in a treatment using the non-minimal payment rule (treatments Sophi-All-MR and Sophi-All-MR2). The mixed effects estimation equation is

$$d_{ikt} = \beta_o + \beta_1 I_{ikt}^{\text{Non-minimal}} + \nu_i + \nu_k + u_{ikt} \quad (2)$$

⁷When a marker is missing, such as in period 2 in the treatment Sophi-All-MR2, it is because all auction data is classified as boundary data.

where the dependent variable, d_{ikt} , is the normalized overbid of bidder i in session k , auction period t and where ν_i is the random effect of subject i and ν_k is the random effect of session k . We also use a mixed effects specification that adds a dummy variable indicating if the observation is observed in treatment Sophi-All-MR2. This allows to pick up differences between both non-minimal-rule treatments. This specification is given by

$$d_{ikt} = \beta_o + \beta_1 I_{ikt}^{\text{Non-minimal}} + \beta_2 I_{ikt}^{\text{Sophi-All-MR2}} + \nu_i + \nu_k + u_{ikt}. \quad (3)$$

Table 4 summarizes the estimation results of both models. The regression results show that

	coefficient $\hat{\beta}$	σ_{β}	p -value	[95% Conf. Interval]
Equation (2):				
Intercept	0.301	0.097	0.002	0.110 0.491
Non-minimal payment rule	-0.237	0.121	0.050	-0.474 0.000
Equation (3):				
Intercept	0.300	0.101	0.003	0.102 0.498
Non-minimal payment rule	-0.248	0.143	0.082	-0.527 0.031
Sophi-All-MR2	0.026	0.152	0.862	-0.271 0.323

Table 4: Mixed Effects Estimation Results

there is significantly less overbidding under the non-minimal payment rules thus reducing the overbidding as the estimate of coefficient β_1 is negative. There is also no difference between the non-minimal rule treatments 'Sophi-All-MR' and 'Sophi-All-MR2' as the estimate of coefficient β_2 is insignificant.

5 Concluding Remarks

We we introduced a payment rule that internalize the adverse selection in common value auction and results in sincere bidding with no regret. The motivation for such a rule and the expectation that it would eliminate, at least mitigate, the WC is based on its simplicity and the fact that it caters to past observed behavior whereby bidders bid closer to their signal than warranted by theory. There are other payment rules that also induce sincere bidding and are less desirable on theoretical ground: They do have (*ex-post*) regret and use redundant information. However, they maybe more intuitive and further help bidder find their way to the sincere-bidding equilibrium.

We find that the *no-regret*, minimal payment, rule (Sophi auction) is worse than the allocation-price equivalent English auction in overcoming the WC. We also find that the non-minimal with-regret payment rules (Sophi-All) reduces overbidding and leads to higher bidder profits and after calibrating for revenue it matches the performance of the English auction. Although the such accomplishment is far from the Holy Grail in terms of eliminating the WC, it is the first time, as far as we are aware, that a static (simultaneous) bidding mechanism performs as well the dynamic English auction.

A Appendix

A.1 Experimental Procedures

Participants were recruited by email and could register for the experiment on the internet. At the beginning of the experiment participants were assigned to their cubicles randomly. Then they received written instructions about the experiments. The experiment was computerized using the software z-Tree (Fischbacher, 2007). After treatment, participants answered a short on-screen questionnaire and were paid their earnings in cash.

A.2 Instructions

The instructions of the pilot experiment are in German. In the following we provide a translation to English.

A.2.1 General information for participants

You are participating in a scientific experiment that is sponsored by the research institute METEOR and the National Science Foundation. If you read the following instructions carefully then you can – depending on your decisions – gain a considerable amount of money. It is, hence, very important that you read the instructions carefully.

The instructions that you have received are for your private information only. **During the experiment no communication is permitted.** Whenever you have any question, please raise your hand. We will then come to you and answer your question at your seat. Not following this rule leads to the exclusion from the experiment and all payments.

During the experiment we do not talk about Euro, but about ECU (Experimental Currency Unit). Your entire income will be determined in ECU first. The total amount of ECU that you will have obtained during the experiment will be converted into Euro and paid to you **in cash** at the end of the experiment. The conversion rate will be shown on your screen at the beginning of the experiment.

A.2.2 Information regarding the experiment

Today you are participating in an experiment on auctions. The experiment is divided into separate rounds. In the following we explain what happens in each round.

1. In each round you are a buyer and bid for a fictitious object that is auctioned off. Next to you, another three participants bid for the same object. There are, hence, **four bidders** in total in your auction in each round. In each round you will be allocated randomly with three other participants for the auction, so that **your co-bidders change randomly in each round.**
2. **The precise value of the object at the time you make your bids will be unknown to you and any other bidder.** Instead, each of you will receive information as to the value of the object which you should find useful in determining your bid since it allows

you to narrow down the value of the object. The process of determining the value of the object and the information you will receive about it will be described in sections 6 and 7 below.

3. The **high bidder gets the object** and receives a round income equal to the difference between the value of the object and the price of the object, that is:

$$\text{round income of the high bidder} = \text{value of the object} - \text{price of the object}$$

[In Sophi instructions: **The price of the object is equal to the average of the second-highest bid and the smallest bid.**

Example: If the second-highest bid is 150 ECU and the smallest bid is 130 ECU, then the price of the object is 140 ECU since this is the average of the second-highest bid and the smallest bid, $(150 + 130) : 2 = 140$ ECU.]

[In SPA instructions: **The price of the object is equal to the second-highest bid.**]

Caution: If the **price is greater than the value of the object**, then the **round income is negative** so that the high bidder makes a **loss**.

If you do not make the high bid, your round income is 0 ECU, so that your income from the experiment neither increases nor decreases from bidding in the auction.

4. You will be given a starting capital balance of 10 ECU at the beginning of the experiment. **Any profit earned by you will be added to this sum, and any losses incurred will be subtracted from this sum.** At the end of the experiment, the net balance of these transactions will be converted into Euro and paid to you in cash.

The starting capital credit balance, and whatever subsequent profits you earn, permit you to suffer losses in one auction to be recouped in part or in total in later auctions. However, should your net balance at any time during the experiment drop to zero or even less, you will no longer be permitted to participate. Instead we will give you your show-up fee of 4 EUR and you have to leave the experiment. (Of course, you are permitted to submit bids in excess of your capital credit balance.)

5. After all bidders have submitted their bids, you will be shown all bids, the price of the object, and the value of the object on the screen. We will also show you whether a profit or loss was earned by the high bidder.
6. **The value of the auctioned object (W) will be assigned randomly and will lie between 50 and 250 ECU (including 50 and 250). The value of the object is the same for any bidder.** For each auction, *any value within this interval has an equally likely chance of being drawn.* The value of the object can never be less than 50 ECU or more than 250 ECU. **The object values W are determined randomly and independently in each auction.** As such a high W in one round tells you nothing about the likely value in the next round whether it will be high or low. It doesn't even preclude drawing the same W value in later rounds.

7. Private information about the value of the object:

Although you do not know the precise value of the object at the time of bidding, you

10. Every participant will receive, in addition to the earnings from the experiment, a show-up fee of 4 EUR.
11. In case it is not possible to allocate all participants in groups of four, at most three participants will be designated as "inactive bidders". The designation of "inactive bidders" follows a rotation rule that keeps the number of rounds as an inactive bidder per participant over the course of the experiment as small as possible. All participants that are designated as inactive bidders in any given round will be informed about it before bidding in the corresponding round; all participants that are not informed about it are designated "active bidders" where all rules apply as described above. Inactive bidders will receive a signal value, will submit a bid, and will be shown the outcome of a randomly chosen auction with active bidders. Further, inactive bidders will receive a round income of 0 ECU.

Summary of the main points: (1) The high bidder wins the auction and earns the value of the object minus the price of the object as round income. (2) The price of the object equals the [only in Sophi instructions: average of the second-highest and the smallest bid] [only in SPA instructions: second-highest bid.] (3) Profits will be added to your starting balance of 10 ECU, losses subtracted from it. Your balance at the end of experiment will be converted in Euro and paid in cash. If your balance turns negative at any time during the experiment, you are no longer allowed to bid. (4) Your private signal value is randomly drawn and lies between $(W - 18)$ ECU and $(W + 18)$ ECU. The value of the object can never be smaller than your signal value-18 or greater than your signal value+18. (5) The value of the object will always lie between 50 ECU and 250 ECU.

A.2.3 Screens

The next two pages sketch the input screen and the feedback screen used in the experiment.

Period 1 out of 15	Remaining Time [sec]: 20
<p>The object value is unknown to you and lies between 50 and 250 ECU. The object value is also unknown to any of the other 3 bidders.</p> <p>To narrow down the object value, you receive a signal value that lies between (object value-18) and (object value+18). To narrow down the object value, any of the other bidders receives a signal value between (object value-18) and (object value+18).</p>	
<p>Your randomly determined signal value for this auction is: 155.14</p> <p>Therefore, the object value of this round cannot be smaller than your (signal value-18) = 137.14 ECU Therefore, the object value of this round cannot be greater than your (signal value+18) = 173.14 ECU</p>	
<p>Please submit your bid for the auctioned object: <input type="text" value="155.14"/></p> <p>Please note: Your income in this round if you submit the high bid is: Income = (object value - price) ECU</p> <p>[Only in Sophi auction treatments:] The price is equal to the average of the second-highest bid and the lowest bid. [Only in second-price auction treatment:] The price is equal to the second-highest bid.</p> <p>Your income in this round if you do not submit the high bid is: Income = 0 ECU.</p> <p style="text-align: right;"><input type="button" value="Go on !"/></p>	

The object value is unknown to you and lies between 50 and 250 ECU.

The object value is also unknown to any of the other 3 bidders.

To narrow down the object value, you receive a signal value that lies between (object value-18) and (object value+18).

To narrow down the object value, any of the other bidders receives a signal value that lies between (object value-18) and (object value+18).

Your randomly determined signal value for this auction is: 155.14

Therefore, the object value of this round cannot be smaller than your (signal value-18) = 137.14 ECU

Therefore, the object value of this round cannot be greater than your (signal value+18) = 173.14 ECU

Please submit your bid for the auctioned object:

Please note:

Your income in this round if you submit the high bid is: Income = (object value - price) ECU

[Only in Sophi auction treatments:] The price is equal to the average of the second-highest and the lowest bid.

[Only in second-price auction treatment:] The price is equal to the second-highest bid.

Your income in this round if you do not submit the high bid is: Income = 0 ECU.

All bids	All signal values
190.00	159.89
160.00	143.64
155.14	155.14
145.00	160.99

[If high bidder:] **You submitted the high bid of 190.00 ECU and receive the fictitious object.**

[If not high bidder:] **Your bid of 155.14 ECU is lower than the high bid of 190.00 ECU, so that you do**

not receive the fictitious object.

In this round, the object value is 160.59 ECU

The price of the object is 152.50 ECU.

[If Sophi auction:] **This is the average of the second-highest bid (160.00 ECU) and the lowest bid (145.00 ECU).**

[If second-price auction:] **This is the second-highest bid (160.00 ECU).**

[If not high bidder] **In this round, the high bidder made a profit[or: loss] of 8.09 ECU.**

[If high bidder:] **Your income in this round = object value - price = 160.59 - 152.20 = 8.09 ECU.**

[If not high bidder:] **Your income in this round = 0 ECU.**

[If high bidder] **In this round you made a profit that increases [or: loss that decreases] your ECU account balance.**

[If not high bidder:] **In this round you neither made a profit nor a loss so that your ECU account balance does not change.**

[If not high bidder:] **Your [if not high bidder: old and] new ECU account balance amounts to 18.04 ECU.**

A.2.4 Average Actual Profits

Treatment (Rds.)	Average actual profits (std. dev.)			Average profits with equil. bids		
	1-20	1-10	11-20	1-20	1-10	11-20
1) English-MR	1.81 (8.41)	1.03 (8.16)	2.62 (8.62)	2.48 (5.85)	2.11 (5.70)	2.86 (5.90)
2) Sophi-MR	-0.17 (9.74)	-1.55 (8.50)	1.26 (10.74)	2.96 (5.64)	2.88 (5.57)	3.05 (5.74)
3) Sophi-All-MR	-0.31 (8.82)	-0.69 (10.38)	0.08 (6.99)	1.16 (6.02)	1.00 (5.88)	1.31 (6.18)
4) Sophi-All-MR2	2.24 (14.50)	0.38 (16.21)	3.71 (12.95)	2.08 (12.95)	1.90 (12.48)	2.22 (13.41)
5) English-AV	2.49 (7.86)	2.37 (8.17)	2.74 (7.64)	1.49 (1.58)	1.56 (1.78)	1.35 (1.18)
6) Sophi-AV	-1.18 (3.50)	-1.45 (4.12)	-0.89 (2.68)	1.39 (1.46)	1.39 (1.60)	1.39 (1.32)

Table 5: Average Actual Profits of Bidders per Auction in EUR

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