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

Dan Levin†
The Ohio State University

J. Philipp Reiss‡
Karlsruhe Institute of Technology (KIT)

March 17, 2020

Abstract

The Winner's Curse (WC) is a non-equilibrium behavior in common-value auctions involving systematic overbidding leading to significant losses. We propose a static auction mechanism with a payment rule that internalizes the adverse selection, resulting in sincere bidding, as *no-regret* equilibrium. We compare this mechanism with other payment rules resulting in sincere bidding equilibrium but with regret. The other rules use *excessive* information, and we study whether that helps bidders find their way to equilibrium bidding. Our no-regret rule generates significantly less WC than the static first-price auction, but more than the dynamic English auction. Yet, our other, more intuitive, sincere bidding rule mitigates overbidding better than the no-regret rule, and remarkably for a sealed-bid design, matches the performance of the dynamic English auction.

Keywords: common value auction, direct mechanism, English auction, lab experiment.

JEL classification: C72, C92, D44

*Financial support from Maastricht University through METEOR and the Department of Economics (AE1) is gratefully acknowledged. We thank Lawrence Ausubel, B. Douglas Bernheim, Vitali Gretschko, Jacob Goeree, Ron Harstad, Sergiu Hart, Michael Mandler, Marco Pagano, Marco Pagnozzi, Robert Porter, Orly Sade, Jereon Swinkels, Leeat Yariv and audiences in Ankara, Berkeley, Evanston (MEA2012; Kellogg), Exeter, Istanbul (GAMES2012), London (RHUL), Mannheim (2017 ZEW Market Design Workshop), Naples, Salerno, Stanford (seminar and SITE2011), Jerusalem, and Maastricht (MBEES2011) for helpful comments. Special thanks to Yaron Azrieli for many helpful comments and to John Kagel for providing the comparison data on first-price common value auctions.

†Department of Economics, The Ohio State University, 1945 North High Street, Columbus, OH 43210, e-mail: levin.32@osu.edu.

‡Karlsruhe Institute of Technology (KIT), Institute of Economics (ECON), Bluecherstr. 17, 76185 Karlsruhe, Germany, e-mail: philipp.reiss@kit.edu.

1 Introduction

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

Eyster and Rabin (2005) and Crawford and Iriberri (2007) suggested behavioral explanations that extend Nash equilibrium by relaxing its stringent requirements on equilibrium beliefs, while maintaining individual rationality in terms of best-responding to these relaxed beliefs. However, these models do not explain deviations from equilibrium bidding.[3] In particular, overbidding relative to the equilibrium seems to be due to the cognitive limitations of the kind suggested by Charness and Levin (2009) or Charness, Levin, and Schmeidler (2018).[4]

In this paper, we attempt to overcome, at least mitigate, the WC by using an auction design that simplifies the bidders' decision task and helps them to discover the optimal equilibrium bid strategy. We propose a *direct mechanism* that induces sincere bidding, "bid your own signal," as a simple and easy rule to follow. In the symmetric equilibrium of first-price, or second price, CV auctions, where the signal of each bidder is an *ex-ante* unbiased estimate of the CV, a bidder ought to bid below her signal, often well below, in order to correct for the WC. However, many experimental studies of such auctions document clearly that though subjects bid lower than their signals, they do not bid low enough and, hence, fall prey to the WC. Our proposed mechanism caters to this behavioral tendency as it makes bidding one's signal an optimal bidding behavior, i.e. the best-response to others' sincere bidding. In fact, sincere bidding is the unique ex-post equilibrium under the proposed mechanism.

In a nutshell, we introduce and study a mechanism that seeks to avoid the WC by making it easy for bidders to bid, which means to allow them bidding exactly the signal as an equilibrium bid. In this way, both, rational bidders along with behavioral bidders, can obey equilibrium behavior more easily. To evaluate this hypothesis of overcoming the WC by auction design, we run an experiment and analyze WC statistics and 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.

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

[2] For example, see Goeree and Offerman (2002), Levin, Kagel, and Richard (1996), Charness and Levin (2009), Ivanov, Levin, and Niederle (2010).

[3] See 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.

[4] Charness and Levin (2009) study adverse selection in an individual choice environment. Charness, Levin, and Schmeidler (2018) study the relation between the complexity of public information, estimation dispersion, and the adverse selection problem.

2 Theoretical considerations

Our main design objective is to help subjects bid optimally by simplifying the decision problem and catering to their behavioral biases. Bidding one's signal is both simple and behaviorally appealing. Therefore, we begin by introducing an auction mechanism, we call it Sophi, where such bidding is an *ex-post* equilibrium[5] in a general CV framework. We then apply our general approach to two prominent CV models, a *mineral-rights* and a *signal-average*. Depending on the specific CV model, there may exist other auction mechanisms where sincere bidding is an equilibrium, but with *regret*.

Before introducing Sophi, in the next section, we address two natural concerns it may raise: The first one is that in the general case Sophi is subject to the "Wilson critique",[6] and the second one is that we don't see it in practice. We address the first concern by noting that instead of starting with the general common values auction (CVA) model, as in Milgrom and Weber (1982), we could start with an important and convenient special case, used for experimental and applied work, where the expectation of the CV is the average of all bidders' signals/estimates plus some *white-noise*.[7] For such a case, Sophi induces a simple and intuitive "modified average" payment (MAP) rule[8] with sincere bidding as the unique, *no-regret*, Bayes-Nash equilibrium (BNE), and is immune to the Wilson critique. Our work then can be regarded as presenting the general case and identifying conditions that yield such, or reasonably close equilibrium.

Consider for example the first-price, second-price or English auctions, (FPA, SPA, EA), that are all immune to the critique, but rely on the bidders to derive and coordinate on the BNE which is likely to be quite difficult and assumes that bidders are rational and have a common-knowledge that also includes distributional aspects. An alternative approach is to start with the simple and immune MAP rule, which may have a solution that is not too far from sincere bidding. In that case, behaviorally, the MAP rule and nearly optimal sincere bidding might be closer to BNE than under the "equivalent" (as we shall see in the next section) English auction.

We address the second concern by noting that there are many examples of new or modified forms of auctions resulting from theoretical, and experimental work on auctions. Chang, Wei-Shiun, Bo Chen, and Timothy C. Salmon (2014) provide several example of governments and agencies (e.g., Taiwan, Switzerland, Italy) that use variations of an "average bid mechanism" in procurement auctions to deal with the WC, that often results in bankruptcies and stoppage of projects.[9] Given Sophi's good properties, the fact that it is not used so far ought not be a

[5] See Krishna (2010, p. 297) for the definition. Sometimes this is referred to as a no-regret equilibrium, because upon learning all private information, no bidder regrets his earlier bidding.

[6] "Game theory has a great advantage in explicitly analyzing the consequences of trading rules that presumably are really common knowledge; it is deficient to the extent it assumes other features to be common knowledge, such as one agent's probability assessment about another's preferences or information. I foresee the progress of game theory as depending on successive reduction in the base of common knowledge required to conduct useful analysis of practical problems. Only by repeated weakening of common knowledge assumptions will the theory approximate reality." Wilson (1987, p.34).

[7] If the CV is a monotonic function $h(\cdot)$ of the average of all bidders' estimates, $\overline{x}_n = \sum_{i=1}^{n} \frac{x_i}{n}$, plus a white noise, $CV = h(\overline{x}_n) + \eta$, implementing Sophi only requires knowing h, but not other distributional details.

[8] Denote the vector of the n submitted bids by $(b^1, b^2, ..., b^n)$ arranged so that for $b^i \geq b^{i+1}$, $i = 1, 2, ..., (n-1)$. The modified average payment rule is: $[b^2 + b^2 + b^3 +, ..., +b^n]/n = [\sum_i^n b^i - (b^1 - b^2)]/n =: \overline{b}_n - \frac{b^1 - b^2}{n}$.

[9] The experimental literature on auctions documents many examples. Kagel, Lien and Milgrom (2010) is an example of the contribution of experimental work to guide combinatorial auctions with multi-units and synergies

reason not to study it, on the contrary, it ought to be studied and possibly implemented.

2.1 Common-value auction and ex-post equilibrium

Consider a general CV framework,[10] where $(V, X) =: (V, X_1, ..., X_n)$ denotes a vector of $(n+1)$ random variables drawn from a joint distribution function, $F(V, X)$. Let x and x_{-i} denote, respectively, the vector of realizations and the vector of realizations where x_i is deleted. For ease of exposition, we order those vectors by $(x^i \geq x^{i+1})$. Denote by $T_x = \max\{x\}$ the highest signal of all agents, and by $T_{-i} = \max\{x_{-i}\}$ the highest signal of all agents other than i. We assume that there exists a finite expected value of the CV, V, conditional on the realizations of x, $E[V|x] =: h(x)$ with $\partial h(x)/\partial x_i \geq 0$, for all i and $\partial h(x)/\partial x_M > 0$, where $x_M = T_x$.[11] We assume $n \geq 2$ risk-neutral bidders, with each bidder i privately observing signal $X_i = x_i$.

"*Sophi*" (= *sophisticated*) Payment Rule: Consider the direct mechanism, where each bidder j reports a signal $\widetilde{x}_j$, the winner, say bidder i, pays $E[V|\widetilde{x}_i = \widetilde{T}_{-i}, \widetilde{x}_{-i}]$ and all others pay nothing.

Proposition 1 *Consider a direct mechanism that satisfies the following properties:*

1. *If there is a unique highest signal, then its holder wins the object.*[12]
2. *A bidder who doesn't get the object pays nothing.*
3. *Truthful reporting is an ex-post equilibrium.*

Then, the bidder who wins the object pays according to the "Sophi" rule.

Proof. Fix an agent i and a vector of signals of all other agents x_{-i}, and until the end of the proof, simplify by having $T = T_{-i} = \max\{x_{-i}\}$, the highest signal of all agents other than i. Consider two different realizations of i's signal, $x_i > x'_i$, where $x'_i > T$. Property number (1) implies that agent i wins the object in both realizations. It follows from property number (3) that i pays the same price in both cases, since otherwise she would have an incentive to misreport her signal to pay the lower price of the two. Thus, as long as $x_i > T$ the price that i pays is constant in x_i, and we denote it by c. (Obviously, c may depend on the vector x_{-i}, but since we fixed it for the entire proof, we omit it from the notation). Now, if $x_i > T$ and i reports truthfully, then she wins the object and her utility is $E[V|x_i, x_{-i}] - c$. If instead i lies and reports some $\tilde{x}_i < T$, then she doesn't win the object (by property (1)), and by property (2), her utility is 0. Thus, by property (3) we must have $E[V|x_i, x_{-i}] - c \geq 0$ for every $x_i > T$. Suppose now that $x_i < T$, reporting truthfully results in losing, and earning 0. If instead i misreports with $\widetilde{x}_i > T$, then her utility is $E[V|x_i, x_{-i}] - c$. Again from property (3) it must be the case that $0 \geq E[V|x_i, x_{-i}] - c$. We established that $\forall \varepsilon > 0$, $E[V|x_i = T + \varepsilon, x_{-i}] \geq c \geq E[V|x_i = T - \varepsilon, x_{-i}]$. Thus, in the limit as $\varepsilon \to 0$ yields, $c = E[V|x_i = T, x_{-i}]$, the proof is complete. ■

and cites several additional works. A recent experimental work by Breuer, Cramton, and Ockenfels (2019) introduces "soft reserve prices", never yet used in practice, and show that it could increase both efficiency and revenue. The work on *Position Auctions* was developed jointly using theory and practice. E.g., Edelman, Ostrovsky and Schwarz (2007) and Varian (2007).

[10] See Wilson (1977) for the seminal common value model.

[11] Note, that our assumption is weaker than the commonly used assumption that the $(n+1)$ random variables are positively affiliated. (With the extra assumption that $\partial h(x)/\partial x_1$ is strictly positive.)

[12] Extending to allow for random tie breaking is simple, but does not add much.

In equilibrium *Sophi* "asks" bidders to simply bid their signals, which may help less sophisticated bidders, who typically ignore the adverse selection and overbid, to avoid, or mitigate, the WC. This simple bidding rule sharply contrasts with the complicated equilibrium strategies in CV auctions such as in first-price and English auctions, where bidders do not bid, or drop at, their signal. In the symmetric equilibrium of a first-price auction, each bidder ought to bid as if holding the highest signal, and then use a complicated Bayesian calculation to correct her estimation of the CV and also decide on the proper (optimal) shading. In English auctions each bidder typically (with the lowest signal holder as a possible exception) drops at a lower clock price than her own signal while remaining bidders continuously need to update after each drop-out. It is important to note that in both auctions, the highest signal holder wins the object and pays $E[V|x_i = T, x_{-i}]$.[13]

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 $E[V|x_i = T, x_{-i}]$. ■

The Sophi auction is susceptible to the Wilson critique since, and in contrast to the first-price, and the English auction, its payment rule requires knowing the joint distribution function $F(V, X)$ to form $E[V|x_i = T, x_{-i}]$.[14] In the special case where the average of all signals, $\sum_{i=1}^{n} \frac{x_i}{n} =: \overline{x}_n$, is a sufficient statistic for V (i.e., $E[V|x] = h(\overline{x}_n)$), then the price rule, $h(\overline{x}_n - \frac{x^1 - x^2}{n})$, implements Sophi without additional knowledge of $F(V, X)$. For unbiased and, possibly, noisy signals the price rule further simplifies as detailed in the following corollary.

Corollary 3 *Under the often used assumption that $V = \overline{x}_n + \eta$, that our experimental design implements, where η is a random variable such that for all x, $E[\eta|x] = 0$, the Sophi auction is immune to the Wilson critique, because in equilibrium, with sincere bidding, the price is simply $(\overline{x}_n - \frac{x^1 - x^2}{n})$.*

2.2 Two common-value models

In this section, we show how *Sophi* auction induces sincere bidding in two models with different specifications of the CV. The information structure of signals is the same in both cases and follows Kagel and Levin (1986) and Levin, Kagel, and Richard (1996). Specifically, let the random variable, V, be distributed *uniformly* on the interval $[a, b]$, and denote its realization by v. Conditional on $V = v$, the private signals, X_i ($i = 1, ..., n$), are i.i.d. *uniformly* on $[v - \varepsilon, v + \varepsilon]$, where $\varepsilon > 0$ is a commonly known parameter. (Since in equilibrium $\widetilde{x} \equiv x$, we simplify from here on by using x also for the reports $\widetilde{x}$.)

[13] Sophi has an additional normative appeal, instructing bidders to "just bid your estimate" does not just sound simple, but is also optimal (in equilibrium). It is much harder to see what bidding advice one could instruct bidders in other commonly used auctions.

[14] "Game theory has a great advantage in explicitly analyzing the consequences of trading rules that presumably are really common knowledge; it is deficient to the extent it assumes other features to be common knowledge, such as one agent's probability assessment about another's preferences or information. I foresee the progress of game theory as depending on successive reduction in the base of common knowledge required to conduct useful analysis of practical problems. Only by repeated weakening of common knowledge assumptions will the theory approximate reality." Wilson (1987, p.34).

2.2.1 The Mineral-rights model

In the mineral-rights model the CV **is** V, so that signals are symmetrically distributed around V. For this case, and given that the signals have a *uniform* distribution, thus $E[V|x] = \frac{x^1+x^n}{2}$, the average of the highest and lowest signals - form a sufficient statistic for V.[15] Thus, the price rule of the *Sophi* auction here - the expected value of V conditional on the reported signals, where the highest reported signal is replaced by the second-highest reported signal - is a simple rule:

$$p^{\text{Sophi}} = \frac{x^2 + x^n}{2}.$$

Note that in our mineral-rights model the simple price rule, $\frac{\tilde{x}^2+\tilde{x}^n}{2}$, depends on a particular form of $F(V, X)$ being common-knowledge. In our works, as in almost all experimental work, we implement the distribution and announce it publicly which (presumably) makes this feature of our experimental design common knowledge. This introduces a potential behavioral trade-off. On the one hand, the payment rule uses fewer bidders' messages to compute the price paid by a winner but, on the other hand, it relies on the rather restrictive assumption that our student experimental subjects are sufficiently sophisticated to recognize these statistical relationships. Our next model enable us to "control" for such possible opposing "forces."

2.2.2 The Signal-average model

In the signal-average model, we denote the CV by W, and assume that it is given by the average of signals, $W \equiv \frac{1}{n}\sum_{j=1}^{n} X_i$. In this model, the realizations determine the CV; and the price rule of the *Sophi* auction here is also quite simple:

$$p^{\text{SigAv}} = \sum_{j=1}^{n} \frac{x_j}{n} - \frac{x^1 - x^2}{n}.$$

2.2.3 Sincere bidding with a non-minimal-information payment rule

Proposition 4 *In the mineral-rights model with $n > 2$ bidders, the (adjusted) average pricing rule, $p(x) = \frac{x^2+x^2+x^3+,...,+x^n}{n}$, induces sincere bidding as equilibrium, but not as an ex-post equilibrium.*

Proof. The claim that the equilibrium is not *ex post* follows from our first proposition which implies uniqueness in this class of mechanisms, and the fact that for almost any x, $p(x) \neq \frac{x^1+x^n}{2} := E[V|x]$. The rest of the proof is in the Appendix, see page 24.

3 Experimental design

We use an experimental design with two primary treatment variables: The first treatment variable is the auction mechanism. We either implement a *Sophi* payment rule or an English

[15] Strictly speaking, this applies to signals drawn from the interior interval, $x_i \in [a + \varepsilon, b - \varepsilon]$, since signals close to the borders of the CV allow for asymmetric inference on discarding CVs to the left or right of the signal. Having a signal sufficiently close to the CV borders does not occur too often, as we use a relatively large domain of [50,250]. In our data analysis we restrict attention to the interior case. To simplify the exposition, we also focus on the interior case in the theoretical part throughout, unless stated otherwise.

auction. This is done to study whether, and how well, the *Sophi* payment rules mitigate the WC relative to standard forms of auctions such as the English auction as our benchmark. We also compare the WC resulting with the Sophi payment rules, as data allow, to previous experimental results of the WC with first-price auctions. The second treatment variable is the CV model, mineral-rights or signal-average. An additional treatment is the change (increase) in the number of competing bidders (after twenty market periods) as it is well known from previous studies that the WC worsens with more bidders.

3.1 Treatments

Table 1 summarizes our treatment conditions along with the number of sessions and participating subjects. We implemented the mineral-rights model in treatments 1-4 and the signal-average model in treatments 5 and 6. In both common-value models, we use the English auction as a basis for comparison, rather than the first-price auction, because it provides a tougher test. Levin, Kagel, and Richard (1996) find that the WC in English auctions was roughly 50% of that in first-price auctions with the same parameters. This is a consequence of additional information that is available in the open English auction, but not in the first-price sealed-bid auction as suggested by the findings of Kagel and Levin (1986). They showed that releasing informative public information in first-price CV auctions reduces the average seller's revenue in auctions with severe WC, in contrast to theoretical predictions (cf. Milgrom and Weber, 1982), as it helps bidders to realize that their (otherwise) estimates are upward biased. In response, bidders adjust their bids downwards, which helps to mitigate the WC substantially. The English auction is a dynamic auction, and bidders' drop-out prices are public. Thus, such prices help remaining bidders to correct their (earlier) upward bias in estimation and bidding in a similar way as in a first-price auction with informative public information, albeit in an English auction, the additional public information, in the form of earlier drop out prices, is endogenous to the auction. To have the opportunity to study the mitigation of the WC, we created several WC situations in our English auction benchmark treatments, 'English-MR' and 'English-AV'. For that, we selected a relatively large signal range parameter of $\varepsilon = 18$.

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 "informationally efficient," since its payment rule uses the minimal sufficient statistic of bidders' reports. To see if minimal use of information matters, treatments 3 and 4 employ a modified *Sophi* auction that uses all reports for setting the price. In both 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 4).

A comparison of the payment rules used in treatments 'Sophi-MR' and 'Sophi-All-MR' (Table 1) shows that the price in the modified treatment, 'Sophi-All-MR', with the same realizations, is always higher than that in 'Sophi-MR.' This is a consequence of Milgrom's (1982) linkage principle.[16] With the same realizations, winners in treatment 'Sophi-All-MR' earn only half of the winners' payoffs in 'Sophi-MR'.[17] Several previous experimental studies of common-value auctions (Kagel and Levin, 2002) show that such differences in equilibrium payoffs bias the comparisons of bidders' actual payoffs and the frequencies of the WC. To control (or mitigate) this bias, treatment 'Sophi-All-MR2' implements a modified parametrization of the common-value model, such that the expected equilibrium earnings of bidders in this treatment are equal to those in treatments 'English-MR' and 'Sophi-MR'. This is achieved by doubling the signal range parameter ε, so that treatment 'Sophi-All-MR2' employs $\varepsilon = 36$ instead of $\varepsilon = 18$.[18]

The treatment 'Sophi-All-MR' implements the basic parametrization of the CV information structure used in all other treatments. This allows us to study whether and how deviations from equilibrium, 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 study whether and how, the modification of the information structure's parametrization affects bidding behavior. Moreover, it allows to test the comparative-static prediction that the seller's revenue is higher under the Sophi-All auction.

3.2 Basic setup and procedures

To facilitate comparisons to the literature on CV auctions, our experimental design closely follows the one in 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 respectively. In each of our treatments, subjects were randomly matched into auction groups and bid for a fictitious object with a pure CV. If the number of participants did not allow all bidders to be matched for an auction group, then some participants were inactive bidders in a given period.[19]

[16] Specifically, $[p^{\text{Sophi-all}} - p^{\text{Sophi}}] = [\frac{x^2+x^2+x^3+x^4}{4} - \frac{x^2+x^4}{2}] = \frac{x^3-x^4}{4} > 0$.

[17] Conditional on winning, the expected payoffs for the payment rule $p^{\text{Sophi-all}}$ is, $[\frac{x^1+x^2+x^3+x^4}{4} - \frac{x^2+x^2+x^3+x^4}{4}] = \frac{x^1-x^2}{4}$, and for p^{Sophi} it is, $[\frac{x^1+x^4}{2} - \frac{x^2+x^4}{2}] = \frac{x^1-x^2}{2} (= 2p^{\text{Sophi-all}})$.

[18] A legitimate concern of comparing 'Sophi-All-MR2' with $\varepsilon = 36$ to 'English-MR' or 'Sophi-MR,' with $\varepsilon = 18$, is that outside the laboratory a designer typically faces a given ε. Thus, we ought to keep this in mind. However, in more general environments, both English and Sophi-MR will use all information (drop-outs and reporting) available for the price rule, and we would not need such a treatment to control for profits. Ideally, we would compare all auctions under the same ε, this is to use Sophi-All-MR and English-All-MR, but we were constrained by our budget.

[19] 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 enough non-bankrupt subjects left at the end of 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).[20]

In all of our treatments, except for treatment Sophi-All-MR2, the random variable C, measured in Experimental Currency Units (ECU), is uniformly distributed on interval [50, 250] and, conditional on $C = c$, private signals are i.i.d uniformly on $[c - 18, c + 18]$. Note that with our exchange rate of 1 EUR for 1 ECU, our subjects competed for a very valuable common value, ranging from 50 EUR to 250 EUR, in each auction.

In treatment Sophi-All-MR2, the support of private signals was extended to $[c - 36,\ c + 36]$ and C was uniformly drawn from [32, 268] to reduce the amount of boundary data. Before the experiment, we randomly generated all the 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 15 and varied between 12 and 17 due to variations in the show-up rates across sessions. We admitted all shown-up subjects to the experiment. Note that bankruptcies in our experiment changed the number of subjects participating during an experimental session endogenously.[21]

Subjects were randomly allocated to their cubicles and received written instructions at the beginning of any experimental session. After all subjects in a session were finished reading the instructions, they participated in two trial ("dry") rounds without real payments to familiarize themselves with the auction environment and computer interface. The CV and private signals used in both trial periods were the same in each session, except for treatment Sophi-All-MR2, where we used the aforementioned scaled parameters ($\varepsilon = 36$) 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 followed by 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 experimental sessions implementing any *Sophi* auction lasted 80 minutes on average, and those of English auctions lasted 100 minutes on average. The appendix provides the instructions.[22] 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 may result in larger losses, even in equilibrium. At the end of each market period, subjects' winnings and losses were added to their starting balances. If a subject's balance turned negative during the experiment,[23]

[20] We don't report the results with seven bidders, because of a limited number of data points. This is due to abundant bankruptcies of subjects over the course of the experiment, so that very few groups of seven bidders survived.

[21] Thus, different sessions may have different number of bidders over the course of the experiment, even when they start with the same number of subjects in the first market period.

[22] Screenshots of the input and feedback interfaces for treatments *Sophi-MR* and *English-MR* are available for download at: `http://io.econ.kit.edu/downloads/LevinReiss_2018_Screens_OvercomingWC.pdf`

[23] Subjects' payoffs were accumulated to ensure that the data is comparable to previous auction experiments,

that subject was excluded from the experiment immediately and paid the show-up fee. Subjects with a non-negative balance were paid their balance in cash at the end of the experiment, where 1 Experimental Currency Unit (ECU) was worth 1 EUR. The earnings of non-bankrupt subjects ranged from 4.10 EUR to 151.90 EUR with 23.33 EUR on average and a standard deviation of 24.85 EUR. The experiment was fully computerized and programmed using the z-Tree software (Fischbacher, 2007).

3.3 Equilibrium bid predictions

All treatments with a *Sophi* payment rule induce sincere bidding, $b_i(x_i) = x_i$. In the English auction, equilibrium bidding is more involved: 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 (earlier) dropping prices and on other active bidders having the same signal as bidder i. The equilibrium dropout strategy is much simpler in our design, because 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 $a \in \{32, 50\}$, $b \in \{250, 268\}$, 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

$$d_{n-i}(x^{n-1}) = \frac{d_n + x^{n-i}}{2} \qquad (i = 1,\ \ldots\ ,\ n-1),$$

for any other bidder.

4 Experimental results

We structure the presentation of our experimental results in three main parts. In the first main part, covered in sections 4.1 and 4.2, we benchmark the *Sophi* auction against two prominent auctions: the first-price sealed-bid auction and the English auction, the two leading auction designs in sealed-bid and open-bid auctions employed in practice. We ask whether, and to what extent, the *Sophi* auction helps to overcome the WC as compared to these two alternative auction designs. In section 4.1, we start out by comparing the performance of the *Sophi* auction to that of the first-price auction. For that, we rely on aggregated data from previous experimental studies. In section 4.2., we investigate the *Sophi* auction in comparison to the English auction in more detail; more specifically, we address whether the *Sophi* auction induces more, or closer, equilibrium bidding than the English auction.

The second main part on experimental results, covered in section 4.3, addresses the overbidding bias generated by the *Sophi* auction. There, we investigate if modifying the payment rule of the minimal-information *Sophi* auction to use all bids, resulting in the *Sophi-All* auction, reduces overbidding as observed in the lab. The third main part, covered in section 4.4, studies individual bidding behavior. Previewing results, there it is shown that bidding behavior is quite heterogenous across subjects and to a large extent stable over time.

specifically, Levin, Kagel, and Richard (1996) and Kagel and Levin (1999).

Our data analysis discards data from auction periods where the lowest (or highest) of the signals' realization is sufficiently close to the boundaries of the common-value's support. Such realizations induce a complicated equilibrium due to asymmetry, as extreme signal holders (but not all bidders) have additional information from being close to the common-value's support.[24]

4.1 *Sophi* auctions vs. First-price auctions

We begin our experimental analysis of the Sophi *auction* by investigating whether it mitigates the WC found in earlier first-price auction experiments. For that, we compare our data obtained for the mineral-rights model to that of previous papers, specifically, from Levin, Kagel, and Richard (1996) and Kagel and Levin (1999), on first-price auctions under the same conditions (inexperienced subjects, four bidders) except for the signal range parameter ε; in ours, $\varepsilon = 18$, while $\varepsilon \in \{6, 12, 24\}$, in earlier studies.[25]

Statistic (No. of auctions)	Sophi-MR $n = 4$ $\varepsilon = 18$ EUR (177)	Sophi-All-MR $n = 4$ $\varepsilon = 18$ EUR (186)	FPA LKR (1996) $n = 4$ $\varepsilon = \{\$6, \$12, \$24\}$	FPA KL (1999) $n = 4$ $\varepsilon = \{\$6, \$12, \$24\}$
$\pi_T :=$ eq. payoffs (on realized data)	2.96 EUR	1.16 EUR	\$2.76, $\varepsilon = \$6$ \$5.01, $\varepsilon = \$12$ \$9.83, $\varepsilon = \$24$	\$2.40, $\varepsilon = \$6$ \$4.80, $\varepsilon = \$12$ \$9.60, $\varepsilon = \$24$
$\pi_A :=$ actual payoffs (per auction)	-0.17 EUR	-0.31 EUR	−\$2.13, $\varepsilon = \$6$ −\$1.32, $\varepsilon = \$12$ \$1.20, $\varepsilon = \$24$	−\$2.40, $\varepsilon = \$6$ −\$1.10, $\varepsilon = \$12$ \$0.25, $\varepsilon = \$24$
$\Delta := \pi_T - \pi_A$	$\Delta = 3.14$	$\Delta = 1.47$	$\Delta = 4.89$, $\varepsilon = \$6$ $\Delta = 6.33$, $\varepsilon = \$12$ $\Delta = 8.63$, $\varepsilon = \$24$	$\Delta = 4.80$, $\varepsilon = \$6$ $\Delta = 5.90$, $\varepsilon = \$12$ $\Delta = 9.35$, $\varepsilon = \$24$
% of auction with negative exp.payoffs	0.49	0.54	NA	NA

Table 2: Winner's Curse aggregate statistics for Sophi and first-price auctions (MR model)

Table 2 shows WC statistics, subject to availability, for first-price auctions in the context of the mineral-rights model. The first line gives the average winner's payoff per auction in equilibrium conditional on realized signals and common values. The equilibrium payoff, π_T, generated by our minimal-information *Sophi* auction, with $\varepsilon = 18$, is 2.96 EUR. Since the reported first-price auction experiments each employ three different values for the signal-parameter, $\varepsilon \in \{\$6, \$12, \$24\}$, we report all three.[26] As can be seen from the numbers in the table, the equilibrium payoffs in the first-price auction increase in ε, reflecting the (proportional in ε) larger spacing

[24] Specifically, we discard the data for any auction where for at least one signal x_i satisfies $x_i < 50 + \varepsilon$ or $x_i > 250 - \varepsilon$. Recall that in treatment Sophi-All-MR2 the CV boundaries are replaced by 32 and 268.

[25] The US\$ was used as 'experimental currency' in the reported first-price auction experiments. Recall that the experimental currency unit used in our experiments was converted into Euro at rate of 1 ECU = 1 EUR.

[26] Note that the calculations for the reported first-price auction equilibrium ignore the exponential part in the equilibrium bidding strategy that are negligible (less than \$0.05, particularly for the winners whose signals are

average between the winner and the closest follower. The first-price equilibrium payoff most comparable to that of the minimal-information *Sophi* auction with 2.96 EUR obtains for $\varepsilon = \$6$.

Turning attention to actual payoffs (second line) shows that the *Sophi* auction does not eliminate the WC, because actual payoffs there were −0.17 EUR, substantially below the equilibrium value of 2.96 EUR.[27] Importantly, the extent of the WC in first-price auctions is much larger as actual payoffs for $\varepsilon = \$6$ are −\$2.13 and −\$2.40, thus, way below equilibrium values. In fact, comparing the payoff gap between equilibrium payoffs and actual payoffs, $\Delta = \pi_T - \pi_A$, under the *Sophi* auction to those under the first-price auction shows that the payoff gap under the *Sophi* auction (3.14 EUR) is much smaller than in any first-price auction ($\geq$ \$4.80), for all levels of ε. The same conclusion applies to the non-minimal-information Sophi-*All* auction employing the adjusted average rule, although this variant of the *Sophi* auction, Sophi-All, yields less equilibrium payoffs to the bidder than the minimal-information *Sophi* auction and the first-price auction. Therefore, we conclude that the payoff data strongly suggest that both variants of the *Sophi* auction mitigate the WC found in the first-price auction.[28] This assessment is corroborated by the share of auctions that yield negative experimental payoffs (last line). In the *Sophi* auctions, roughly 49% and 54% of the auctions yield negative payoffs, while 100% of first-price auctions end with negative payoffs. We record this finding as follows.

Finding 1 *The Sophi auction allows inexperienced bidders to overcome the Winner's Curse better than the first-price auction.*

4.2 *Sophi* auctions with minimal-information vs. English auctions

4.2.1 Equilibrium bidding: Minimal-information *Sophi* auctions vs. English auctions

Sophi's price rule that induces simple sincere bidding, "corrects" the adverse selection that bidders face in first-price and, to a lesser extent, in English auctions. It also caters to the subjects' tendency of bidding closer to their own signal which is often well above equilibrium in first-price auctions, resulting in substantial and systematic losses. To study if the *Sophi* auction does indeed induce more, or closer to, equilibrium bidding than the English auction, we first compare the share of bids consistent with equilibrium behavior under both auctions. Because the price clock in the English auction stops when the next-to-the-last bidder drops out, the high bid under the English auction is not observed. To avoid a biased comparison of bidding data, we disregard the high bid under the *Sophi* auction.[29] Figure 1 depicts the shares of bids that are consistent with equilibrium bidding under both auctions, seperately for the two CV models. We use the absolute deviation between observed bid and equilibrium prediction (in ECU) to allow for some error tolerance. The share of bids consistent with equilibrium bidding is higher

further away from the lower signal boundary.) Further, for the first-price auction data from Kagel and Levin (1999), the winner's equilibrium's profit, π_T, is calculated ex-ante, i.e., not on realized signals.

[27] This difference is statistically significant according to a t-test with corrected standard errors that account for potential dependencies of data within sessions ($p = 0.034$).

[28] We didn't compare with several other first-price auction studies due to different numbers of bidders n and/or different signal range parameter values ε. But, with the exception of very experienced subjects in those experiments, eyeballing the data leads to similar conclusions.

[29] Recall that Sophi auction and English auction are price and allocation equivalent.

in the *Sophi* auction (solid line) than in the English auction (dashed line), independent of the particular error tolerance (in ECU) and CV model.

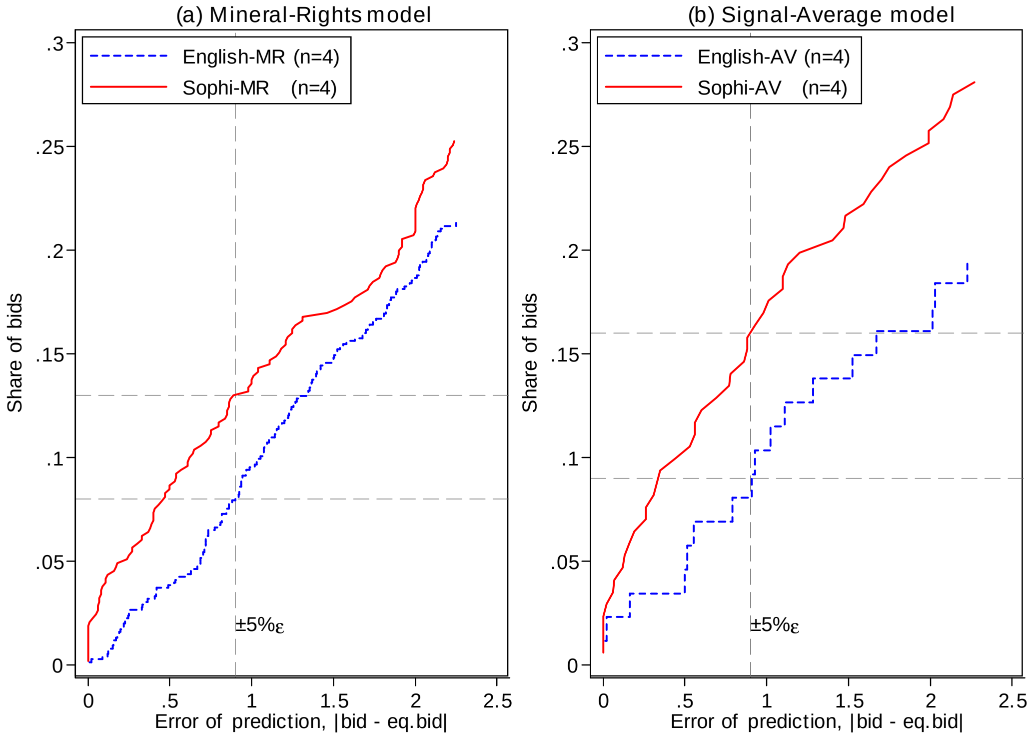


Figure 1: Share of bids consistent with equilibrium bidding under Sophi and English auctions.

As a basis for comparison, we focus on the error tolerance at 5% of ε, i.e. 0.9 ECU, that is indicated as a vertical dashed line in each panel of Figure 1. Allowing for this error margin, 13% of the bids are consistent with equilibrium bidding under the *Sophi* auction compared to 8% of the bids under the English auction in the mineral-rights model (left panel). To see whether this difference is statistically significant, we use a Probit cluster regression that takes potential dependencies within matching groups into account. We regress the binary dependent variable coding a bid's consistency with equilibrium bidding on an indicator variable indicating if the observation was generated under the *Sophi* auction. The regression uses data generated in treatments English-MR and Sophi-MR with four bidders. Regression results are reported in Table 3 and show that a bid under the *Sophi* auction in the mineral-rights model (treatment Sophi-MR) is more likely to be consistent with equilibrium bidding than a bid under the English auction (treatment English-MR) at a significance level of 5% ($p = 0.023$).

Explanatory variable	coefficient	robust std. err.	p-value	[95% conf.	interval]
Intercept	-1.40	0.02	0.000	[-1.44,	-1.37]
I_Sophi-MR	0.27	0.12	0.023	[0.04,	0.51]

Table 3: Probit cluster regression results on the probability of equilibrium bidding in the Sophi and English auction.

As can be seen in the right panel of Figure 1, this finding seems to extend to the signal-average model. At an error margin of 5% of ε, the percentage of bids consistent with equilibrium bidding is 16% under the *Sophi* auction and 9% under the English auction.[30]

Finding 2 *Bidding behavior in the Sophi auction is more often consistent with equilibrium bidding than in the English auction.*

The percentage of equilibrium bidding that we observed in the *Sophi* auction, although lower than what we expected, is significantly higher than in the English auction. Next, we compare the WC performance of the *Sophi* auction to that of the English auction.

4.2.2 Winner's Curse performance: Minimal-information *Sophi* auctions vs. English auctions

	Statistic (No. of auctions)	English-MR (252)	Sophi-MR (177)	English-AV (29)	Sophi-AV (57)
1)	Actual payoffs π_A (per auction)	1.81 ECU	-0.17 ECU	2.49 ECU	-1.18 ECU
2)	Equilibrium payoffs π_T	2.48 ECU	2.96 ECU	1.49 ECU	1.39 ECU
3)	$\Delta := \pi_T - \pi_A$	$\Delta = 0.67$	$\Delta = 3.13$	$\Delta = -1.00$	$\Delta = 2.57$
4)	Auction share with negative exp.payoffs	0.36	0.49	0.41	0.65
5)	Share: bid>E[V|x]	0.43	0.64	0.47	0.60
6)	Bankruptcy share	0.27	0.41	0.22	0.27
7)	Share periods 'out'	0.12	0.26	0.14	0.12
8)	Auction share won with high signal	0.58	0.62	0.41	0.65

Note: Share period 'out' gives the share of periods a subject was inactive due to rotation, averaged over all subjects.

Table 4: Winner's Curse aggregate statistics (4 bidder auctions)

Previous studies show that the static, sealed-bid first-price auction results in a WC that is roughly twice as large as that in the dynamic English auction with the same parameters. It has been suggested that whenever there is a severe WC, additional public information provided either exogenously or endogenously mitigates the WC by helping bidders realize their overestimation, resulting in lower bids and less frequent and lower losses.[31] Bidders' dropout prices help remaining bidders realize they were overestimating. Thus, maybe not surprising, it may be too ambitious for a static auction such as the *Sophi* auction to outperform the English auction.

Table 4 reports various WC statistics for the *Sophi* auction and the English auction in both CV models. The statistics for the Sophi-MR and Sophi-AV treatments show that the WC is alive and well there, and even stronger than in the English-MR and English-AV treatments,

[30] Because we collected very few data for either treatment in the average-signals model (one session each), we cannot subject this conjecture to statistical testing.

[31] See Kagel and Levin (1986) and Levin, Kagel, and Richards (1996).

respectively, although the *Sophi* auction attracts more bidding that is consistent with equilibrium predictions, as we showed in the preceding section. Comparing the statistics obtained for the *Sophi* auction to those of the English auction in either CV model shows that the English auction fares better in overcoming the WC: The share of auctions with negative expected bidder payoffs (fourth line) is 36% in English-MR, but 49% in Sophi-MR and 41% in English-AV, as compared to 65% in Sophi-AV. Similarly, the actual payoffs accruing to an auction winner on average (first line) in the English auction and the Sophi auction fall short of the equilibrium predictions in the mineral rights model (second line). As can be seen, the data on payoff gaps (third line) show that auction earnings in the Sophi auction are much farther away from equilibrium earnings than in the English aucion; the payoff gap in the Sophi auction, either 3.13 EUR or 2.57 EUR depending on the CV model, is much larger than that found in the English auction, where it amounts to 0.67 EUR or -1.00 EUR, respectively.

Finding 3 *The English auction overcomes the Winner's Curse better than the Sophi auction does.*

The aggregate statistics on bidding behavior suggest that the reason the English auction mitigates the WC better than the *Sophi* auction (relative to the first-price auction) is due to larger bids relative to the CV under the *Sophi* auction. Specifically, the share of bids exceeding the expected CV, displayed in the fifth line of the table, is larger in the *Sophi* auctions, 64% in Sophi-MR, and 60% in Sophi-AV, than in the English auctions, where it is 43% in English-MR and 47% in English-AV.

Another property of equilibrium bidding in either auction is the monotonicity of equilibrium bid functions. It implies that the bidder with the highest signal submits the highest bid and, henceforth, wins the auction. The eighth line of Table 4 shows the share of auctions won by the highest signal holder as it ought to be in equilibrium. Interestingly, this share is higher in the *Sophi* auctions as compared to the corresponding English auctions treatments.

Although actual bidding in the *Sophi* auction is somewhat closer to equilibrium bidding than in the English auction, in the sense of more sincere bidding and the correlation between the high-signal holder and winning the auction, the WC statistics in Table 4 show that it produces more WC by several other measures. Payoffs per auction is one way to document this inferiority in performance. Bidders in treatment English-MR earned on average 1.81 EUR per auction as compared to -0.17 EUR in Sophi-MR. This pronounced difference of winners' earnings is striking, because both auction formats are predicted to result in identical prices and allocations for any given realization of signals. This raises the question: "Why does the observed closer equilibrium bidding in the *Sophi* auction not result in less WC as compared to the English auction?" To answer this question, we explore the determination of prices in both of these auctions for the mineral-rights model more closely.

Recall that the equilibrium price in both auctions, *Sophi* and English, is the average of the second-highest signal and the lowest signal. The *Sophi* auction's payment rule computes this average directly. In the English auction, the determination of the equilibrium price is dynamic and more involved:[32] In our model, the lowest signal holder ought to drop at her signal and

[32] A typical English auction requires remaining (active) bidders to update after every drop; our design requires

every other bidder ought to drop at the average of the lowest observed drop-out bid, being the lowest signal, and their own signal value, and thus, the price is set by the second-highest signal holder who drops at the average of her signal and the lowest signal, resulting in the same price as in the *Sophi* auction. Therefore, we can use deviations from equilibrium bidding to trace back the earnings differences to differences in bidding behavior, while controlling for differences in the realizations of the CV.

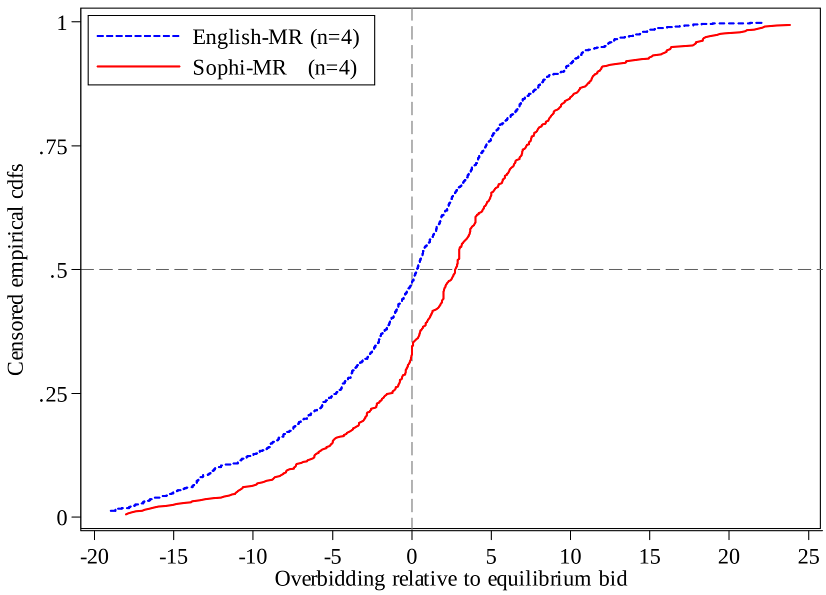


Figure 2: Censored overbidding distributions in treatments English-MR and Sophi-MR ($n = 4$)

Ideally, we would compare the distributions of observed deviations from equilibrium bidding in each treatment; but since we do not observe the winner's drop-out price in English auctions, we compare the censored distributions of equilibrium deviations, where we drop the highest bid in the Sophi-MR auction to avoid a biased comparison. We use the term "overbidding" to refer to bids exceeding the equilibrium predictions. Figure 2 depicts the censored distributions of both treatments. The comparison of distributions clearly shows that there is more overbidding in the *Sophi* auction as its cumulative-distribution-function (cdf) first-order stochastically dominates that of English-MR. A comparison, using 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). Figure 2 also illustrates that the *Sophi* auction promotes more equilibrium behavior as its cdf is steeper than that of the English auction at zero overbidding, indicating more observations with small deviations from equilibrium under the *Sophi* auction. We record this finding as follows.

Finding 4 *Overbidding is more pronounced under the Sophi auction than under the English auction.*

to update only once, after the lowest signal holder drops. Levin, Kagel and Richard (1996) report for the same design that bidders' drop-out-prices are influenced by previous drop-outs.

4.3 Amending the minimal-information *Sophi* auction to mitigate the overbidding bias

The observation that the minimal-information *Sophi* auction induces a higher percentage of equilibrium bidding, but more WC losses, points to larger overbidding when it occurs. Our initial data analysis and conversations with experimental subjects after they exit the lab suggested that they may have the erroneous impression that, since the payment rule is the average of two bids, the lowest and the second-highest, bidding above signal increases the probability of winning at little cost. We modified the Sophi payment rule to an average payment rule that is based on the average of *all* bids such that the highest bid is replaced by the second-highest.[33] Thus, two bids that are higher than the lowest bid are included additionally in the computation of the average that increases in turn. This price rule preserves the equilibrium property of sincere bidding, albeit not as an ex-post equilibrium. As introduced in the theory part, we refer to this auction design as the Sophi-*All* auction, because it uses all bids (with the highest bid replaced by the second-highest one) to compute the price. We conjectured that such a price rule would narrow the gap between the actual and predicted bids, reducing overbidding. We refer to the hypothesis that overbidding is reduced when moving from the Sophi auction to the Sophi-All auction as the overbidding-reduction hypothesis.

4.3.1 Winner's Curse performance: Minimal-information *Sophi* auctions vs. *Sophi-All* auctions

Does modifying the *Sophi* auction to Sophi-*All* help in mitigating the WC? Table 5 summarizes WC statistics for the Sophi-All auctions. The second line of the table shows the average equilibrium payoffs of the winner conditional on realized signals. Theory predicts that replacing the payment rule of the Sophi auction by the Sophi-*All* payment rule increases the price paid to the seller,[34] thereby reducing the winner's payoffs. The equilibrium predictions (second line) illustrate that this change of the payment rule has a strong effect on the winner's payoff. For the same information structure with $\varepsilon = 18$, the average winner payoff of 1.16 EUR per auction predicted for treatment Sophi-All-MR is just 39% of that in treatment Sophi-MR, where the winner is predicted to earn a payoff of 2.96 EUR on average. To correct for this payoff disadvantage to bidders in the Sophi-All-MR treatment when assessing the WC performance of Sophi-All, we ran treatment Sophi-All-MR2, where the signal range is doubled. As can be seen from the table, the average winner payoff conditional on realizations of 2.08 EUR predicted for treatment Sophi-All-MR2 is 79% larger than that in Sophi-All-MR, albeit somewhat smaller than that in Sophi-MR. According to actual payoffs observed (first line), qualitatively the theoretical prediction is satisfied. Winners' payoffs decrease when moving from Sophi-MR to Sophi-All-MR and increase when moving from Sophi-All-MR to Sophi-All-MR2. Notably, the payoff gaps (third line) show

[33] This particular average rule is due to the uniform distribution. More generally, auction designs, where the average of all signals is a sufficient statistic for the CV and that use the 'replaced' average price rule, induce sincere bidding as a no-regret equilibrium.

[34] Theoretically, the Sophi-*All* auction generates strictly larger equilibrium revenue than the Sophi auction, because for any profile of realized signals, the price under Sophi-All-MR is strictly higher than the price under Sophi-MR: $[p^{\text{Sophi.All}} - p^{\text{Sophi}}] = [\frac{x^2+x^2+x^3+x^4}{4}] - [\frac{x^2+x^4}{2}] = \frac{x^3-x^4}{4}$. For our parameterization, the last expression equals $\frac{\varepsilon}{10} = 1.8$, with $\varepsilon = 18$.

that the Sophi-All payment rule leads to actual winner payoffs that are much closer to equilibrium (in treatments Sophi-All-MR and Sophi-All-MR2) than those for the minimal-information Sophi payment rule used in treatment Sophi-MR. Also, when moving from the Sophi auction (treatment Sophi-MR) to the Sophi-All auction (treatments Sophi-All-MR and Sophi-All-MR2), the share of bids exceeding the expected CV drops slightly (fifth line).

	Statistic (4 bidders) (No. of auctions)	Sophi-MR (177)	Sophi-All-MR (186)	Sophi-All-MR2 (111)
1)	Actual payoff π_A	-0.17 EUR	-0.31 EUR	2.24 EUR
2)	Equilibrium payoffs π_T	2.96 EUR	1.16 EUR	2.08 EUR
3)	$\Delta := \pi_T - \pi_A$	$\Delta = 3.13$	$\Delta = 1.47$	$\Delta = -0.16$
4)	Auction share with negative exp.payoffs	0.49	0.54	0.36
5)	Share: bid>E[V|x]	0.64	0.57	0.52
6)	Bankruptcy share	0.41	0.40	0.28
7)	Share periods 'out'	0.26	0.22	0.21
8)	Auction share won with high signal	0.62	0.63	0.63
9)	Average bid	149.8 EUR	146.7 EUR	148.1 EUR
10)	Equilibrium bid	144.6 EUR	144.2 EUR	146.5 EUR

Table 5: Winner's Curse Aggregate Statistics by Treatment

Next, we explore treatment differences in the WC more formally. We use the expected payoffs of the winner, conditional on actual bidding, to quantify the strength of the WC. The use of expected payoffs allows to control for differences in realized common values across treatments and avoids unnecessary noise in the regression. For the mineral-rights model with four bidders, the expected payoffs conditional on observed bidding are given as follows:

$$\boldsymbol{\pi}^W(\widetilde{x}, \mathbf{x}) := \begin{cases} \text{E[CV}|x] - \frac{\widetilde{x}_{(2)}+\widetilde{x}_{(4)}}{2} & \text{under the Sophi auction} \\ \text{E[CV}|x] - \frac{\widetilde{x}_{(2)}+\widetilde{x}_{(2)}+\widetilde{x}_{(3)}+\widetilde{x}_{(4)}}{4} & \text{under the Sophi-All auction} \end{cases}$$

To test for treatment differences, we estimate a mixed effects model that accounts for dependency of observations within sessions, where the expected winner payoff $\pi^W_{k\tau}$ 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

$$\pi^W_{k\tau} = \beta_o + \beta_1 I^{\text{Sophi-MR}}_{k\tau} + \beta_2 I^{\text{Sophi-All-MR}}_{k\tau} + \beta_3 I^{\text{Sophi-All-MR2}}_{k\tau} + \nu_k + u_{k\tau}, \tag{1}$$

where ν_k is the random effect of session k and $u_{k\tau}$ is the residual. Table 6 provides the regression results.

The intercept of the regression equation gives the expected payoff of auction winner's conditional on actual bidding in the English auction (treatment English-MR). As can be seen from Table 6, the winner's payoff in the English auction is estimated to be 2.51 EUR per auction. The negatively estimated coefficients of the two indicator variables for treatments Sophi-MR and

Explanatory variable	coefficient $\hat{\beta}$	σ_β	p-value	[95% conf. interval]
Intercept (Eng.-MR)	2.51	0.70	0.000	[1.13, 3.89]
I_Sophi-MR	−2.52	1.05	0.016	[−4.57, −0.52]
I_Sophi-All-MR	−2.55	1.04	0.014	[−4.59, −0.52]
I_Sophi-All-MR2	0.74	1.17	0.526	[−1.55, 3.03]

Table 6: Mixed effects estimation results of Equation (1) with English-MR as benchmark.

Sophi-All-MR show that winners' expected payoffs per auction are significantly smaller in treatments Sophi-MR and Sophi-All-MR than those in the English auction; the former documents the better performance of the English auction than the Sophi auction, the latter is predicted, because for each profile of realizations, the winner payment under Sophi-All is strictly higher than under the English auction. A comparison of the Sophi auction and the Sophi-All auction (treatments Sophi-MR and Sophi-All-MR) shows that both price rules generate the same expected auction payoff as the estimated coefficients do not differ significantly ($p = 0.973$). Notice that this is in stark contrast to theory, because the equilibrium payoff in the Sophi-All-MR auction is much smaller than that in the minimal-information Sophi-MR auction (see line 2 in Table 5); in fact, theory predicts the auction payoff in Sophi-All-MR to be just 39% of the auction payoff predicted for Sophi-MR as noted before. The inconsistency of the data with the comparative-statics prediction stems from the fact that bidding behavior under the Sophi-All-MR auction is somewhat closer to equilibrium bidding than under the Sophi-MR auction: there is less overbidding and less WC in the Sophi-All-MR auction than in Sophi-MR, in line with the overbidding-reduction hypothesis that is addressed in the next subsection. Importantly, the estimate of the indicator variable for treatment Sophi-All-MR2 is not significantly different from zero ($p = 0.526$). This shows that bidders in treatment Sophi-All-MR2 earn the same amount as bidders in the English auction.

In summary, the Sophi-All auction exhibits more equilibrium attraction than the original, minimal-information, *Sophi* auction, and generates a similar WC performance as the dynamic English auction, when we correct for the differences in auction revenues.

Finding 5 *(i) The average payoff of the winner under the Sophi-All auction that uses the average of bids after bid replacement in its price rule is equal to that under the Sophi auction with minimal information. This finding contrasts with the theoretical predictions (see fn 17). (ii) After accounting for the revenue disadvantage of the Sophi-All auction, the average payoff of the winner is not significantly different from that under the English auction (Sophi-All-MR2 vs. English-MR); therefore, the Sophi-All-MR2 results in the same WC performance as the dynamic English auction.*

4.3.2 The overbidding bias: Minimal-information *Sophi* auctions vs. *Sophi-All* auctions

Here, we test the overbidding-reduction hypothesis that stipulates that when moving from the minimal-information Sophi auction to the non-minimal-information Sophi-All auction overbidding is reduced. To facilitate the comparison of overbidding data across all *Sophi* treatments, we normalize overbidding relative to the signal range, which is 2ε. This is necessary, because the signal range parameter ε varies across treatments, $\varepsilon \in \{18, 36\}$. Accordingly, 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 3 shows the median of normalized overbidding over the course of the experiment for the *Sophi* treatments.[35] The large majority of bidders in the Sophi-MR treatment (left panel) repeatedly submitted bids exceeding the signal value. The median of normalized overbidding

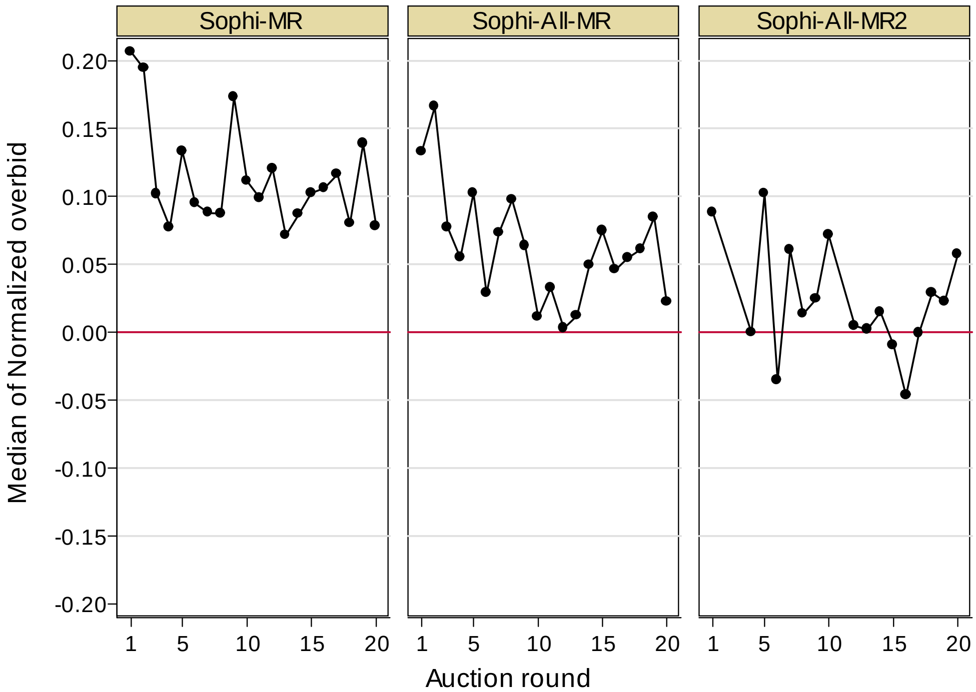


Figure 3: Median of normalized overbidding in the Sophi treatments.

in Sophi-MR fluctuates around 0.1 and is always strictly positive. In comparison, the less informationally efficient payment rules used in treatments Sophi-All-MR (middle panel) and Sophi-All-MR2 (right panel) induce less overbidding. For example, the median of normalized overbidding in treatment Sophi-All-MR (middle panel) seems to fluctuate around 0.05 except for the first two periods. To formally confirm that the Sophi-*All* auction reduces overbidding relative to the *Sophi* auction, we regress normalized overbids on an indicator variable that indicates if the observation was generated in a treatment using the non-minimal-information payment rule (treatments Sophi-All-MR and Sophi-All-MR2). The mixed effects estimation equation is

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

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

[35] When 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.

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-information rule treatments. This specification is given by:

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

	coefficient $\hat{\beta}$	σ_β	p-value	[95% Conf.	Interval]
Equation (2):					
Intercept	0.30	0.09	0.001	[0.12,	0.48]
I_Non-minimal payment rule	−0.24	0.11	0.034	[−0.46,	0.02]
Equation (3):					
Intercept	0.30	0.09	0.001	[0.12,	0.48]
I_Non-minimal payment rule	−0.25	0.13	0.049	[−0.50,	−0.001]
I_Sophi-All-MR2	0.03	0.13	0.845	[−0.24,	0.29]

Table 7: Mixed Effects Estimation Results: Normalized overbidding in Sophi treatments

Table 7 summarizes the estimation results of both models. The regression results show that there is much less overbidding under the non-minimal payment rules, as can be seen by the sizable and negative estimate of coefficient β_1. Moreover, there is no difference between the non-minimal rule treatments Sophi-All-MR and Sophi-All-MR2, as the estimate of coefficient β_2 is insignificant.

Finding 6 *The Sophi-All-auction leads to less overbidding of the equilibrium bid (=signal) than the minimal-information Sophi-auction confirming the overbidding-reduction hypothesis.*

4.4 Individual bidding behavior in the *Sophi* and *Sophi-All* auctions

The evolution of the overbidding median of treatment Sophi-MR suggest stationary bidding behavior on the aggregate level, as can be seen from the left panel of Figure 3. Therefore, the minimal-information *Sophi* auction (Sophi-MR) creates an overbidding bias on the aggregate level that seems to neither sharply increase, nor decrease, over the course of the experiment. Here, we explore whether the stationarity of the aggregate overbidding bias is implied by stationary bidding on the individual level. Is it that subjects who overbid their signal always do so by a similar amount, or are there pronounced movements up or down over the course of the experiment on the individual level, that cancel out on the aggregate level? The left panel of Figure 4 illustrates the bidding behavior of six subjects (out of 75) in treatment Sophi-MR. Each graph shows a subject's overbid, $b_{it} - x_{it}$, over time. Apparently, bidding behavior is quite heterogenous at the individual level. For example, subjects 3 and 6 exhibit stationary bidding with subject 3 behaving consistently with theory in almost all rounds, while subject 6 exhibits positive overbidding with a few jumps downward. In contrast, subject 4 increases, and subject 5 decreases overbidding over the course of the experiment.

To investigate systematically the stationarity of each individual's bidding behavior, we regress, separately for each subject i, the overbid, $b_{it} - x_{it}$, on time by using Ordinary Least

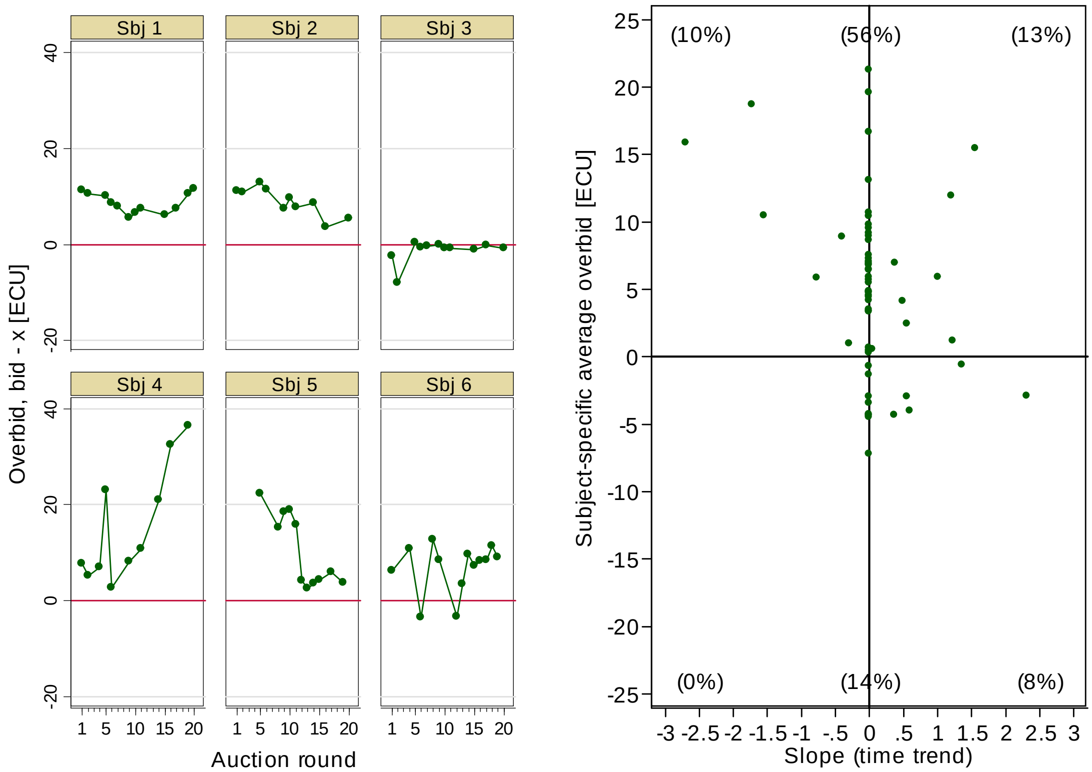


Figure 4: Individual bidding behavior in treatment Sophi-MR

Squares (OLS), such that the estimated intercept gives subject i's average overbid. We call a subject's bidding behavior 'stationary', if the regression's slope does not differ from zero significantly according to a t-test. The resulting estimates (in terms of intercept and slope) are plotted in the right panel of Figure 4, where each marker summarizes the bidding behavior of a single subject; if the slope was estimated to be insignificant, it is depicted as zero in the figure. The bidding behavior of approximately 70% of subjects does not follow a significant time trend ('slope = 0') as indicated by the majority of markers lying on the vertical axis. Furthermore, there is more overbidding than underbidding among the individuals with stationary bids, as 56% of the subjects submit bids exceeding signals, while 14% of subjects only submit bids smaller than signals.

Treatment	no time trend 'slope = 0'	overbids decreasing 'top-left'	overbids increasing 'top-right'	underbids decreasing 'bottom-left'	underbids increasing 'bottom-right'
Sophi-MR	69%	10%	13%	0%	8%
Sophi-All-MR	85%	9%	3%	1.5%	1.5%
Sophi-All-MR2	74%	6%	6%	8%	6%

Table 8: Shares of subjects by overbid and time trend

The finding of mostly stationary bidding behavior on the individual level also applies if all bids are used for computing the object's price (treatments Sophi-All and Sophi-All-MR2), instead of using the second-highest and the lowest bid only (treatment Sophi-MR). Analogously, we estimated a subject's overbid on time for each individual separately for treatments Sophi-All-MR and Sophi-All-MR2. Table 8 summarizes the regression results and also includes the data for treatment Sophi-MR. It gives the relative frequencies of subjects exhibiting no time trend at all, along with these associated with each of the four quadrants depicted in the right panel of Figure 4.

Finding 7 *All Sophi auctions (treatments Sophi-MR, Sophi-All-MR, and Sophi-All-MR2) lead to individual bidding behavior that is predominantly stationary on the individual level: The bidding pattern of at least 69% of the subjects does not exhibit a time trend.*

5 Concluding Remarks

We introduced a payment rule that internalizes the adverse selection in common-value auction and results in sincere bidding as an ex-post equilibrium. The motivation for such a rule is the expectation that its simplicity, and the fact that it "asks" bidders to do what they are inclined to do all along – bid close to their signal–, would eliminate, or at least mitigate, the WC.

There are other payment rules that also induce sincere bidding, but not as an ex-post equilibrium and, thus, are less desirable on theoretical grounds. On the other hand, they may be more intuitive, and thus, further help bidders find their way to the sincere-bidding equilibrium.

We find that when we compared with the first-price auction with four inexperienced subjects, and accounting for ε, the *Sophi* auction does much better by mitigating the WC, but does not as well as the dynamic English auction, its allocation-price equivalent, in overcoming the WC. We also find that the Sophi-All auction, that uses more bids in the price rule, reduces overbidding and results in higher bidders' payoffs, and (after calibrating for revenue) it matches the performance of the English auction. Although this finding comes short of the Holy Grail of eliminating the WC, it is the first time, as far as we are aware, that a static (simultaneous) bidding format mechanism performs as well the dynamic English auction. The simplicity and intuitiveness of the rule gives hope that outside the laboratory, and with more bidders, this mechanism will perform much better than existing mechanism but that still has to be further studied in the future.

A Appendix

A.1 Proof of Proposition

Proposition 3

In the mineral-rights model, the (adjusted) average pricing rule, $p(x) = \frac{x^2+x^2+x^3+...+x^n}{n}$, induces sincere bidding as a Bayesian equilibrium, but not as an ex-post equilibrium.

Proof. The claim that the equilibrium is not *ex-post* follows from our first proposition which implies *uniqueness* of our Sophi payment rule in this class of mechanisms and that for almost any x, $p(x) \neq \frac{x^1+x^n}{2} =: E[V|x]$. The rest of the proof is accomplished by the following two observations:

(i) A direct mechanism, where each bidder reports his signal, the highest reported signal x^1 wins and pays $p(x) = E[V|X^1 = X^2 \geq X^3 \geq, ..., \geq X^n]$, is *incentive compatible.*[36]

(ii) In our setup, the random variable V is distributed *uniformly* on the interval $[a, b]$ and conditional on $V = v$, the private signals, $X_i (i = 1, ..., n)$, are i.i.d. *uniformly* on $[v - \varepsilon, v + \varepsilon]$. Thus, in the region that we consider in our analysis, $x \in [a + \varepsilon, b - \varepsilon]$, $E[V|X^1 = X^2 \geq X^3 \geq, ..., \geq X^n] = E[V|X^2 \geq X^n]$.

Therefore, the (adjusted) average pricing rule generates the same (ex-ante) $p(x)$ as the Sophi payment rule. □

A.2 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.3 Instructions

In each treatment, the instuctions consisted of the two parts "General information for participants" and "Information regarding the experiment". While the first part was the same for each treatment, the second one was specific to the treatment.

A.3.1 General information for participants [The same in all treatments]

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 – earn a considerable amount of money. It is, hence, very important that you read the instructions carefully.

[36] The highest signal holder wins by reporting her signal and earns non-negative (positive) payoffs. Reporting a higher signal changes nothing, and reporting a lower signal, if it matters, leads to zero profits. Any other bidder earns zero by reporting sincerely; reporting a lower signal changes nothing, and reporting a higher signal that result in winning earns negative payoffs.

This set of instructions is for your private information only. **During the experiment communication is not permitted**. Whenever you have any question, please raise your hand. We will then come to you and answer your question at your seat. If you do not follow this rule you will be excluded from the experiment and all payments.

During the experiment we do not talk about Euro, but about a ficticious currency called "Experimental Currency Unit" (ECU). Your entire income will be determined in ECU first. The total amount of ECU that you will have earned 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. [The conversion rate shown on screen was 1 ECU = 1 EUR.]

A.3.2 Information regarding the experiment [Treatments *Sophi-MR*, *Sophi-All-MR, and English-MR*]

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

1. In each period you will act as a buyer and bid for a fictitious object that is auctioned off. Next to you, three other participants bid for the same object. There are, hence, in total **four bidders** in your auction in each period. In each period you will be randomly matched with three other participants for the auction, so that **the other bidders in the auction randomly change in each period**.

2. **The precise value of the object will be unknown to you and any other bidder at the time** [*Sophi-MR*, *Sophi-All-MR*: **you make your bids.**] [*English-MR*: **of bidding.**] 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. [*Sophi-MR*, *Sophi-All-MR*:] The **high bidder gets the object** and receives a profit equal to the difference between the object value and the price of the object, that is:

   Profit of the high bidder = Object value − Price

   If this difference is negative since the **price is greater than the object value**, then the **profit is negative** which represents **a loss**.
   [*Sophi-MR*: The **price of the object is the *average of the second-highest bid and the lowest bid.***
   Example: If the second-highest bid is 150 ECU and the lowest 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 lowest bid, $(150 + 130) : 2 =$ 140 ECU.]
   [*Sophi-All-MR*: The **price of the object is the *average of all bids reduced by a fourth of the difference between the highest-bid and the second-highest bid.***
   Example: If the bids 180 ECU, 150 ECU, 140 ECU and 130 ECU are submitted, then the price of the object is 142.50 ECU = (180+150+140+130)/4 - (180-150)/4 since this is

the average of the bids reduced by a fourth of the difference between the highest bid (180 ECU) and the second-highest bid (150 ECU).]

If you do not make the highest bid, your profit is 0 ECU. In this case you neither gain nor lose from bidding on the object.

3. [*English-MR*:] **In the auction, the price of the object will automatically increase over time**, starting at a price of 50 ECU. You and all the other bidders will bid for the object at the increasing price right from the start. You can stop bidding and leave the auction by clicking the button "Stop bidding!" that will be shown on the screen along with the increasing price and the number of other bidders that continue bidding in the auction. Similarly any other bidder can stop bidding and leave the auction. At the beginning of the auction the price increases by 1 ECU every 0.5sec. It increases by the smaller amount of 0.50 ECU as soon as the first bidder stops bidding. Finally, it increases by 0.20 ECU if only two bidders continue bidding. If the next-to-last bidder stops bidding (in other words, if all bidders except for one stopped bidding), the auction ends and the price does not increase further. **The bidder who continues bidding in the auction while anyone else stopped bidding (=the high bidder)** gets the object and receives a profit equal to the difference between the object value and the price of the object, that is:

   Profit of the high bidder = Object value − Price

   If this difference is negative since the **price is greater than the object value**, then the **profit is negative** which represents **a loss**.
   The price of the object is the price at which the next-to-last bidder stops bidding.
   Example: If the next-to-last bidder stops bidding at 140 ECU so that only one bidder continues bidding, then the price of the object is 140 ECU.
   If you are not the high bidder, your profit is 0 ECU. In this case you neither gain nor lose from bidding on the object.
   If two (or more) bidders stop bidding at the same price such that no bidder continues bidding in the auction, chance decides who of these two (or more) bidders gets the object. In this case, the final price of the object is equal to the price at which these two (or more bidders) stopped bidding.

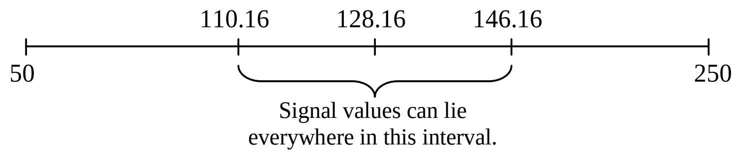
4. You will be given a starting capital balance of 10 ECU at the beginning of the experiment. **Any profit earned by you will be added to your balance and any losses incurred will be subtracted from your balance**. At the end of the experiment, the net balance of these transactions will be converted into Euro and paid to you in cash.
   The starting capital 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. [*Sophi-MR*, *Sophi-All-MR*: (Of course, you are permitted to submit bids greater than your capital credit balance.)]

5. After [*Sophi-MR*, *Sophi-All-MR*: all bidders have submitted their bids, you will be shown all bids,] [*English-MR*: the auction will have finished, you will be shown the prices at

which each bidder stopped bidding,] the price of the object, and the object value on the screen. We will also show you if the high bidder earned a profit or loss.

6. **The value of the auctioned object** (V) **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 object value can never be less than 50 ECU or more than 250 ECU. **The object values V are determined randomly and independently in each auction.** As such a high V in one period tells you nothing about the likely value in the next period whether it will be high or low. It doesn't even preclude drawing the same V value in later periods.

7. <u>Private information about the value of the object</u>:
   Although you do not know the precise value of the object at the time of bidding, you will receive information which will narrow down the range of possible values of the object. **This will consist of a signal value which is selected randomly from all values between $V - 18$ and $V + 18$.** *Any value within this interval has an equally likely chance of being drawn and being assigned to one of you as your signal value.*
   Example: Suppose that the value of the auctioned item is 128.16 ECU, then each of you will receive a signal value which will consist of a randomly and independently drawn number that will be between 110.16 ECU ($= V - 18 = 128.16 - 18$) and 146.16 ECU ($= V + 18 = 128.16 + 18$). Any number in this interval has an equally likely chance of being drawn. The diagram illustrates this example geometrically.



   As an example, the following six signal values were randomly selected by the computer for illustration ($V = 128.16$ ECU):

   116.21 ECU, 129.05 ECU, 124.83 ECU, 141.71 ECU, 124.74 ECU, 131.57 ECU.

   You will note that some signal values were above the value of the auctioned object, and some were below the value of the object. Over a sufficiently long series of signal values, **the average of the signal values will equal the value of the object** (or will be very close to it). For any given signal value, however, your signal value is most likely either above or below the value of the object.
   Please also note that the selection of signal values is such that **the value of the object must always be larger than or equal to your signal value minus 18 and be smaller than or equal to your signal value plus 18**. The interval of object values that is possible with your signal value will be shown to you on the screen at the time of bidding.
   You may receive a signal value below 50 ECU (or above 250 ECU). This is no problem with the software, but indicates that the value of the object is close to 50 ECU (or 250 ECU) relative to the interval width of ± 18 ECU.

8. At the time of bidding you know your own signal value only. **The signal values of all other bidders are unknown to you.** Similarly any other bidder knows his/her own signal value only and not the signal value of anyone else. After all bidders have submitted their bids, you will be shown all of the signal values drawn along with the bids on the screen.

9. [*Sophi-MR*, *Sophi-All-MR*: Please note that any bid less than 50 ECU and any bid exceeding 300 ECU will not be accepted. Any bid in between these two values is acceptable. Bids must be rounded to the nearest cent to be accepted. In case of ties for the high bid, chance determines who will receive the object.]
   [*English-MR*: Please note that the auction ends latest at a price of 300 ECU if at least two bidders continue bidding at that price. Chance will determine which one of them will receive the object at that price.]

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 periods as an inactive bidder per participant as small as possible over the course of the experiment. All participants that are designated as inactive bidders in any given period will be informed about it before bidding in the corresponding period; 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 [*Sophi-MR*, *Sophi-All-MR*: submit a bid,] [*English-MR*: have to stop bidding,] and will be shown the outcome of a randomly chosen auction with active bidders. Further, inactive bidders will earn a profit of 0 ECU so that the capital balance does not change.

12. Before we begin with the auction experiment as described, you will practice the auction situation for two periods of practice. This allows you to better familiarize yourself with the auction situation. The auction outcomes in these two practice periods will not affect your cash payment at the end of the experiment.

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 period income. (2) The price of the object equals [*Sophi-MR*: the average of the second-highest bid and the smallest bid] [*Sophi-All-MR*: the average of all bids reduced by a fourth of the difference between the highest bid and the second-highest bid.] [*English-MR*: the price at which the next-to-last bidder stopped bidding.] (3) payoffs 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 $(V - 18)$ ECU and $(V + 18)$ ECU. (5) The value of the object will always lie between your signal value–18 and your signal value+18, but it is never smaller than 50 ECU and never greater than 250 ECU. (6) The first two periods are for practice only.

A.3.3 Average actual payoffs

Treatment	Average actual payoffs (std. dev.)			Average payoffs with equil. bids		
(Rds.)	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 9: Average Actual Profits of Bidders per Auction in EUR

References

Bazerman, Max H. and William F. Samuelson, 1983. "I Won the Auction but Don't Want the Prize," *Journal of Conflict Resolution*, 27(4), 618-634.

Breuer Kevin, Peter Cramton, and Axel Ockenfels, 2019. "How softening an auction reserve price not only increases efficiency but also revenue," working paper presented at a conference at Maryland University.

Chang, Wei-Shiun, Bo Chen, and Timothy C. Salmon, 2014. "An Investigation of the Average Bid Mechanism for Procurement Auctions," *Management Science* 61(6), 1237-1254.

Charness, Gary and Dan Levin, 2009. "The Origin of the Winner's Curse: A Laboratory Study," *American Economic Journal: Microeconomics*, 1(1), 207-236.

Charness, Gary, Dan Levin, and David Schmeidler, 2018. "An Experimental Study of Estimation and Bidding in Common-Value Auctions with Public information," Mimeograph, Ohio State University.

Crawford, Vincent P. and Nagore Iriberri, 2007. "Level-k Auctions: Can a Nonequilibrium Model of Strategic Thinking Explain the Winner's Curse and Overbidding in Private-Value Auctions?", *Econometrica*, 75(6), 1721-1770.

Edelman Benjamin, Michael Ostrovsky, and Michael Schwarz, 2007. "Internet Advertising and the Generalized Second-Price Auction: Selling Billions of Dollars Worth of Keywords," *American Economic Review*, 97(1), 242-259.

Eyster, Erik and Matthew Rabin, 2005. "Cursed Equilibrium", *Econometrica*, 73(5), 1623–1672.

Fischbacher, Urs (2007). "z-Tree: Zurich Toolbox for Ready-made Economic Experiments," *Experimental Economics*, 10(2), 171-178.

Goeree, Jacob K. and Theo Offerman, 2002. "Efficiency in Auctions with Private and Common Values: An Experimental Study", *American Economic Review*, 92(3), 625-643.

Hansen, Robert G. and John R. Lott, jr., 1991. "The Winner's Curse and Public Information in Common Value Auctions: Comment", *American Economic Review*, 81, 347-361.

Ivanov, Asen, Dan Levin, and Muriel Niederle, 2011. "Can Relaxation of Beliefs Rationalize the Winner's Curse?: An Experimental Study," *Econometrica*, 78(4), 1435-1452.

Kagel, John H., 1995. "Auctions: A Survey of Experimental Research," in The Handbook of Experimental Economics, J. H. Kagel and A. E. Roth (eds). Princeton: Princeton University Press.

Kagel, John H. and Dan Levin, 1986. "The Winner's Curse and Public Information in Common Value Auctions," *American Economic Review*, 76(5), 894-920.

Kagel, John H., Dan Levin, Raymond C. Battalio, and Donald J. Meyer, 1989. "First-Price Common Value Auctions: Bidder Behavior and the Winner's Curse", *Economic Inquiry*, 27(2), 241-258.

Kagel, John H. and Dan Levin, 1999. "Common Value Auctions with Insider Information," *Econometrica*, 67(5), 1219-1238.

Kagel, John H. and Dan Levin, 2002. *Common Values Auctions and the Winner's Curse*, Princeton, NJ: Princeton University.

Kagel John, YC Lien, and Paul Milgrom, 2010. "Ascending Prices and Package Bidding: A Theoretical and Experimental Analysis," *American Economic Journal: Microeconomics*, 2, 160-185.

Kirchkamp, Oliver and J. Philipp Reiß, 2011. "Out-of-Equilibrium Bids in First-Price Auctions: Wrong Expectations or Wrong Bids?", *Economic Journal*, 121(557), 1361-1397.

Krishna, Vijay. (2010). *Auction Theory*, 2nd edition, Academic Press.

Levin, Dan, John H. Kagel, and Jean-Francois Richard, 1996. "Revenue Effects and Information Processing in English Common Value Auctions," *American Economic Review*, 86(3), 442-460.

Lind, Barry and Charles R. Plott, 1991. "The Winner's Curse: Experiments with Buyers and with Sellers", *American Economic Review*, 81, 335-346.

Mares, Vlad and Ronald M. Harstad, 2007. "Ex-Post Full Surplus Extraction, Straightforwardly", *Economic Theory*, 32(2), 399-410.

Matthews, Steven, 1997. "Information Acquisition in Competitive Bidding Process," Mimeograph, California Institute of Technology, Pasadena.

McAfee, R. Preston, John McMillan, and Philip J. Reny, 1989. "Extracting the Surplus in the Common-Value Auction", *Econometrica*, 57(6), 1451-1459.

Milgrom, Paul R. and Robert J. Weber, 1982. "A Theory of Auctions and Competitive Bidding," *Econometrica*, 50(5), 1089-1122.

Varian, Hal R., 2007. "Position Auctions," *International Journal of Industrial Organization*, 25(6), 1163-1178.

Wilson, Robert, 1977. "A Bidding Model of Perfect Competition," *Review of Economic Studies*, 44(3), 511-518.

Wilson, Robert, 1987. "Game-theoretic Analyses of Trading Processes," in: T. Bewley (ed.): Advances in Economic Theory: Fifth World Congress. Cambridge: Cambridge University Press, 33-70.