Declining Prices Across Second-Price Procurement Auctions[⋆]

Karl-Martin Ehrhart[a], Marion Ott[b]

[a] *karl-martin.ehrhart@kit.edu, Karlsruhe Institute of Technology (KIT), ECON, Neuer Zirkel 3, Building 20.53, 76131 Karlsruhe, Germany*
[b] *marion.ott@rwth-aachen.de, RWTH Aachen University, School of Business and Economics, Templergraben 64, 52056 Aachen, Germany*

Abstract

In four experimental second-price auction formats for procuring a good for which bidders have private uncertain valuations, we find declining auction prices across the four formats. Willingness-to-pay-willingness-to-accept disparity and reference-point shifts during auctions predict the order of the declining prices. We conclude that mechanisms influence the reference state, and that auctions that foster reference shifts lead to lower payments for the procurer. In particular, assigning a leading bidder position during the auction process leads to more aggressive bids. These results support and generalize findings on sales auctions.

Keywords: Procurement auction, experiment, private uncertain valuations, WTP-WTA disparity

JEL: D44, L11, D91, C72, C92

1. Introduction

Understanding drivers of price differences between different auction formats is crucial for choosing the appropriate auction design. A potential source of aggressive bidding (i.e., low bids) in procurement auctions is a willingness-to-pay-willingess-to-accept (WTP-WTA) disparity[1] that comes to the fore when the reference state shifts during an auction. We predict that certain auction designs foster a shift of the reference state, which causes lower bids and therefore lower auction prices.

[⋆]Financial support from the Deutsche Forschungsgemeinschaft, SFB 504, at the University of Mannheim, is gratefully acknowledged. We thank Thomas Gottfried for programming excellent experimental software and Susanne Abele for helpful discussions.

[1]Experiments on the WTP-WTA disparity find that the average WTP for buying a lottery ticket is less than the average WTA for selling the same lottery ticket, and that this difference is larger than what wealth effects can explain (e.g. Knetsch and Sinden, 1984; Marshall et al., 1986).

This draft: January 22, 2018

We implement four experimental procurement (i.e., reverse) auction formats, which have in common that bidding (down to) the price at which the bidder is indifferent between selling and not selling the good is a weakly dominant strategy. The four auction formats determine the four main treatments. The auction formats are a sealed-bid and three dynamic second-price auctions in which we expect that the exit price (i.e., the indifference price) moves from being equal to the WTA more and more towards the lower WTP. The sealed-bid second-price procurement auction asks bidders for their WTA and a bidder's reference state is his objective before-the-auction state of owning the good. We argue that in dynamic (descending) second-price procurement auctions the subjective reference state shifts from the objective before-the-auction state towards the after-the-auction state of not owning the good. As a consequence, the price at which the bidder quits the dynamic procurement auction is not the WTA but moves towards the WTP. This reference shift may be fostered by assigning a leading bidder position and by making the leading bidder position more prominent by assigning it to the bidder who is the first to submit his bid. As a consequence, we predict that auction prices decline when comparing the sealed-bid auction to a dynamic auction without leading-bidder selection, to a dynamic auction with random leading-bidder selection, and finally to a dynamic auction with first-to-bid leading-bidder selection.

Bidders have private uncertain valuations for the procured good, that is, the good is a lottery for the bidder and he has private information about his lottery. The reason for choosing this setting is that lottery tickets are among the goods for which the WTP-WTA disparity has been detected in experiments (e.g. Knetsch and Sinden, 1984; Marshall et al., 1986). Thus, uncertain valuations, in contrast to certain valuations, can be used to test our hypothesis, which bases on a WTP-WTA disparity. In contrast to real goods, for which the WTP-WTA disparity has also been observed, lotteries provide stronger experimental control over valuations.

Our main finding is that auction prices decline across the four treatments, as predicted. The mean price in the forth treatment undercuts that of the first by 13%. In particular, we observe more aggressive bidding behavior in the form of lower bids in auctions that assign a leading-bidder position during the auction process. The mean prices in the dynamic procurement auctions lie in between those of the sealed-bid procurement auction and those of a control treatment with a sealed-bid sales auction. Contrasting bids in these two sealed-bid auctions to compare WTA and WTP, we find evidence for a WTP-WTA disparity, which further supports that such a disparity underlies our results. Our results mirror and thereby support those by Ehrhart et al. (2015) on sales auctions and extend the insights to procurement settings.

The strength of the approach of basing the hypotheses on comparisons across strategically equivalent auction formats[2] is that it allows to exclude many other factors as relevant for treatment differences. (However, they might influence bidding in all our treatments or in other settings.) Such factors that have been considered in the literature are the following. Risk aversion, spiteful bidding, joy of winning or another extra utility from winning (e.g. Andreoni et al., 2007; Bartling and Netzer, 2016; Cox et al., 1982; Cooper and Fang, 2008; Jones, 2011; Malmendier and Lee, 2011; Kagel and Levin, 2016) cannot capture differences between any of our auction formats. Duration of being the high bidder or time in the auction (e.g. Heyman et al., 2004; Malmendier and Lee, 2011) and rivalry (Ku et al., 2005) cannot capture differences between our descending auctions. Similarly, we argue that it is unlikely that subject misconception (Plott and Zeiler, 2005) of lotteries or mechanisms causes differences between the descending auctions. Competitive arousal due to social facilitation or time pressure, escalation of commitment (Ku et al., 2005; Haruvy and Popkowski Leszczyc, 2010), loser regret and fear of losing in repeated first-price auctions (e.g. Engelbrecht-Wiggans, 1989; Filiz-Ozbay and Ozbay, 2007; Delgado et al., 2008; Cramton and Sujarittanonta, 2010), and charitable motives (Goeree et al., 2005) as drivers of high bids in sales auctions do not apply to our auctions, either because of the design (second-price auction, slow progress) or because the auctions take place in a standard anonymous laboratory environment.

This study on procurement auctions complements experimental studies on sales auctions, which are the focus of most auction experiments. In standard auction theory, most results on procurement auctions are easily derived as an inversion of the results on sales auctions. However, it is not obvious how behavior that systematically deviates from equilibrium predictions for monetary-payoff maximizing bidders translates from sales auctions to procurement auctions. We do find support for an inversion of the hypothesized effect

[2]We call two auctions strategically equivalent if their sets of relevant strategies (bids in a sealed-bid auction and minimum bids in a descending auction) are the same and if each combination of strategies leads to the same outcome in both auctions. As a consequence, the equilibrium outcome (i.e., winner and price) of both auctions is the same.

of WTP-WTA disparity and reference shift from sales to procurement auctions. However, we do not find an inversion of the often observed tendency to bid above the valuation in sales auctions (cp. Kagel and Levin, 2016), i.e., we do not find underbidding. Instead, we find overbidding in procurement auctions with private certain valuations (with which we compare our uncertain valuations treatments).[3] Thus, motives for deviating from bidding the valuation may differ between sales and procurement auctions. Joy of winning or spite motives, wich capture overbidding in sales auctions (e.g. Andreoni et al., 2007; Bartling and Netzer, 2016; Cooper and Fang, 2008), cannot account for overbidding in procurement auctions, which may be triggered by a profit-targeting motive.

This paper is structured as follows. The experimental design, the theory and the hypotheses are introduced in Sections 2 and 3. The main finding on the procurement auctions is presented in Section 4. Section 5 evaluates the results by comparing the data with a control treatment with a sealed-bid sales auction and with procurement auctions with private certain valuations, and by comparing the results with those on sales auctions with private uncertain values by Ehrhart et al. (2015). Before we conclude with Section 6, we discuss our findings with respect to competing hypotheses and further related literature.

2. Experimental Design

This section describes the organization of the experiment and the auction formats that define the treatments.

2.1. Organization of the Experiment

The experiment was conducted at the University of Karlsruhe with randomly selected students from various disciplines. In every auction, three subjects participated. Every subject participated in one single auction. We decided in favor of this setting instead of several consecutive auctions in order to induce the subjects to fully concentrate on the auction and because our auctions are simple and easy to understand (cp. Ehrhart et al., 2015). Moreover, in practice, many procurement auctions are one-shot auctions.

[3]Bernard (2006) also finds mean bids above the private valuation in his experiment with sealed-bid second-price procurement auctions.

Table 1: Bidders' private information about their individual valuations

Bidder	PA1 to PA4, and SA1	Expected valuation
B1	$U\{112, 113, \ldots, 312\}$	212
B2	$U\{117, 118, \ldots, 317\}$	217
B3	$U\{122, 123, \ldots, 322\}$	222

We implemented four procurement auctions, PA1 to PA4, and, as a point of comparison, one sales auction, SA1. Overall, 36 subjects participated in each treatment and a total of 288 subjects participated in the experiment.[4]

The experiment was computerized and each subject was seated at a separated computer terminal. Communication was not permitted. The subjects received printed instructions, which were read aloud by an experimental assistant. Before the experiment began, each subject answered several questions regarding the instructions at his or her computer terminal. When all subjects had answered all questions correctly, the subjects were given their private information, and then the auction began. Subjects could not identify their competitors in their auction. The experimental sessions lasted less than one hour. At the end of an experimental session, the subjects were paid in cash according to their profits in the game. The conversion rate was 5 Euro for 100 Experimental Currency Units (ECU). The mean, minimum, and maximum payments realized were €10.9, €5.5, and €17.9, respectively.

2.2. Valuations, Information, and Auction Formats in the Experiment

Three bidders compete in an auction. Each bidder is endowed with one good and has private but incomplete information about its value. We call this setting, in which the good is a lottery, a private uncertain valuations setting.[5] Table 1 displays the three discrete uniform distributions that are used in all groups of three. The subjects know that their opponents'

[4]The main treatments are PA1 to PA4 with uncertain valuations. SA1 is a control treatment. Treatments PA1c, PA2c, and PA4c are further points of comparison with the same procurement auction formats when valuations are certain and are discussed in Section 5.2. Treatments PA1, PA2, PA4, PA1c, and PA4c were conducted in two sessions with six groups of three each. PA3 (PA2c) was conducted in three sessions with six, five (four), and one (two) group(s). Subjects were distributed over two separate rooms. In one session, which became necessary due to no-shows, one PA3-group was in one room and and two PA2c-groups were in the other room, such that the subjects did not know that they were the only group(s) of the treatment. SA1 was conducted in two sessions with six groups each in a lab with separated cabins.

[5]Experimental and theoretical analyses of auctions with private uncertain valuations are, e.g., by Ehrhart et al. (2015), Haile (2003), Lange et al. (2011), McGee (2013), Thompson and Leyton-Brown (2007). Acquiring information about one's valuation during the auction, as in the theoretical papers by Bergemann and Välimäki (2002); Compte and Jehiel (2007); Rasmusen (2006), is not possible in our design.

valuation distributions differ from theirs. They do not learn anything more about the others' distributions because we want subjects to concentrate on their individual valuations and because the optimal bid is independent of this information. We choose the distributions in Table 1 to create a competitive situation with differences in expected valuations (212, 217, and 222) of only a decrement. To prevent bidders from taking their expected valuation as an anchor, they lie between two feasible bids, which are multiples of five.

We choose lotteries as procured goods because the WTP-WTA disparity plays an important role for our hypothesis and lotteries are a typical good for which such a disparity has been observed (e.g. Knetsch and Sinden, 1984; Marshall et al., 1986). Compared with real goods, which would be an alternative, lotteries provide more experimental control over valuations.

The setting of interest is the procurement of a non-commodity good.[6] We implement four different procurement auction formats PA1 to PA4, one sealed-bid and three descending auctions that differ with respect to the selection of the current leading bidder. The auction winner is paid the price. The unsuccessful bidders receive the realization of their private valuation lottery. In all descending auctions, a starting price of 350 ECU and a constant decrement of 5 ECU are set.

Subjects in second-price sealed-bid auction experiments with certain valuations tend to bid higher than weakly dominant strategies predict (cp. Kagel and Levin, 2016), whereas this is not common in dynamic auctions. We follow previous studies and describe the static auction in a dynamic way to reduce such distortions (Seifert, 2006; Ehrhart et al., 2015).

The four procurement auction designs are:

Auction format PA1. All subjects submit their lower bidding limit. A bidding mechanism outbids these bids against each other, as in a reverse English auction. That is, bidders face a second-price or Vickrey auction (Vickrey, 1961). The bidder with the lowest bid sells the good. The price equals the second-lowest bid. In case of a tie, the winner is randomly drawn from the set of bidders with the lowest bid and is paid the lowest bid.

[6] That is, our analysis applies to a unique or unfamiliar market for the bidders, in contrast to the setting with experienced dealers acting in a familiar market by List (2003). In the experiment, each bidder is assigned the role of a shipping company owner that owns a virtual good (a ship). This makes it easy to explain the uncertain valuations environment because owning the ship generates uncertain revenues. Another advantage is that it is unlikely that the students have a particular interest in or prior experience with owning ships.

Auction format PA2. In the clock auction PA2, we introduce dynamics. The price decreases in discrete decrements, and bidders are asked at every stage whether they accept the current price. A bidder who does not accept the price within 50 seconds quits the auction. Bidders are not informed about the number of remaining bidders. The process stops at the first stage at which only one or no bidder accepts the price. If only one bidder remains, this bidder sells his good and is paid the price of the penultimate stage. If all remaining bidders quit at the same stage, the winning bidder is randomly drawn from this set of bidders and receives the price of the previous stage. The pricing rule is thus identical to that of auction PA1.

Auction format PA3. PA3 is a variation of PA2. As in auction PA2, the price decreases in discrete decrements, and bidders are asked at every stage if they accept the current price. In addition, at every price level a current leading vendor is randomly chosen from the set of accepting bidders. The process stops when none of the other bidders accepts the next price level within 50 seconds. The last leading vendor sells his good and receives the price of the stage before the auction stops, that is, the stage at which he was designated the leading vendor.

Auction format PA4. The descending auction PA4 is an English clock auction. As in PA2 and PA3, the price decreases in discrete decrements. At every price level, the bidder who first accepts the price is designated the current leading vendor. Then, the price decreases by one decrement, and after five seconds the button to accept this new price is enabled for the other bidders. The process stops when the new price is not accepted by any other bidder within 45 seconds. The last leading vendor sells the good and receives the price at which he became this leading vendor (as in PA3).

In the descending auctions, each price level is shown for at least five seconds to enable subjects to recognize the current price and, potentially, their leading vendor position.

The auction SA1 has the same format as PA1, but as a sales auction. The successful bidder receives the realization of his valuation lottery and pays the price. All subjects in SA1 receive a lump-sum payment of 10 euros.

3. Theory and Hypotheses

We present theoretical benchmarks for the different auctions and derive our hypothesis.

3.1. Theoretical Benchmarks

Consider a procurement auction with n bidders with private uncertain valuations. That is, bidders are privately informed about the distribution of their valuation. To ensure comparability, we use strategically equivalent auctions PA1 to PA4 and SA1. To show strategic equivalence, we analyze the benchmark case of continuous bidding and valuation spaces. Let strategies be mappings at each stage of the auction from private uncertain valuations to bids or bidding limits. Strategic equivalence holds because in every auction the optimal bidding limit is the indifference price, that is, the price at which a bidder is indifferent between winning and not winning the auction.

Proposition 1. *A bidder who is expected-utility maximizing or has a WTP-WTA disparity will bid his indifference price in PA1 and SA1 and will quit auctions PA2 to PA4 only if the current price falls below his indifference price.*

Thus, an expected-utility maximizing bidder chooses the same bid or bidding limit in PA1 to PA4 and in SA1: he bids his certainty equivalent of his private valuation lottery. The strategic considerations are the same for a bidder whose WTA exceeds his WTP. However, we hypothesize that his indifference price depends on the auction format, i.e., on the way one inquires his indifference price.

In equilibrium, the bidder with the lowest indifference price sells the good and receives the second-lowest indifference price. We therefore predict a price equal to the second-lowest indifference price in all auction formats PA1 to PA4. We expect a price equal to the second-highest indifference price in SA1, which with three bidders is the same as the second-lowest indifference price in the procurement auctions if the submitted bids are the same. Only if bidders bid differently in the auctions, the prices will differ.

The proof of Proposition 1 is given in Appendix A. There, we also discuss the impact of discrete bid decrements on equilibrium prices and show the comparability of PA1 and SA1. In the sealed-bid auction and the descending auctions with continuous bidding and valuation spaces a bidder's indifference price constitutes a weakly dominant bid or bidding limit, while with our discrete bid decrements the bidder has has two undominated strategies. He either

Table 2: Valuation measures (cp. Knetsch, 2010) and reference state shifts in dynamic auctions

Auction	Change in case of award	Valuation measure with the reference state before the change	after the change
Procurement	Negative	WTA to accept loss	WTP to avoid (inferior) reference
Sales	Positive	WTP to improve	WTA to forego (superior) reference
		$\xrightarrow[\text{during a dynamic auction}]{\text{Shift of the reference state}}$	

bids the next feasible bid below or above his certainty equivalent of his valuation lottery. As a point of reference, we derive the equilibrium prices with risk-neutral expected-utility maximizers, which in all four treatments are 210 and 215.

3.2. Hypotheses

According to Knetsch (2010, p. 184) "The choice of measure of the valuation for particular cases will largely depend on whether the basis for people's valuation is the reference state being before the change or after the change." We hypothesize that certain design factors of an auction create or foster a shift of the reference state during the auction. If a bidder's reference state shifts during a procurement auction from the before-the-auction state of owning the good towards the after-the-auction state of not owning the good in case of winning, then his indifference price will decrease during the auction because the indifference price shifts from being a WTA statement towards being a WTP statement. Note that the reverse holds for a sales auction. Table 2 illustrates the shift and its consequences.

We expect the shift of the reference state to occur and to differ between the auctions for the following reasons.[7] According to Proposition 1, in all four auctions PA1 to PA4, we predict that bidders bid their indifference price. However, we expect that bidders have a WTP-WTA disparity and they construct their indifference price differently in the different auctions.

The sealed-bid auction PA1 asks the bidders for their indifference price for giving up the good when they are in a state of owning it. That is, bidders are asked for their WTA to accept losing the good.

[7] The arguments generalize those by Ehrhart et al. (2015) from sales to procurement auctions.

Auctions PA2 to PA4 are descending auctions in which bidders at each stage decide to accept the current price or to leave the auction. This multi-stage process, in which bidders repeatedly reconsider their indifference price, permits a shift of the reference state from the objective state of not selling the good towards a subjective state of being close to winning the auction and selling the good. Such a shift comes with a decrease of the indifference price from being equal to the WTA to accept losing the good towards the WTP to avoid giving up the good (i.e., the WTP to avoid the inferior reference; see Table 2).

Being the current leading vendor in the auction PA3 or PA4 may foster the shift of the reference state. Being assigned a leading-vendor position increases a bidder's awareness of the potential ownership change, which is necessary for the change of perspective: "It is not ownership per se, but awareness of ownership that causes reference point shifts." (Strahilevitz and Loewenstein, 1998).

This shift of the reference state may be strengthened in PA4, where achieving the leading-vendor position by an own prompt bid may further strengthen the awareness of getting closer to selling the good. This idea relates to the "source-dependence effect" (Loewenstein and Issacharoff, 1994).

Formally, by the WTP-WTA disparity, WTA > WTP. We denote a bidder's indifference price in PA1 by $\mathrm{IP}_{\mathrm{PA1}}$ and his indifference price in SA1 by $\mathrm{IP}_{\mathrm{SA1}}$. PA1 asks for the WTA and SA1 asks for the WTP, so $\mathrm{IP}_{\mathrm{PA1}} = \mathrm{WTA}$ and $\mathrm{IP}_{\mathrm{SA1}} = \mathrm{WTP}$. According to our hypothesis, the indifference price IP in auctions PAj, $j \in \{1,2,3,4\}$, can be described by

$$\mathrm{IP}_{\mathrm{PA}j} = (1-\lambda_{\mathrm{PA}j})\mathrm{IP}_{\mathrm{PA1}} + \lambda_{\mathrm{PA}j}\mathrm{IP}_{\mathrm{SA1}} = (1-\lambda_{\mathrm{PA}j})\mathrm{WTA} + \lambda_{\mathrm{PA}j}\mathrm{WTP}$$

with $0 = \lambda_{\mathrm{PA1}} \leq \lambda_{\mathrm{PA2}} \leq \lambda_{\mathrm{PA3}} \leq \lambda_{\mathrm{PA4}}$ with at least one strict inequality. Therefore, $\mathrm{IP}_{\mathrm{PA1}} \geq \mathrm{IP}_{\mathrm{PA2}} \geq \mathrm{IP}_{\mathrm{PA3}} \geq \mathrm{IP}_{\mathrm{PA4}}$, and, as a result, the auction prices $p_{\mathrm{PA}j}$ decrease: $p_{\mathrm{PA1}} \geq p_{\mathrm{PA2}} \geq p_{\mathrm{PA3}} \geq p_{\mathrm{PA4}}$ with at least one strict inequality.

Summarizing, we hypothesize that bidders who have a WTP-WTA disparity have different indifference prices and, thus, bid differently in strategically equivalent auctions because their reference state may shift during an auction. We expect that the indifference prices, and, therefore, the auction prices decrease from PA1 to PA4.

Hypothesis 1. *Auction prices decrease from PA1 to PA4.*

Table 3: Average auction prices (in ECU)

Treatment	PA1	PA2	PA3	PA4
Mean price	235.0	225.4	205.4	203.8
Median price	230	217.5	205	210

4. Experimental Results

There are twelve independent prices per treatment and 36 independent bids in the sealed-bid treatments. In all tests, we apply a significance level of 5%. Boxplots show the median, first and third quartiles, whiskers with maximum 1.5 interquartile ranges, and outliers ($\star$).

We find a trend in our auctions' prices: the mean auction price decreases from treatment to treatment. The median price in PA3 is, however, by a decrement lower than the median price in PA4. The mean and median auction prices in the four treatments are given in Table 3, and Figure 1 shows boxplots with further details. The range of the means of the prices of the treatments covers 31.2 ECU, which amounts to 15.6% of the individual valuation intervals' spread of 200 ECU, or six decrements. The non-parametric Jonckheere-Terpstra test rejects equality of prices in the four treatments in favor of the alternative hypothesis of declining prices from PA1 to PA4.[8]

Result 1. *The average auction price decreases significantly from PA1 to PA4.*

We compare auction prices pairwise using Dunn's test for stochastic dominance. PA1 and PA4 as well as PA1 and PA3 differ statistically significantly, as do PA2 and PA3 as well as PA2 and PA4.[9] Hence, there is no evidence of an effect of auction dynamics alone, whereas a strong effect appears to result from giving bidders the possibility of becoming the leading vendor. There is no evidence that the reason for becoming the leading vendor plays a role for the stated indifference price.

[8] H_0: $p_{\mathrm{PA1}} = p_{\mathrm{PA2}} = p_{\mathrm{PA3}} = p_{\mathrm{PA4}}$; H_1: $p_{\mathrm{PA1}} \geq p_{\mathrm{PA2}} \geq p_{\mathrm{PA3}} \geq p_{\mathrm{PA4}}$ with at least one strict inequality, $JT = 256$, z-value $= -3.2393$, p-value $= 0.001$.

[9] Note that if we adjust for multiple comparisons, the differences between PA2 and PA3/PA4 are only significant at a ten percent level. Kruskal-Wallis one-way analysis of variance on ranks omnibus test: $\chi^2 = 11.711$, df $= 3$, p-value $= 0.008$. Dunn's test (in brackets: p-values adjusted for multiple comparisons with the Holm method): H_0: Prob$(p_{PAi} > p_{PAj}) = 1/2$, H_1: Prob$(p_{PAi} > p_{PAj}) > 1/2$, for all $i < j$. PA1 vs. PA2: $p = 0.223$ (0.446), PA1 vs. PA3: $p = 0.003$ (0.016), PA1 vs. PA4: $p = 0.004$ (0.018), PA2 vs. PA3: $p = 0.022$ (0.09), PA2 vs. PA4: $p = 0.027$ (0.08), PA3 vs. PA4: $p = 0.465$ (0.465).

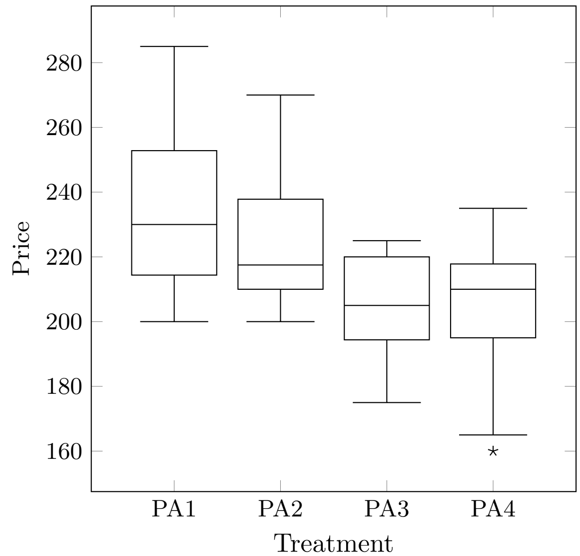

Figure 1: Boxplot of the prices in treatments PA1 to PA4

Table 4: Location of the observed auction price relative to the equilibrium price with risk-neutral bidders

		<	=	>	Sum
Treatment	PA1	3 (25.0%)	1 (8.3%)	8 (66.7%)	12
	PA2	5 (41.7%)	2 (16.6%)	5 (41.7%)	12
	PA3	8 (66.7%)	2 (16.6%)	2 (16.6%)	12
	PA4	7 (58.3%)	4 (33.3%)	1 (8.3%)	12
Sum		23 (47.9%)	9 (18.8%)	16 (33.3%)	48

A look at the ranking of all groups' prices in increasing order supports these results (see Table B.6 in Appendix B). For example, prices strictly below 200 are achieved only in auctions PA4 and PA3 (by four groups of PA4 and three groups of PA3). The groups with the lowest ranks from PA4, PA3, PA2, and PA1 have ranks 1, 3, 8, and 8, respectively. In contrast, prices strictly above 235 are achieved only in auctions PA2 and PA1 (by three groups of PA2 and five groups of PA1).

The impact of the auction format is also evident when comparing the auction prices with the equilibrium prices 215 and 220 when bidders are risk-neutral utility maximizers. In PA4, seven auctions end below and one above the risk-neutral prediction, whereas in PA1 the ratio is three to eight (see Table 4).

We do not observe irrational bidding in the sense that subjects bid below the lower bound of their valuation distribution. In PA1 and PA2, two (6%) and three (8%) bidders bid above the upper bound of their interval, and in PA3 one bidder submits no bid (none of these bids is decisive for a price). In PA4, all bidders bid within the boundaries of their intervals.

Susceptibility to aggressive bidding in the descending auctions appears to differ between subjects. In PA2, only nine subjects bid at least one full decrement below their expected valuation. In PA3, this number increases to 14 subjects and in PA4 to 15 subjects. This amounts to 29%, 45%, and 60% of the subjects for whom we know whether they bid that much below the expected value, because for five winners each in PA2 and PA3 the auctions ended above or less than a decrement below their expected values and in PA4 there are eleven bidders (five winners and six unsuccessful bidders that did not determine the price) for whom we do not observe whether their bidding limit is below their expected valuation.

5. Evaluation and Discussion

We compare our results to the results of a control treatment with a sales auction, to procurement auction results with certain valuations, and to the results in a comparable experiment on sales auctions by Ehrhart et al. (2015). First, to assess WTA and WTP, we compare bids in the procurement auction PA1 with bids in the corresponding sales auction SA1. Next, we compare prices in the procurement auctions PA1 to PA4 with those in SA1 to see where these prices lie as compared to the measured WTP prices. Second, in order to detect potential confounding factors, we analyze three more treatments PA1c, PA2c, and PA4c, which are equal to PA1, PA2, and PA4, however, with certain instead of uncertain valuations. Then, we compare our ranking of procurement auctions by prices with the ranking of sales auctions by revenue in Ehrhart et al. (2015).

Finally, we summarize our results and discuss potential drivers of the results.

5.1. Comparison of PA1 to PA4 With the Control Treatment SA1

The control treatment SA1 measures the WTP via a sealed-bid sales auction. To compare WTA and WTP, we compare the bids' deviation from the expected value of the bidder's lottery, $\Delta_b = b - \mathrm{E}[V]$, in PA1 and SA1 (see Table 5). According to Appendix A, the Δ_b should be the same in the two auctions if there is no WTP-WTA disparity. We expect

Table 5: Deviation $\Delta_b = b - \mathrm{E}[V]$ of all 36 bidders in PA1 and SA1 (#: number of)

Treatment	# Observations	# ($\Delta_b < 0$)	# ($\Delta_b > 0$)	Mean Δ_b	Median Δ_b
PA1	36	12	24	20.8	15.5
SA1	36	27	9	−28.5	−14.5

a WTP-WTA disparity and find a statistically significant difference between the two auctions.[10] Thus, WTA > WTP in this auction setting. The difference amounts to 49.3 ECU, which is about 10 price steps or 25% of the valuation intervals' spread of 200 ECU.

We compare the prices of the four procurement auctions PA1 to PA4 with those of the sales auction SA1 to get an impression of their relative location. The predicted equilibrium prices are the same and for risk-neutral bidders equal to 215 and 220 in all auctions. In SA1, the observed mean and median prices are 185.8 and 195, while the lowest mean and median prices in the procurement auctions are 203.8 and 201 and occur in PA4 and PA3, respectively (see Table 3 and Figures 2 and 3). The mean and median prices in the descending auctions thus fall in between those in PA1 and SA1. Pairwise comparisons reveal that price differences are statistically significant between SA1 and PA1 as well as PA2.[11]

Irrational bids above the upper boundary of the valuation interval do not occur in SA1. Three bidders (8%) bid below the lower boundary; one of them bids zero. This reverses the pattern of the procurement auctions in which, if we observe bidding outside the intervals at all, we observe bidding above the upper boundary.

5.2. Comparison of the Results of PA1 to PA4 With Results on Auctions with Certain Values

Three treatments with certain valuations serve to find out whether subjects behave the same in all auction mechanisms when a WTP-WTA disparity is not expected. The treatments PA1c, PA2c, and PA4c use the sealed-bid auction, the dynamic auction without leading-vendor assignment, and one dynamic auction with leading-vendor assignment. In each treatment, there are twelve groups of three bidders with the certain valuations 212, 217, and 222. These valuations are equal to the expected valuations of the three bidders in the auctions with uncertain valuations (see Table 1). With certain valuations, no WTP-WTA

[10] Wilcoxon-Mann-Whitney test on Δ_b in PA1 vs. SA1 (one-tailed): sample sizes: 36, 36; $p < 0.001$.

[11] Pairwise Wilcoxon-Mann-Whitney tests (one-tailed; with continuity correction): SA1 vs. PA1: $p < 0.001$, SA1 vs. PA2: $p = 0.002$, SA1 vs. PA3: $p = 0.058$, SA1 vs. PA4: $p = 0.077$.

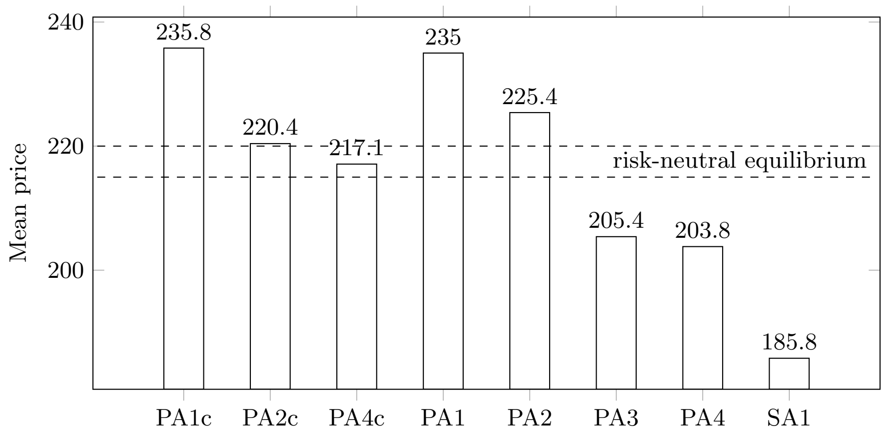

Figure 2: Mean prices in all treatments

disparity is expected and the equilibrium prices are 215 and 220.[12]

In contrast to this prediction, prices differ between the treatments PA1c, PA2c, and PA4c.[13] While almost all prices in PA2c and PA4c are within the equilibrium range (there are two exceptions in PA2c and none in PA4c), the prices in PA1c are on average (and in seven groups) above the equilibrium prediction (see Figures 2 and 3). The prices in the lottery treatments and in their respective certain-valuations counterpart only differ between PA4 and PA4c, where the lottery auction PA4 generates lower prices than PA4c.[14]

The overbidding in the sealed-bid auction PA1c[15] is surprising because one might expect that the commonly observed high percentage of overbidding in sealed-bid second-price sales auctions translates into underbidding in procurement auctions, e.g., because it is due to spite motives. A reason for this overbidding might be that procurement auctions trigger profit-targeting strategies. In a sealed-bid auction bidders presumably focus on making a profit by selling their good and therefore bid more than their valuation. In an English

[12]In particular, equilibrium prices are 215 and 220 independent of the bidder's risk attitude. The analysis in Appendix A applies also to the certain valuations setting. Arguments by Kahneman et al. (1990) and Coursey et al. (1987) why no WTP-WTA disparity is expected in induced certain valuation settings are collected in Ehrhart et al. (2015).

[13]Kruskal-Wallis test, PA1c, PA2c, and PA4c: $\chi^2 = 6.0816$, df = 2, p-value = 0.048.

[14]Wilcoxon-Mann-Whitney tests (two-tailed, continuity correction). PA1 vs. PA1c: W = 70, p-value = 0.931; PA2 vs. PA2c: W = 66, p-value = 0.746; PA4 vs. PA4c: W = 38, p-value = 0.044.

[15]Sign test (binomial test, two-tailed). 21 of 36 bids are above the prediction (+), 13 are in line with the prediction (=), and 2 are below (−). p-value = $\Pr(21; 23, 0.5) < 0.001$. This is in line with the mean bids above the certain independent private valuations in the experimental procurement auctions by Bernard (2006).

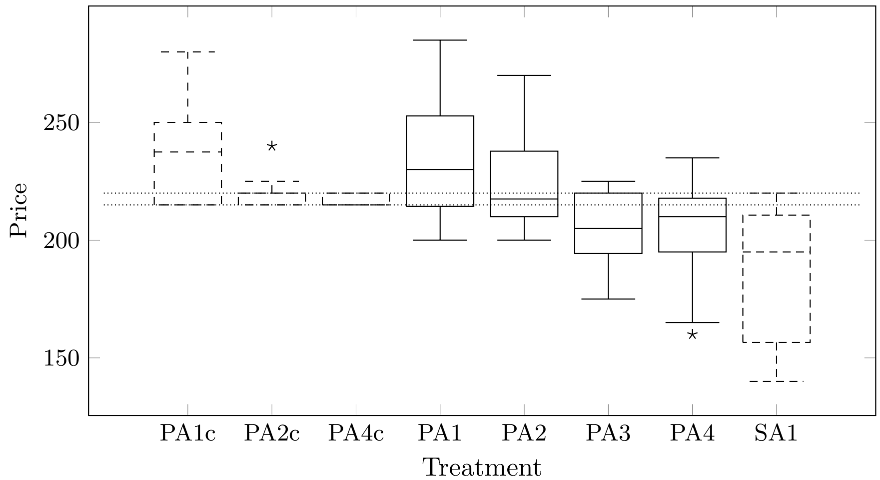

Figure 3: Boxplot of the prices in all treatments (solid lines: main treatments; dotted lines: risk-neutral equilibrium prediction)

auction, in contrast, they bid down to their valuation because the binary decision at each stage – whether to quit or to bid – makes them realize that accepting a lower a profit is better than making zero profit once their targeted profit is out of reach.

If such profit-targeting behavior causes the overbidding in PA1c, then comparability of PA1c and its counterpart PA1 depends on whether profit-targeting motives translate from certain to uncertain valuations. On the one hand, a bidder in PA1 may bid to secure a price above his certainty equivalent in case of award. In this case, the overbidding or profit-targeting effect in the sealed-bid auction may capture part of the observed difference between PA1 and PA3/PA4. On the other hand, as the profit depends on the uncertain lottery outcome at the time of bidding and as this uncertainty will not be resolved for an awarded bidder, profit-targeting considerations may vanish when a lottery is for sale.

From the results of these treatments, we conclude for our main treatments that the price differences between PA1 and PA3/PA4 might be driven by overbidding in PA1 and/or a WTP-WTA difference, while differences between PA2 and PA3/PA4 are not driven by a misunderstanding of the mechanisms.[16]

[16] Plott and Zeiler (2005) remark that valuation bidding with induced certain valuations might not provide evidence of understanding the mechanism (i.e., of the absence of misconceptions). Bidders might simply bid the given valuation because of a tendency to bid the announced value, e.g., due its prominence or due to anchoring. Our design does not allow valuation bidding and might thereby eliminate such anchoring.

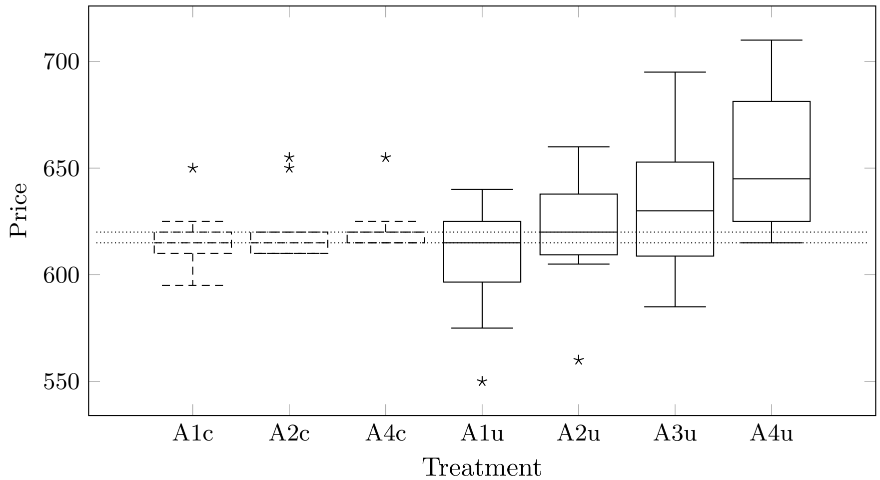

Figure 4: Boxplot of the prices in in all treatments of the sales auctions by Ehrhart et al. (2015) (solid lines: main treatments; dotted lines: risk-neutral equilibrium prediction)

5.3. Comparison of the Results on Procurement Auctions With Sales Auctions

Our results on procurement auctions are similar to and mirror those of Ehrhart et al. (2015) for sales auctions. They find increasing prices across their treatments A1u, A2u, A3u, and A4u (see Figure 4), where auction format A1 equals SA1, and A2 to A4 are reverse forms of our designs PA2 to PA4. The extension "u" indicates uncertain valuations for the good for sale in the auction. A WTP-WTA disparity and a reference shift in dynamic sales auctions predicts these increasing prices (compare Table 2). This analogy of results provides further evidence that design differences influence bidding in the way predicted by a WTP-WTA disparity and a reference shift.

The difference of mean prices between their sales auctions A1u and A4u is 45 ECU, which is 22.5% of the spread of the valuation interval or nine increments, while we find a mean difference of 31.2 ECU (15.6%, six decrements) in the procurement auctions.[17]

Furthermore, in the design by McGee (2013), the individual valuation lotteries are characterized by a value z that is the center of the uniform valuation distribution with a support of width 160. Salience arguments thus predict that bidders bid z, but McGee does not report clustering of bids at z in the English auctions.

[17]The larger range of mean prices in Ehrhart et al. (2015) might be due to the fact that their strongest bidder is by 40 ECU stronger than the weakest bidder while in our study this difference is 5 ECU. Apart from that, comparability is given: their valuation lotteries have the same range of 200 ECU (and are uniform distributions, but with means 612, 617, and 652), their increment is 5 ECU, and their weakest two bidders differ by 5 ECU in their expected valuation. They use our PA1 as their control treatment P1u, which is the only data of this study that appears also in their study. The auction format SA1 (A1) is used in both

In their treatments A1c, A2c, and A4c with certain valuations, the mean (median) prices are within or close to the range of the equilibrium prices 615 and 620 (see Figure 4). Unlike the overbidding we observe in PA1c, they do not observe systematic deviations from truthful bidding in any of their treatments with certain valuations.

In both the sales and procurement settings the effect of auction dynamics alone appears to be rather small, whereas the strongest effect results from giving bidders the possibility of becoming the current leading bidder. In the sales auctions, becoming the leading bidder by the own effort appears to be of importance while this is not the case in the procurement auctions. Pairwise differences occur between A1u/A2u and A4u, and we observe differences between PA1 and PA3/PA4 as well as PA2 and PA3/PA4 (with weaker significance).

5.4. Summary and Discussion

We find that auction prices decline from treatment PA1 to PA4 and conclude that bidders bid more aggressive in the auctions that are designed to foster a reference shift towards the after-the-auction state. Pairwise differences are pronounced between auctions PA1 and PA3/PA4 as well as PA2 and PA3/PA4. On average, price-determining bidders tend to bid above the expected value of their valuation lottery in PA1 and PA2 and below their expected valuation in PA3 and PA4. Auctions PA3 and PA4 appear to be on a similar level. In particular, explanations that base only on auction dynamics do not capture these results. Assigning a leading bidder position appears to be a relevant factor that influences a bidder's indifference price. Mean prices in the procurement auctions are above those in a control treatment with a sealed-bid sales auction that measures the WTP. Contrasting bids in this sales auction with those in the procurement sealed-bid auction to compare WTP and WTA we find evidence for the predicted WTP-WTA disparity.

We frame our procurement auctions as auctions in which the awarded bidder sells a good he owns to the auctioneer and the unsuccessful bidders keep their good. Alternatively, the awarded winning bidder in a procurement auction might have to produce the good whereas unsuccessful bidders have zero costs. According to Knetsch (2010) and our arguments illustrated in Table 2, the difference in framing should not make difference for the bidding behavior. The reference shift from a before-the-auction state of owning the good or no costs

studies, and the Δ_b (see 5.1) in our control treatment SA1 have a lower mean but the same median as those in their treatment A1u (means are -28.5 and -17.6 while medians are -14.5).

to an after-the-auction state in case of being awarded of not owning the good or incurring the costs, respectively, causes a shift from reporting the WTA to accept a loss to reporting the WTP to avoid the (inferior) reference. However, whether this framing indeed does not make a difference for the bidding behavior is an open empirical question.

Our treatment differences appear to be driven by bidders who are prone to aggressive bidding, which we attribute to their WTP-WTA disparity and a reference shift that is influenced by the mechanism. In a related experimental setup with uncertain valuations and sales auctions, McGee (2013) attributes treatment differences to participants that appear prone to overbidding. He finds indicators for stronger overbidding over the risk-neutral equilibrium prediction in an English open-outcry auction than in a first-price auction. Participants bid in several rounds and there are no indicators that giving scope to experience has an effect on overbidding. The measured risk attitude is not predictive for bidding above the expected value of the lottery in the English and in the first-price auction.[18]

Although we have uncertain valuations, risk aversion does not capture our observations. A risk-averse bidder bids his certain valuation in all auctions and, in case of uncertain valuations, bids the same amount (i.e., the risk premium) below the expected value of the lottery in all procurement and sales auctions. However, we observe decreasing prices in PA1 to PA4 (with the mean price moving from above to below the risk-neutral prediction) and Ehrhart et al. (2015) observe increasing prices in A1 to A4 (with the mean price moving from below to above the risk-neutral prediction). Explaining the observations via the risk-attitude would require to say that bidders behave less averse towards risk in the sealed-bid procurement auction than in the sales auction and they show more and more aversion to risk when moving from PA1 to PA4, while in the sales auctions bidders behave less and less averse towards risk when moving from A1 to A4.

Hypotheses derived from a WTP-WTA disparity combined with a reference shift predict both our results and those by Ehrhart et al. (2015). Competing explanations should therefore lead to the same hypotheses. Several explanations for aggressive bidding that have been identified in the literature (as listed in Section 1) are excluded by design as being the cause

[18]McGee's setting with recurring auctions allows him to test several further explanations. Bids above the expected value are also not captured by regret of previous high bids, by regret of not having won at a price below the expected value or the upper bound of the valuation interval, by loss aversion with the starting balance as a reference point, by a house money effect (due to a higher starting balance), or by eagerness (a stronger wish to win the more periods have passed since the last award).

of our results.

Our arguments are related to those by Engelmann and Hollard (2010) who distinguish between valuation uncertainty and trade uncertainty. They investigate the effect of trade uncertainty on the exchange asymmetry of less than fifty percent exchanges when participants are randomly assigned one of two different goods and are asked whether they want to exchange it for the other good. In their experiment they find that reducing trade uncertainty by forcing participants to experience trade reduces the exchange asymmetry.

In our study, we have valuation uncertainty because the good for sale is a lottery. The purpose of choosing uncertain valuations rather than certain valuations is to generate a setting in which the WTP-WTA disparity arises. A potential reason is the following. A necessary condition for the exchange asymmetry or the WTP-WTA disparity to occur is the evaluation of the exchanged goods in separate consumption dimensions (as in the model of expectation-based reference dependent preferences by Kőszegi and Rabin, 2009).[19] This separation occurs when different goods are exchanged (as in Engelmann and Hollard, 2010) or when a good/lottery is traded for money (as in our study), but not when money is traded for money (as with induced valuations).

Trade uncertainty might capture our observations. If being the leading vendor or the high bidder makes the bidder more comfortable with the state of trading (or teaches him about trading), he might bid more aggressive in auctions that emphasize this state. Being more comfortable with the state of trading seems closely connected to taking a WTA rather than a WTP perspective, as in our arguments that base on a shift of the reference state, and both foster the willingness to trade.

6. Conclusion

Our experiment identifies a potential driver of price differences between strategically equivalent procurement auction designs. We find evidence for a ranking of procurement auctions designs by price, which we attribute to different strengths of a reference shift

[19]The agent's evaluation then depends on the consumption dimension and the related gains and losses that he emphasizes. For example, List (2004) notes that his experienced traders that do not exhibit an exchange asymmetry may "have learned to treat goods leaving their endowment as an opportunity cost rather than a loss." In terms of Table 2, these traders may evaluate their state before the (positive) change via their WTP for the opportunity of an exchange and the state after the change (in case of trade) via their WTA to forego the superior opportunity.

towards the after-the-auction state during dynamic procurement auctions, in particular when a leading bidder is assigned. Our findings are supported by evidence on sales auctions (Ehrhart et al., 2015). Thus, promoting a reference shift during the auction process may lead to lower prices and better bargains for procurers.

Procurers can use these insights to reduce their costs. They can choose auction formats that promise lower prices. The model applies to settings in which a WTP-WTA disparity is present, that is, to the procurement of non-commodities. A bidder who plans to participate in a dynamic auction should be aware of the possible adjustment of his indifference price and take it into account before deciding to participate. A bidder in a sealed-bid auction should be aware that conditional on winning the auction and selling the good his indifference price might be lower than from the point of view when the bid has to be submitted.

References

Andreoni, J., Che, Y.-K., Kim, J., 2007. Asymmetric information about rivals' types in standard auctions: An experiment. Games and Economic Behavior 59, 240–259.

Bartling, B., Netzer, N., 2016. An externality robust auction: Theory and experimental evidence. Games and Economic Behavior 97, 186–204.

Bergemann, D., Välimäki, J., 2002. Information acquisition and efficient mechanism design. Econometrica 70 (3), 1007–1033.

Bernard, J. C., 2006. Finding and retaining the dominant strategy: The second-price, English and 'sealed offer' English auctions. Journal of Economic Behavior & Organization 60, 553–561.

Compte, O., Jehiel, P., 2007. Auctions and information acquisition: sealed bid or dynamic formats? RAND Journal of Economics 38 (2), 355–372.

Cooper, D. J., Fang, H., 2008. Understanding overbidding in second price auctions: An experimental study. Economic Journal 118, 1572–1595.

Coursey, D. L., Hovis, J. L., Schulze, W. D., 1987. The disparity between willingness to accept and willingness to pay measures of value. Quarterly Journal of Economics 102 (3), 679–690.

Cox, J. C., Roberson, B., Smith, V., 1982. Theory and behavior of single object auctions. In: Smith, V. (Ed.), Research in Experimental Economics. Vol. 2. Greenwich, CT: JAI Press, pp. 1–43.

Cramton, P., Sujarittanonta, P., 2010. Pricing rule in a clock auction. Decision Analysis 7 (1), 40–57.

Delgado, M. R., Schotter, A., Ozbay, E. Y., Phelps, E. A., 2008. Understanding overbidding: Using the neural circuitry of reward to design economic auctions. Science 321, 1849–1852.

Ehrhart, K.-M., Ott, M., Abele, S., 2015. Auction fever: Rising revenue in second-price auction formats. Games and Economic Behavior 92, 206–227.

Engelbrecht-Wiggans, R., 1989. The effect of regret on optimal bidding in auctions. Management Science 35 (6), 685–692.

Engelmann, D., Hollard, G., 2010. Reconsidering the effect of market experience on the "endowment effect". Econometrica 78 (6), 2005–2019.

Filiz-Ozbay, E., Ozbay, E. Y., 2007. Auctions with anticipated regret: Theory and experiment. American Economic Review 97 (4), 1407–1418.

Goeree, J., Maasland, E., Onderstal, S., Turner, J. L., 2005. How (not) to raise money. Journal of Political Economy 113 (4), 897–918.

Haile, P. A., 2003. Auctions with private uncertainty and resale opportunities. Journal of Economic Theory 108, 72–110.

Haruvy, E., Popkowski Leszczyc, P. T. L., 2010. The impact of online auction duration. Decision Analysis 20 (1), 99–106.

Heyman, J. E., Orhun, Y., Ariely, D., 2004. Auction fever: The effect of opponents and quasi-endowment on product valuations. Journal of Interactive Marketing 18, 7–21.

Jones, M. T., 2011. Bidding fever in eBay auctions of Amazon.com gift certificates. Economics Letters 113 (1), 5–7.

Kagel, J. H., Levin, D., 2016. Auctions: A survey of experimental research. In: Kagel, J. H., Roth, A. E. (Eds.), The Handbook of Experimental Economics. Vol. 2. Princeton, NJ: Princeton University Press, Ch. 9, pp. 563–637.

Kahneman, D., Knetsch, J., Thaler, R., 1990. Experimental tests of the endowment effect and the Coase theorem. Journal of Political Economy 98 (6), 1325–1348.

Kőszegi, B., Rabin, M., 2009. Reference-dependent consumption plans. American Economic Review 99 (3), 909–936.

Knetsch, J., Sinden, J., 1984. Willingness to pay and compensation demanded: Experimental evidence of an unexpected disparity in measures of value. The Quarterly Journal of Economics 99 (3), 507–521.

Knetsch, J. L., 2010. Values of gains and losses: Reference states and choice of measure. Environmental and Resource Economics 46, 179–188.

Ku, G., Malhotra, D., Murnighan, J. K., 2005. Towards a competitive arousal model of decision-making: A study of auction fever in live and Internet auctions. Organizational Behavior and Human Decision Processes 96, 89–103.

Lange, A., List, J. A., Price, M. K., 2011. Auctions with resale when private values are uncertain: Evidence from the lab and field. International Journal of Industrial Organization 29 (1), 54–64.

List, J. A., 2003. Does market experience eliminate market anomalies? The Quarterly Journal of Economics 118 (1), 41–71.

List, J. A., 2004. Neoclassical theory versus prospect theory: Evidence from the marketplace. Econometrica 72 (2), 615–625.

Loewenstein, G., Issacharoff, S., 1994. Source dependence in the valuation of objects. Journal of Behavioral Decision Making 7, 157–168.

Malmendier, U., Lee, Y. H., 2011. The bidder's curse. American Economic Review 101 (2), 749–787.

Marshall, J., Knetsch, J., Sinden, J., 1986. Agents' evaluations and the disparity in measures of economic loss. Journal of Economic Behavior & Organization 7 (2), 115–127.

McGee, P., 2013. Bidding in private-value auctions with uncertain values. Games and Economic Behavior 82, 312–326.

Plott, C. R., Zeiler, K., 2005. The willingness to paywillingness to accept gap, the "endowment effect," subject misconceptions, and experimental procedures for eliciting valuations. The American Economic Review 95 (3), 530–545.

Rasmusen, E. B., 2006. Strategic implications of uncertainty over one's own private value in auctions. Advances in Theoretical Economics 6 (1), Article 7.

Seifert, S., 2006. Posted Price Offers in Internet Auction Markets. Heidelberg: Springer.

Strahilevitz, M., Loewenstein, G., 1998. The effect of ownership history on the valuation of objects. Journal of Consumer Research 25, 276–289.

Thompson, D. R. M., Leyton-Brown, K., 2007. Valuation uncertainty and imperfect introspection in second-price auctions. Proceedings of the Twenty-Second AAAI Conference on Artificial Intelligence, 148–153.

Vickrey, W., 1961. Counterspeculation, auctions, and competitive sealed tenders. Journal of Finance 16, 8–37.

Appendix A. Proof of Proposition 1 and Impact of the Decrement

Proof of Proposition 1. Consider a single-item procurement auction with n bidders, whose wealth before the auction is $w_1, w_2, \ldots, w_n$. Bidders' valuations for the good are private and independent but uncertain. Bidder i's uncertainty about his valuation is modeled by the random variable V_i with distribution $F_i(\cdot)$ and support $[\underline{v}_i, \bar{v}_i] \subset \mathbb{R}$, $i = 1, 2, \ldots, n$.

Let $u_i\colon \mathbb{R} \to \mathbb{R}$ denote an expected-utility maximizing bidder's von Neumann-Morgenstern increasing utility function. Let b_{max} denote the maximum possible bid with $b_{max} > \bar{v}_i$, and let $H_i^k(x) = \Pr(\min_{j \neq i} b_j \leq x)$ denote the distribution of bidder i's beliefs about his opponents' lowest bid in the auction of type $k \in \{\text{PA1, PA2, PA3, PA4}\}$. Bidder i may update $H_i^k(\cdot)$ in the course of PA2, PA3, and PA4. Bidder i's strategy $b_i \in [0, b_{max}]$ in a sealed-bid or a descending clock auction is characterized by his bid in PA1 or his bidding limit in PA2, PA3, and PA4. In what follows, we skip the index i.

Bidder i's objective is to choose b to maximize his expected utility

$$U(b) = H^k(b) \int_{\underline{v}}^{\bar{v}} u(w+v)\, dF(v) + \int_{b}^{b_{max}} u(w+x)\, dH^k(x).$$

The first-order condition $\partial U(b)/\partial b = 0$ gives the following equation for the optimal bid b^*:

$$\int_{\underline{v}}^{\bar{v}} u(w+v)\, dF(v) = u(w+b^*). \tag{A.1}$$

The second-order condition $\partial^2 U(b)/\partial b^2 = -u'(w+b^*) < 0$ is fulfilled for all increasing utility functions. The solution b^* does not depend on i's belief about his opponents and constitutes a weakly dominant strategy (with respect to expected utility). Updating the beliefs in the course of an auction has no impact on the optimal bidding limit b^*. The optimal b^* equals the price p, at which the bidder is indifferent between owning the good, $\int_{\underline{v}}^{\bar{v}} u(w+v)\, dF(v)$, and giving up the good for p, $u(w+p)$. This indifference price equals his certainty equivalent at wealth w. For example, a risk-neutral bidder, whose utility is given by $u(x) = x$, bids his expected valuation $b^* = \int_{\underline{v}}^{\bar{v}} v\, dF(v) = E[V]$. The same b^* maximizes an expected-utility maximizer's utility in all auction formats $k \in \{\text{PA1, PA2, PA3, PA4}\}$.

Next, consider a bidder whose WTA exceeds his WTP. As for an expected-utility maximizer, his optimal bidding limit is given by his indifference price. Shifting the reference state from that of not selling to the state of selling during an auction means to adjust the indifference price downwards, such that bidding down to the current indifference price is a feasible strategy throughout a descending auction.

For the proof on the sales auction see Ehrhart et al. (2015). ■

Impact of the price decrement and risk-neutral prediction in PA1 to PA4. The price decrement of 5 ECU does not have an impact on rational bidding in PA3 and

PA4. A bidder accepts all prices above his optimal bidding limit b^* derived from (A.1) and quits when the price falls below b^*, independent of the decrement. For risk-neutral bidders B1, B2, and B3 with expected valuations 212, 217, and 222, we get bidding limits of 215, 220, and 225. The current leading vendor cannot bid the next price step. Equilibrium prices thus are 215 (if B2 is leading vendor at 220) and 220 (if B1 is leading vendor at 220).

In PA1 and PA2, b^* marks a bidder's indifference price. He may deviate from b^* by less than one decrement, due to the discrete decrement and the tie-breaking rule of randomly choosing the winner. A bidder with b^* between two price steps can choose the next feasible bid above or below b^*, b^*_+ or b^*_-. The outcome from these two bids differs only in case of a tie with one of them. If a bidder expects the lowest of the opponents' bids to equal b^*_+, he is better off choosing b^*_- to win for sure at the same price b^*_+. If he expects the lowest of the opponents' bids to equal b^*_-, he is better off choosing b^*_+ to avoid winning at b^*_-.

For risk-neutral bidders B1, B2, and B3 in PA1 and PA2, b^* equals 212, 217, and 222. Optimal feasible bids are 210 or 215 for B1, 215 or 220 for B2, and 220 and 225 for B3. Equilibrium prices therefore are 215 and 220. If, for example, B2 considers a tie with k other bidders at 215 and at 220 equally likely, he would bid 215 because the gains from avoiding the tie at 220 exceed those from avoiding a tie at 215: $3-3/(k+1) > 2/(k+1) \iff k > 2/3$.

Comparability of SA1. Ehrhart et al. (2015) show in their Appendix A.2 that a risk-neutral bidder or a constant absolute risk-averse bidder has the same indifference price b^* in PA1 as in SA1 (for all w_i). With discrete price steps, similar to the argument given above for PA1, optimal feasible bids of risk-neutral bidders are 210 or 215 for B1, 215 or 220 for B2, and 220 and 225 for B3. Equilibrium prices therefore are 215 and 220.[20]

[20] If, e.g., B2 considers a tie with $k = 1$ opponents at 215 and at 220 equally likely, he would bid 215 because the gains from avoiding the tie at 220 exceed those from avoiding a tie at 215: $-(E[V] - 220)/(k + 1) = 3/2 > 1 = E[V] - 215 - (E[V] - 215)/(k + 1) \iff k < 3/2$. The reverse holds for ties with $k = 2$ opponents.

Appendix B. Ranked Auction Results

Table B.6: Ranked auction results of all groups in the treatments PA1 to PA4

Rank	Price [ECU]	Treatment	Group number	Winning bidder	Rank	Price [ECU]	Treatment	Group number	Winning bidder
1	160	PA4	8	3	27	220	PA1	5	3
2	165	PA4	3	2		220	PA2	5	3
3	175	PA3	9	3		220	PA3	3	1
4	185	PA3	8	2		220	PA3	10	1
5	190	PA3	2	1		220	PA4	1	2
6	195	PA4	11	1		220	PA4	7	2
	195	PA4	12	1	33	225	PA1	7	1
8	200	PA1	4	3		225	PA1	10	2
	200	PA1	8	1		225	PA2	1	2
	200	PA2	2	2		225	PA3	6	1
	200	PA3	1	2		225	PA3	12	1
12	205	PA3	4	3	38	235	PA1	1	3
	205	PA3	7	1		235	PA2	3	3
	205	PA3	11	2		235	PA4	4	2
	205	PA4	5	1	41	240	PA1	11	1
16	210	PA1	3	2		240	PA2	4	2
	210	PA2	6	2	43	250	PA1	12	1
	210	PA2	9	2	44	255	PA1	9	2
	210	PA2	10	1	45	260	PA2	12	2
	210	PA2	11	2	46	270	PA2	7	3
	210	PA3	5	1	47	275	PA1	6	2
	210	PA4	9	2	48	285	PA1	2	1
	210	PA4	10	1					
24	215	PA2	8	2					
	215	PA4	2	3					
	215	PA4	6	1					

Appendix C. Translated Instructions

Instructions for all treatments consist of two pages each. The instructions for treatments PA1 to PA4 share a common first page. The instructions for treatments PAi and PAic for $i \in \{1, 2, 4\}$ share a common second page. The first page differs. We provide the first page for PA1 to PA4 and give the adjustments for PA1c, Pa2c, and PA4c in brackets. In Treatment SA1 we conduct a sales auction and thus the instructions differ from those of the other treatments.

Appendix C.1. First Page of the Instructions of Treatments PA1 to PA4

Instructions You are going to participate in an experiment on selling. In this experiment, you will make your decisions as a bidder at your computer terminal, isolated from the other participants. You may earn money in cash. How much you earn depends on your decisions and on the decisions of the other participants. The monetary units in the experiment are called currency units (CU).

Point of Departure Imagine that you are the owner of a cruise ship. The use of this ship yields profits and it thus has some value for you. You also have the opportunity to sell the ship, via a selling process that will be explained to you in detail in the following. Besides you, 2 other ship owners, who own one ship each, will participate in this selling process, but only **one** ship can be sold.

If you do not sell the ship, the value of the ship for you, $\mathbf{W}$, will be realized only through its use. Calculations show that the value $\mathbf{W}$ of the ship for you lies uniformly distributed between $\mathbf{W_0}$ and $\mathbf{W_1}$. This means, that the ship has a value for you of at least $\mathbf{W_0}$ and at most $\mathbf{W_1}$, where all values (integers) from $\mathbf{W_0}$ to $\mathbf{W_1}$ have equal probability.

Please note: The boundaries $\mathbf{W_0}$ and $\mathbf{W_1}$ are different for every ship owner. Your individual boundaries $\mathbf{W_0}$ and $\mathbf{W_1}$ will be communicated to you on your screen directly before the selling process; the boundaries of the other bidders, however, are unknown to you.

[PA1c, Pa2c, and PA4c: Your ship has the value $\mathbf{W}$ for you. You will learn this value directly before the selling process at your screen.

Please note: The value $\mathbf{W}$ is different for every ship owner. The values of the other ship owners are unknown to you and they do not know yours.]

Payoff

1. If you do **not** sell your ship, its value for you will be determined by drawing a value $\mathbf{W}$ from your uniform distribution over $\mathbf{W_0}$ to $\mathbf{W_1}$, which will then correspond to your **payoff**.

   [PA1c, Pa2c, and PA4c: If you do not sell your ship, you will receive a **payoff** equal to the value $\mathbf{W}$ of your ship.]

2. If you sell your ship at the price $\mathbf{P}$, this selling price corresponds to your **payoff**.

Your payoff will be converted into Euro and paid to you in cash at the end of the experiment, whereby 1 CU corresponds to 5 Euro Cents. The payment will be individual and anonymous.

Appendix C.2. Second Page of the Instructions of Treatment PA1

Selling process The process by which the ship is to be sold has the following rules.

You submit an offer $\mathbf{A}$ exactly **once**, at the beginning of the selling process. With this offer you express the **minimum** CU you want to have for the ship.

An offer has to be **a multiple of 5 CU**.
When submitting your offer, you do not know the offers of the other two vendors, and they do not know your offer.
When all 3 vendors have submitted their offers, the automatic selling process begins, which bids the offers against each other and thereby determines which vendor sells the ship. The selling process starts with the highest offer, which is thus eliminated. The price is then gradually decreased by 5 CU at each step. If the price reaches the size of another offer, this offer also quits the process. The selling process may end in two ways, depending on the offers:

1. If the lowest and the second lowest offer differ, the selling process stops when the price reaches the second lowest offer. We denote the remaining lowest offer by $\mathbf{A}^*$ and the price at which the selling process stops by $\mathbf{P}$, where $\mathbf{P}$ equals the second lowest offer. The vendor who submitted offer $\mathbf{A}^*$ is accepted as seller and sells his ship for the price $\mathbf{P}$. In this case we have $\mathbf{P} > \mathbf{A}^*$. That means that the seller receives for his ship more than what he asked for with his offer $\mathbf{A}^*$.

2. If at least two vendors have submitted the lowest offer $\mathbf{A}^*$, the process stops at price $\mathbf{P} = \mathbf{A}^*$. One of these vendors is then randomly selected as the seller at the price $\mathbf{P} = \mathbf{A}^*$. In this case the selling price equals the offer of the vendor who sells the ship.

Please note: You are only allowed to submit **once** an offer at the beginning of the selling process, and it may not be changed afterwards!
Before the selling process begins, you will be asked some questions on the screen concerning the rules. This is to ensure that all participants have understood the instructions.

Appendix C.3. Second Page of the Instructions of Treatment PA2

Selling process The process by which the ship is to be sold has the following rules.
The selling process starts at a price of **350 CU**. You will be asked on your screen whether you are willing to sell your ship at this price. If this is the case, please click on the OK-button on your screen or press the enter key. You have 50 seconds to do this. If you are not willing to sell at this price, do nothing until the 50 seconds are over. With this you will automatically exit the selling process. On the screen you can always see how many seconds are left until the 50 seconds are over. Every vendor of a ship decides without knowing the decisions of the other vendors.
If at least two vendors are willing to sell for the price of 350 CU, the price will be reduced by **5 CU**. Those vendors that are still in the selling process then again have 50 seconds to decide whether they are willing to sell their ship for 345 CU. If again at least two vendors agree, the price will again be reduced by 5 CU.
The price will be reduced by 5 CU until at a price $\mathbf{P}$ at least vendors are still in the selling process but at the next price $\mathbf{P-5}$ only one or no vendor remains. That is, at the price $\mathbf{P-5}$ either all or all but one vendors quit the selling process. The selling process stops and the vendor who was the last to accept a price or one of those who were the last to accept the price, if there are several of them, will sell his or her ship. The price for the ship in both cases is **P CU**:
1. There is only one vendor who has accepted the price $\mathbf{P-5}$ **CU**. That is, at the price $\mathbf{P-5}$ **CU** all but one vendor have quit. In this case, this vendor sells his or her ship at the price $\mathbf{P}$.

2. There are several vendors who have accepted the price **P CU** but none of them has accepted the price **P − 5 CU**. That is, at the price **P − 5 CU** all vendors have quit. In this case, one of the vendors who have accepted the price **P CU** is randomly selected and sells his or her ship at the price **P**.
Before the selling process begins, you will be asked some questions on the screen concerning the rules. This is to ensure that all participants have understood the instructions.

Appendix C.4. Second Page of the Instructions of Treatment PA3

Selling process The process by which the ship is to be sold has the following rules.
The selling process starts at a price of **350 CU**. You will be asked on your screen whether you are willing to sell your ship at this price. If this is the case, please click on the OK-button on your screen or press the enter key. You have 50 seconds to do this. If you are not willing to sell at this price, do nothing until the 50 seconds are over. With this you will automatically exit the selling process. On the screen you can always see how many seconds are left until the 50 seconds are over. Every vendor of a ship decides without knowing the decisions of the other vendors.
If two or more vendors are willing to sell for the price of 350 CU, then one of these vendors will be randomly selected as the **current leading vendor**, whom we call **LV350**. You will always be informed whether you are the current leading vendor or not.
The price will then be reduced by **5 CU**. Those vendors that are still in the selling process then again have 50 seconds to underbid the current leading vendor **LV350** by accepting the new price of 345 CU. The current leading vendor **LV350** cannot bid in this round but of course stays in the selling process.
If at the price 345 CU no vendor signals his or her willingness to sell the ship for this price, then the current leading vendor **LV350** sells his or her ship at the price 350 CU.
If one or several vendors signal their willingness to sell at 345 CU, then among these a new current leading vendor **LV345** is randomly selected. Then, the price is again reduced by 5 CU to 340 CU. The vendors who are still in the selling process, including the previous leading vendor **LV350**, again have 50 seconds to underbid the current leading vendor **LV345** by accepting the price 340 CU.
If at least one vendor accepts the price 340 CU, then there is a new current leading vendor **LV340** and the price is reduced to 335 CU and so on.
Before the selling process begins, you will be asked some questions on the screen concerning the rules. This is to ensure that all participants have understood the instructions.

Appendix C.5. Second Page of the Instructions of Treatment PA4

Selling process The process by which the ship is to be sold has the following rules.
The selling process starts at a price of **350 CU**. You will be asked on your screen whether you are willing to sell your ship at this price. If this is the case, please click on the OK-button on your screen or press the enter key. You have 45 seconds to do this. On the screen you can always see how many seconds are left until the 45 seconds are over.
The vendor who is the first to accept the price 350 CU becomes **current leading vendor**. We call this vendor **LV350**. The other vendors then cannot accept the price 350 CU anymore. You will always be informed whether you are the current leading vendor or not.
The price will then be reduced by **5 CU**, even if the 45 second have not yet passed, and you will see the new state of the auction process for 5 seconds on your screen. The vendors then have the opportunity for up to 45 seconds to underbid the current leading vendor **LV350**

by accepting the new price 345 CU. The current leading vendor **LV350** cannot bid in this round.
If at the price 345 CU no vendor signals his or her willingness to sell the ship for this price, then the current leading vendor **LV350** sells his or her ship at the price 350 CU.
If a vendor signals his or her willingness to sell at 345 CU, then this vendor becomes the new current leading vendor **LV345**. Then, the price is again reduced by 5 CU to 340 CU. Again, all vendors but the current leading vendor **LV345** can accept this price and the one who accepts the price first is the new leading vendor and so on. However, if at 340 CU no vendor accepts the price, then the current leading vendor **LV345** sells his or her ship at the price 345 CU.
Before the selling process begins, you will be asked some questions on the screen concerning the rules. This is to ensure that all participants have understood the instructions.

Appendix C.6. Instructions of Treatment SA1

Instructions You are going to participate in an experiment on auctions. In this experiment, you will make your decisions as a bidder at your computer terminal, isolated from the other participants. In the auction you may earn money in cash. How much you earn depends on your decisions and on the decisions of the other participants. The monetary units in the experiment are called currency units (CU).

Point of Departure Imagine that you are the owner of a ship that offers cruises. This is why you are participating in an auction in which the cruise ship "One World" will be auctioned **once**. Besides you, 2 other bidders will participate in this auction.
If you purchase the ship through the auction, its value $\mathbf{W}$ will result from its use in your fleet. However, calculations show that the value of the ship for you, $\mathbf{W}$, lies uniformly distributed between $\mathbf{W_0}$ and $\mathbf{W_1}$. This means that the ship has a value for you of at least $\mathbf{W_0}$ and at most $\mathbf{W_1}$, where all values (integers) from $\mathbf{W_0}$ to $\mathbf{W_1}$ have equal probability.
Please note: The boundaries $\mathbf{W_0}$ and $\mathbf{W_1}$ are different for every bidder. Your individual boundaries $\mathbf{W_0}$ and $\mathbf{W_1}$ will be communicated to you on your screen directly before the auction; the boundaries of the other bidders, however, are unknown to you.

Payoff

1. If **you** are awarded the ship for the price $\mathbf{P}$, the value of the ship for you will be determined immediately after the auction by drawing a value $\mathbf{W}$ from the uniform distribution on $\mathbf{W_0}$ to $\mathbf{W_1}$. Your profit from the auction will then be calculated as:

$$\mathbf{G = W - P}$$

Please note: If you pay more for the ship than it is worth to you, that is, if $\mathbf{P > W}$, then your profit from the auction will be negative, that is, $\mathbf{G < 0}$.

2. If you are not awarded the ship, your profit from the action equals zero, i.e.:

$$\mathbf{G = 0}$$

Your profit will then be converted into Euro, whereby 1 CU corresponds to 5 Euro Cents. The payoff you receive is 10 Euros plus your profit from the auction in Euros, i.e.:

Payoff = €10 + Profit from the auction

The payment will be individual and anonymous.

Auction The auction by which the ship is to be sold has the following rules.
You submit a bid $\mathbf{B}$ at the beginning of the auction exactly **once**. Your bid expresses the maximum CU you are willing to pay for the ship.
The minimum bid $\mathbf{B_{min}}$ for the ship is **0 CU**. That means that you have to bid at least 0 CU; that is, $\mathbf{B} \geq \mathbf{B_{min}} = 0$. The bid must be **a multiple of 5 CU**, that is, $\mathbf{B} = 0, 5, 10, 15, 20, \ldots$
When submitting your bid, you do not know the bids of the other bidders, and they do not know your bid.
When all 3 bidders have submitted their bids, the automatic bidding process begins, which places the bids against each other and thereby determines which bidder is awarded the ship.
In this auction, the price starts at the minimum bid of $\mathbf{B_{min}} = 0$.
The auction price is gradually increased by 5 CU at any one time. If a bid is exceeded by the auction price the bid quits the auction. The bidding process may end in two ways, depending on the bids:

1. If the highest bid and the second highest bid differ, the bidding process stops when the auction price exceeds the second highest bid. We denote the remaining highest bid $\mathbf{B}^*$ and the price at which the bidding process stops $\mathbf{P}$ where $\mathbf{P}$ equals the second highest bid. The bidder who submitted bid $\mathbf{B}^*$ is awarded the ship and must pay the price $\mathbf{P}$. In this case $\mathbf{P} < \mathbf{B}^*$. That means that the bidder pays less than his bid $\mathbf{B}^*$.

2. If at least two bidders have submitted the same bid $\mathbf{B}^*$ which is the highest bid, the bidding process stops at the price $\mathbf{P} = \mathbf{B}^*$. One of these bidders is then randomly selected to be awarded the ship at the price $\mathbf{P} = \mathbf{B}^*$. In this case the bidder who is awarded the ship has to pay his bid.

Please note: in this auction you are only allowed to submit a bid **once**, and it may not be changed afterwards!
Before the auction begins, you will be asked some questions on the screen concerning the rules. This is to ensure that all participants have understood the instructions.