EXCESS INFORMATION ACQUISITION IN AUCTIONS

VITALI GRETSCHKO AND ALEXANDER RAJKO
UNIVERSITY OF COLOGNE

Abstract. *The acquisition of information is an important feature in most auctions where one's exact private valuation is unknown ex-ante. We conducted the first experiment in testing a risk-neutral expected surplus maximization model with this feature. Varying the auction format and the cost of information acquisition we found bidders in most cases acquired too much information. Moreover, bidders who remained uninformed placed bids significantly below the optimal bid. The general prediction concerning revenue and efficiency remains valid, as a higher information cost was associated with lower revenues and efficiency rates. We explore different ex-post explanations for the observed behavior and show that regret avoidance can explain the data while risk aversion and ambiguity aversion cannot.*

JEL classification: C91, D44, D80

Keywords: Dynamic auctions, information acquisition, bidding behavior

1. Introduction

Typically, by investing resources bidders can gain a better understanding of the valuation of the object being auctioned. For example, in real estate auctions, bidders can acquire expertise about the value of a property. However, to place a bid, it is not necessary to obtain perfect information about ones valuation. If the cost of information is high, bidders may prefer to place bids based on partial information.

We examined bidders' behavior in second-price and English auctions in a setting where information about a bidder's own private valuation is costly. In an experiment, we varied the cost of information and analyzed the subjects' bidding and information acquisition behavior. We found that in the majority of cases, bidders acquired too much information. Moreover, bidders who chose to remain uninformed placed bids significantly below the optimal bid. Both observations contradicted the theoretical predictions concerning bidder behavior that we derive from a risk-neutral expected surplus maximization model. However, the general predictions concerning revenue and efficiency remain valid, as higher cost of

We would like to thank Jennifer Brown, Jacob Goeree, Axel Ockenfels, Alexander Rasch, and Achim Wambach for their helpful comments and discussion. Financial support from the German Research Foundation through the research unit "Design & Behavior" (FOR 1371) and the Fulbright Commission is gratefully acknowledged. Substantial parts of this paper were written when the first author stayed at Yale University in 2011/2012. The author thanks the department of economics for its hospitality. We would also like to thank our two anonymous referees and the associate editor for their detailed and helpful comments that have greatly improved this paper. All remaining errors are our own.

information is associated with lower revenues and lower efficiency rates. We explore ex-post three alternative models that are frequently used to explain behavior in experimental auctions: regret avoidance, risk aversion, and ambiguity aversion. We show that regret avoidance explains the observed data well whereas risk aversion and ambiguity aversion cannot explain the deviations from standard theory.

The acquisition of information about ones valuation is not only relevant for mergers and acquisitions where due diligence is a well-established part of the process.[1] Most auction environments involve information acquisition. For example, in spectrum auctions, information is usually acquired by means of technical research about the infrastructure, internal reports on future revenues, or the cost of setting up a new network. In preparing a bid for a procurement auction, suppliers may spend a considerable amount of resources estimating their cost to deliver the project. Even simple bidding on eBay for personal objects may require costly information acquisition in terms of cognitive cost.[2]

The typically large data sets from auction platforms cannot help to explain the effects of information acquisition, as these costs usually materialize outside the auction itself, and hence cannot be observed. Therefore, we use a laboratory experiment designed along the lines of the rational choice model of auctions with information acquisition developed by Compte and Jehiel (2007).[3] To our predictions concerning the value of information, we analyze two cases: if the cost of information acquisition is low, the model predicts that in both auction formats, subjects should acquire information with positive probability. Contrary to that, if the cost of information acquisition is high, no information acquisition should be observed in either format.

Based on the data, we provide three new and robust insights into bidders' behavior at such auctions. First, subjects acquire information excessively in the sense that information is acquired in more than 50% of the auctions when the cost of information is high. Second, in terms of the bidding strategies, we find that bidders who remain uninformed bid significantly

[1]Due diligence is costly, and increases the precision of buyers' information about their valuation.

[2]The theoretical works on auctions with information acquisition largely focus on the comparison of different auction formats in terms of information acquisition strategies, revenues, and efficiency. For auctions with interdependent valuations, see Matthews (1984), Hausch and Li (1993), Bergemann, Shi, and Välimäki (2009), Persico (2000), and Hernando-Veciana (2009). For auctions with independent private values, see Lee (1985), Guzman and Kolstad (1997), Gretschko and Wambach (2014), Shi (2012), Engelbrecht-Wiggans (1988), Parkes (2005), Rasmusen (2006), Rezende (2005), Compte and Jehiel (2000), and Compte and Jehiel (2007).

[3]Compte and Jehiel (2000, 2007) compare second-price auctions to English auctions and allow for the bidders to observe the number of remaining competitors in the English auction. The equilibrium bidding and information acquisition strategies obtained by Compte and Jehiel (2000) are very intuitive and do not demand sophisticated reasoning. Essentially, the decisions of the uninformed bidders boil down to comparing two random variables. Hence, their setup is well-suited for a first experimental investigation of bidders' behavior in auctions with information acquisition.

below the optimal bid. Third, in the English auction, subjects buy information prematurely, and thus the timing of their information acquisition is not optimal.

The general prediction for revenue and efficiency still holds true in our experiment, as a higher information cost is associated with lower revenues and lower efficiency. However, an auction designer who is concerned about revenue should worry less about costly information than theory would suggest. This is due to the fact that even with a high cost of information acquisition, subjects overinvest in information. If the auction designer is concerned about efficiency, he should take into account the cost of information acquisition. Even though the allocative efficiency with a high information cost is better than theoretically predicted, the over-investment in information reduces overall efficiency significantly.

We shall proceed by providing an ex-post analysis of the behavior we observed. We show that excess information acquisition and underbidding can be explained by incorporating regret into the initial model.[4] If the bidder is fully informed about his valuation of the object, the ex-ante optimal bids in the second-price auction and the English auction are also optimal ex-post.[5] Hence, the bidders experience no bidder regret. If, however, the valuation is unknown, the bid placed by the bidder may either lead to a negative payoff or the failure to win the object, even when the price is below the realized valuation. Both of these situations may cause regret. If the bidder anticipates the feeling of regret, his willingness to pay for information increases. If, on the other hand, the bidder remains uninformed, our feedback procedure only induces the regret suffered from overpaying.[6] In this case, it is optimal for a regret-sensitive subject to shade the bid below the optimal bid. In contrast to anticipated regret, risk and ambiguity aversion cannot explain our observations.

To the best of our knowledge, there is only one experimental study that is broadly related to the subject at hand: Davis, Katok, and Kwasnica (2011) compared bidder behavior in an English auction and a sequential mechanism. The bidders had to invest in information about their valuation before entering the mechanism. Contrary to our study, bidders were not able to participate if they did not invest in information that made investing more

[4]Anticipated regret in auctions was brought forward as a possible explanation for overbidding in first-price auctions by Engelbrecht-Wiggans (1989), Engelbrecht-Wiggans and Katok (2007), Engelbrecht-Wiggans and Katok (2008) and Filiz-Ozbay and Ozbay (2007). Also see the references therein.

[5]This is due to the fact that both auction formats are solvable in (weakly) dominant strategies.

[6]Filiz-Ozbay and Ozbay (2007) and Engelbrecht-Wiggans and Katok (2007) show that the influence of regret on equilibrium bidding depends strongly on the feedback given to bidders. Our subjects learn their true valuations only if they acquire information or win the auction. In any other case, the valuation is not revealed to the subjects. This feedback procedure only enforces regret due to overpaying, but not regret due to losing the auction.

valuable. Similar to our findings, Davis, Katok, and Kwasnica (2011) found that subjects overinvest in information and enter the mechanisms more often than predicted by theory.

2. Theory

In what follows, we shall proceed along the lines of Compte and Jehiel (2000). N risk-neutral bidders compete in an auction for an indivisible object. Each bidder i assigns a value of v_i to the object. The valuation is independently and identically distributed on $[0, 1]$ according to an absolutely continuous distribution $F(v)$. Before the auction starts, all bidders except for bidder 1 observe their private valuations. Bidder 1 is only informed about the distribution of the valuations.

In a *second-price auction,* bidder 1 decides before the auction starts whether to learn his true valuation at cost $c \in R_+$. After deciding whether to acquire information, all bidders simultaneously submit a bid for the object. The bidder with the highest bid wins the auction and pays the second highest bid to the auctioneer.

In an *English auction,* a price clock starts at 0 and continuously increases. At each price p, bidder 1 may decide whether to learn his true valuation at cost $c \in \mathbb{R}_+$, and whether to stay in the auction or not. All of the other bidders can only decide on whether to leave the auction at price p. Each decision to withdraw is observed by all bidders. The last bidder remaining in the auction wins the object for the price at which the last opponent dropped out.

Second-price auction. It is a weakly dominant strategy for informed bidders to bid their valuations. If bidder 1 remains uninformed, his best reply to the bidding strategies of the other bidders is to bid $E[v_1]$. Hence, he will acquire information before the auction starts if the expected utility of acquiring information is higher than the expected utility of not acquiring information:[7]

$$(1)\qquad E\left[\max\{v_1, v^{(1)}\} - v^{(1)}\right] - c \geq E\left[\max\{E[v_1], v^{(1)}\} - v^{(1)}\right].$$

This generates the following predictions about bidder 1's information acquisition and bidding behavior in a second-price auction:

Fact 1. *In the second-price auction, a cutoff* $c^e = E\left[\max\{v_1, v^{(1)}\} - v^{(1)}\right] - E\left[\max\{E[v_1], v^{(1)}\} - v^{(1)}\right]$ *exists such that bidder* 1 *acquires information if* $c \leq c^e$. *He refrains from information*

[7] Let $v^{(1)}$ denote the highest order statistic of $N - 1$ independent draws from F.

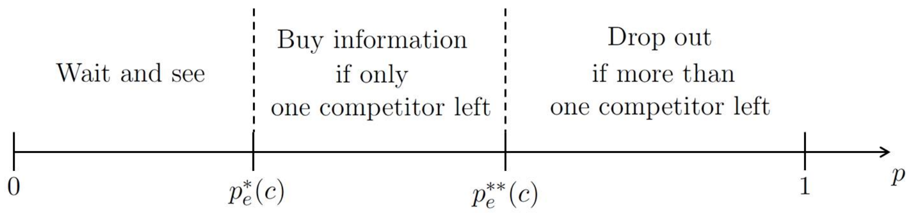

FIGURE 1. Structure of the information acquisition and drop out decisions of the uninformed bidder.

acquisition whenever $c > c^e$. If bidder 1 remains uninformed in the second-price auction, he bids his expected valuation.

English auction. For bidders who are informed about their valuation v_i it is a weakly dominant strategy to drop out if, and only if, $p > v_i$.

To avoid buying at an unfavorable price, it is sufficient for an uninformed bidder to know whether his true valuation is below the current price. As long as more than one competitor is still in the auction, the probability of winning the object is 0. As a result, in this case, it is a weakly dominant strategy not to buy information. As soon as only one competitor is left in the auction, bidder 1 has to weigh the cost of information acquisition, the probability of winning, and the risk of buying at an unfavorable price. To formalize this trade-off, define

$$H(p,c) := E\Bigg[\max\{v_1, v_2\} - v_2 | v_2 \geq p\Bigg] - c,$$

$$K(p) := E\Bigg[\max\{E[v_1], v_2\} - v_2 | v_2 \geq p\Bigg],$$

$$p^{**}(c) := \sup\{p \in [0,1] | H_e(p,c) \geq K_e(p)\}, \text{ and} \tag{2}$$

$$p^*(c) := \inf\{p \in [0,1] | E[\max(p, v_1) - v_1] - c \geq 0\}. \tag{3}$$

$p^{**}(c)$ is the highest p, such that the expected payoff from buying information at p exceeds the expected payoff from not buying information. $p^*(c)$ is the lowest p, such that the information cost is lower than the expected loss from buying at a price above valuation. Bidder 1's equilibrium behavior can then be characterized as follows:

Fact 2. *In the English auction, $p^*(c)$ and $p^{**}(c)$ exist and are given by* (2) *and* (3) *such that:*

(1) If there are at least two other competing bidders left in the auction at price p, bidder 1 does not acquire information and stays in the auction as long as $p < \max\{p^{**}(c), E[v_1]\}$.

(2) If only one other competing bidder is left in the auction, two cases are relevant:

(a) If $p^{*}(c) > p^{**}(c)$, bidder 1 never acquires information and drops out as soon as the price reaches $E[v_1]$.

(b) If $p^{*}(c) < p^{**}(c)$, no information was acquired by bidder 1 and

(i) $p \in [p^{*}(c), p^{**}(c)]$, bidder 1 acquires information, drops out immediately if $p > v_1$, or stays in the auction if $p \leq v_1$;

(ii) $p > p^{**}(c)$, bidder 1 drops out;

(iii) $p < p^{*}(c)$, bidder 1 stays in the auction.

The information acquisition strategy is depicted in Figure 1. A formal proof can be found in Compte and Jehiel (2000).

3. Experimental Design, Procedures, and Predictions

For our experimental design,we have chosen the model of Compte and Jehiel (2000) for several reasons. First, we are mostly interested in how subjects acquire information in auctions, rather than bidding behavior. Thus, it is reasonable to choose auction formats with straightforward bidding strategies that allow subjects to focus on their information acquisition strategies. In a second-price auction and an English auction, truthful bidding is a weakly dominant strategy. In contrast, a first-price and a Dutch auction have more elaborate equilibrium strategies. Second, as this is the first experiment investigating information acquisition in auctions, we wanted to abstract from complex considerations concerning information acquisition strategy. This is best accommodated by a setting in which only one player is faced with the decision as to whether to acquire information, as this allows for equilibrium in pure strategies. In any setting where more than one player can acquire information, no equilibrium can be explicitly derived.[8] Third, showing the number of competitors in the English auction facilitates the decision as to whether to acquire information. This decision would require sophisticated reasoning in a Rezende (2005)-style setting where bidders can only infer the state of the competition from the fact that the auction is still running.

[8] Compte and Jehiel (2007) is a more general version of Compte and Jehiel (2000) in the sense that Compte and Jehiel (2007) allow for information acquisition by more than one bidder. As stated above, this comes at the cost of the information acquisition strategy not being explicitly derivable.

Accordingly, in every auction group, only one player did not know his valuation ex-ante. The other players always have perfect information about their valuations. We choose groups of four players. As we were only interested in the information acquisition strategies of the uninformed player, and the informed players have a salient dominant strategy, we used bidding robots as the three remaining players. These robots were programmed to always bid their true valuation, which was also explained to the human subjects in the instructions.

The uninformed human bidder only knew that his valuation was uniformly distributed between 0 and 100 ECU.[9] Moreover, he knew that the valuations of the three bidding robots were drawn from the same distribution. We allowed the participants with unknown valuations to buy information about their valuations at a specified cost. This cost parameter varied depending upon the treatments: low cost ($c = 2$) and high cost ($c = 8$).

We used the second-price price and the English auction. The object was not specified and profits for the auction were calculated as ones valuation minus the final price, and if applicable minus the cost of information acquisition. This provided a 2×2 between subject design.

In the second-price auction, information acquisition was only possible prior to the auction. In the English auction, information could be acquired at any time throughout the auction. To this end, we implemented a pause button, enabling subjects to pause the price clock at any time to buy information.[10] The price clock increased by 1 ECU every two seconds.[11] Overall, every auction format was repeated for 20 rounds, and valuations for all players were redrawn for every round.

We provided the subjects with the information as to whether they won the auction, at what price the auction was won, what their final bid was, and which subject won or lost this round, including the information cost. If a subject won the auction, we provided additional feedback regarding his valuation.We stressed in the instructions that all losses in experimental money must also be covered with real money following the experiment.

The experimental sessions took place in the Cologne Laboratory for Economic Research (CLER) in April 2011. We had 30 subjects per treatment, and 120 subjects participating overall. The average payment was 13.20 EUR including a guaranteed participation fee of 2.50 EUR. On average, each subject participated in the experiment for 75 minutes. For

[9]ECU is the Experimental Currency Unit. 10 ECU are equivalent to 1 Euro (10 ECU = 1 EUR).
[10]Thus, we can rule out any time pressure effects shaping the decision to buy information or withdraw from bidding.
[11]This is similar to other experiments on English auctions (Levin, Kagel, and Richard, 1996).

the recruitment procedure, we used the online recruitment system ORSEE (Greiner, 2004), and the experiment itself was programmed with z-Tree (Fischbacher, 2007).

Predictions. In the second-price auction, subtracting the expected profit of bidding uninformed from the expected profit of bidding informed yields:

$$c^e = E\left[\max\{v_1, v^{(1)}\} - v^{(1)}\right] - E\left[\max\{E[v_1], v^{(1)}\} - v^{(1)}\right] \approx 3.4.$$

Hence, the subjects should always acquire information if the cost of information acquisition is below 3.4, and always refrain from doing so if the cost is above 3.4. This leads to the following hypothesis:

Hypothesis 1. *In the low-cost treatment of the second-price auction ($c = 2$), all subjects should acquire information prior to bidding. In the high-cost treatment of the second-price auction ($c = 8$), all subjects will refrain from information acquisition.*

Concerning the bidding strategy, we can state the following hypothesis:

Hypothesis 2. *If bidder 1 acquires information, he bids his valuation, i.e., $b = v_1$. If bidder 1 remains uninformed in the second-price auction, he bids his expected valuation, i.e., $b = E[v_1] = 50$.*

In the English auction, bidder 1 will acquire information whenever only one competitor is left in the auction and the price p is above $p^*(c)$ and below $p^{**}(c)$. If $p^{**}(c) > p^*(c)$, information acquisition takes place with probability 0 in equilibrium. Hence, for the English auction, we expect no information acquisition in the high-cost treatment as $p^{**}(8) > p^*(8)$. In the low-cost treatment, we can make a more sophisticated prediction regarding the timing of information acquisition:

Hypothesis 3. *In the low-cost treatment of the English auction ($c = 2$), bidder 1 never acquires information as long as more than one other bidder is active in the auction. If only one other bidder is left in the auction, bidder 1 will acquire information if $p^*(2) = 20 < p < p^{**}(2) = 67$. If $p > 67$, he will exit. In the high-cost treatment of the English auction ($c = 8$), bidder 1 never acquires information.*

Concerning the bidding strategy, we can state the following:

Hypothesis 4. *If bidder 1 learns his true valuation, he drops out of the auction as soon as the price has reached his valuation. If bidder 1 remains uninformed, he drops out at $E[v_1] = 50$.*

TABLE 1. Predictions for information acquisition in the English auction.

	Information acquisition		**Bidding**	
Treatment	$p^*(c)$	$p^{**}(c)$	*informed*	*uninformed*
English auction ($c = 2$)	20	67	$b = v_1$	$b = 50$
English auction ($c = 8$)	never	never	–	$b = 50$

TABLE 2. Predictions for revenue and efficiency.

Treatment	**Efficiency**	**Revenue**
second-price auction ($c = 2$)	100%	58.75
second-price auction ($c = 8$)	70%	51.85
English auction ($c = 2$)	100%	58.65
English auction ($c = 8$)	70%	51.85

Predictions for the English auction are summarized in Table 1.

Whenever information is acquired, both auctions yield an efficient allocation of the object. Without information acquisition, inefficiencies may arise. As bidder 1 only acquires information in the low-cost treatment, we can state the following:

Hypothesis 5. *The efficiency is higher in the low-cost treatment ($c = 2$) than in the high-cost treatment ($c = 8$) in both auction formats.*

Moreover, information acquisition by bidder 1 has a positive effect on revenues in both formats:[12]

Hypothesis 6. *The revenue is higher in the low-cost treatment ($c = 2$) than in the high-cost treatment ($c = 8$) in both auction formats.*

The expected efficiency rates and the expected revenues are summarized in Table 2.[13]

4. Experimental Analysis and Results

4.1. **Excess information acquisition.** For the high-cost treatments, where the prediction is that information is never bought, the data showed that subjects nevertheless bought information in 59% of all second-price and 51% of all English auctions.[14] We deliberately chose a prohibitively high cost of $c = 8$ in order to make the decision to refrain from buying information easy. The observed high information acquisition rates offer a clear indication that subjects assess the situation differently and overestimate the benefits of additional

[12]Whether information acquisition has a positive effect on revenues in general depends on the distribution of the valuations and the number of bidders.

[13]We used the valuations that were actually drawn for the experiments (see Appendix A) to calculate the prediction in Table 2.

[14]T-test:p-value < 0.0001.

information. In Section 5 of this paper, we will discuss a extension to the model assessing this observation.

Result 1. *Information acquisition rates are significantly higher than predicted in both auction formats if the cost of information acquisition is high.*

Even though the information acquisition rates are higher than predicted in both auction formats, the behavior of the subjects in the English auction was slightly more rational as significantly less information was acquired.[15]

Next, we compare the data from the two low-cost treatments. Here, the effect of excess information acquisition was also found in the English auction, where 95% instead of the predicted 75% of the subjects acquired information.[16] In the second-price auction, where the rational model revealed that buying information is always optimal, we found that 88% of the subjects acquire information, which is less information acquisition than predicted.[17] Comparing both formats reveals that significantly more information was acquired in the English auction.[18]

Overall, we observe excess information acquisition in three of the four treatments, and the opposite in one treatment. However, the general prediction that a higher cost of information leads to less information acquisition still holds:

Result 2. *Significantly less information is acquired in both auction formats when the cost of information is high.*[19]

4.2. **Premature information acquisition.** In the English auction, we find that subjects acquired information prematurely. In the low-cost treatment, where subjects should optimally buy at a price of 20 ECU, subjects bought almost immediately after the start of the auction at an average price of 2 ECU.

Table 3 corroborates the initial finding of premature information acquisition, showing that subjects failed to wait for the previous bidders to drop out before they decided on whether or not to purchase information. In the low-cost treatment, where information should be bought in 75% of the auctions when only one bidder remains, only 2.6% of information acquisitions can be classified as optimal in that sense. Interestingly, in the high-cost treatments where information acquisition should never occur, subjects who nevertheless

[15]Mann-Whitney test: p-value=0.0091.
[16]T-test: p-value <0.0001.
[17]T-test: p-value <0.0001.
[18]Mann-Whitney test: p-value<0.0001.
[19]Mann-Whitney test for second-price auction ($c = 2$ vs. $c = 8$): p-value<0.0001. Mann-Whitney test for English auction ($c= 2$ vs, $c = 8$): p-value<0.0001.

Table 3. Number of opponents at information acquisition (English auction).

Treatment	Information acquisition with 1 opponent remaining	Prediction	Information acquisition with ≥ 2 opponents remaining	Prediction
English ($c = 2$)	2.6 %	75.0 %	97.4 %	0 %
English ($c = 8$)	20.2 %	0 %	79.8 %	0 %

engage in information acquisition did so after observing the competition longer, hence factoring in previous drop outs.[20]

Result 3. *Information is acquired prematurely in the English auction.*

4.3. **Underbidding behavior.** We calculate the deviations between the bids and valuations for all auction rounds where a subject had information.[21] We define valuation bidding as bidding one's valuation plus 1 or minus 1, if informed. Hence, underbidding is every bid under the valuation minus , and overbidding is every bid above the valuation plus 1.

Table 4. Bidding strategy of subjects who acquired information.

Treatment	Underbidding	Valuation bidding	Overbidding
2nd price ($c = 2$)	24.0%	55.2%	20.8%
2nd price ($c = 8$)	27.8%	51.7%	20.5%
English ($c = 2$)	34.2%	62.8%	2.9%
English ($c = 8$)	41.7%	45.5%	12.8%

Table 4 shows that we do not find that overbidding was as strong as in previous studies, whereas underbidding was a predominant pattern in our subjects' behavior. This finding differs from many standard results found in second-price auctions (Cooper and Fang, 2008; Kagel and Levin, 1993). It was not the intention of our experiment to analyze the bidding behavior of informed subjects. Thus, we can only speculate as to why subjects tended to underbid in our setting. Nevertheless, we are not the first to observe underbidding in second-price auctions. Garratt, Walker, and Wooders (2012) also found a significant amount of underbidding in their study of bidding behavior of experienced eBay bidders. As an explanation of the observed behavior, they compared their experiment with the experiment of Kagel and Levin (1993), and stated that the difference in behavior was most likely due to

[20]This finding is consistent with the price clock data from the high-cost treatment, where the average clock price at information acquisition is 12 ECU.

[21]The English auction ends once the second to last bidder has dropped out, so we are not able to observe the full bidding strategy of a winner. Hence, the estimated average bid in the English auction is merely the lower boundary of the actual average bid.

the difference in the experimental designs. In contrast to Kagel and Levin (1993) Garratt, Walker, and Wooders (2012) sensitized their subjects to possible losses in the second-price auction. This was also the case in our design (see Appendix E). Moreover, subjects had to pay the full amount of their losses at the end of the experiment, even if the losses exceeded the participation fee. This was prominently mentioned in the experiments' instructions, and can serve as a possible explanation for the observed underbidding behavior.

Result 4. *Bidding strategies of informed bidders exhibit an underbidding effect.*

Additionally, we consider the bidding strategies of uninformed subjects. In the low-cost treatment, almost all subjects always bought the available information. This data is not reliable, however, as the remaining few observations are probably subject to a strong selection effect. Thus, in Table 5 we only report the mean bids of the high-cost treatments.

TABLE 5. Mean bids without information in the high-cost treatment (standard deviations in parentheses).

Treatment	**Mean bid**	**Prediction**
2nd Price ($c = 8$)	40.6 (1.74)	50
English ($c = 8$)	36.7 (1.64)	50

We find underbidding in both treatments, which contrasts with our theoretical prediction:

Result 5. *Bidding strategies of uninformed bidders exhibit an underbidding effect.*

In Section 5 of this paper, we will discuss an extension of the model assessing this observation.

4.4. **Revenue and Efficiency.** In this section, we will discuss how the subjects' behavior impacts revenue and efficiency. The mean auction revenues are reported in Table 6.

TABLE 6. Observed revenues with standard deviations (in parentheses).

Treatment	**Revenue**
2nd price ($c = 2$)	58.7 (0.898)
2nd price ($c = 8$)	56.0 (0.938)
English ($c = 2$)	58.4 (0.913)
English ($c = 8$)	56.1 (0.894)

As expected, we find that the cost of information acquisition had a significant impact on auction revenues.[22]

[22]For second-price auction treatments Mann-Whitney test: p-value=0.047, for English auction treatments Mann-Whitney test: p-value=0.090.

Result 6. *The revenue is higher in both formats when the cost of information acquisition is low.*

Comparing the two auction formats for the same information cost, we do not find a significant difference in revenues.[23] In general, information acquisition had a positive effect on revenues. Thus, the treatments with significantly higher rates of information acquisition also had higher revenues. However, the difference in information acquisition frequencies across formats was not large enough to have a significant impact on revenues.

The percentages of auctions that were efficient in the four treatments can be found in Table 7.

Table 7. Observed efficiency by treatment.

Treatment	**Share of efficient outcomes**
2nd price ($c = 2$)	94%
2nd price ($c = 8$)	80%
English ($c = 2$)	99%
English ($c = 8$)	80%

Testing the differences in efficiency using a Mann-Whitney test, we find a significance for both auctions between the low-cost and the high-cost treatments.[24]

Result 7. *The efficiency is higher in both auctions when the cost of information acquisition is low.*

Testing for the difference in auction formats, we find an advantage in the dynamic format regarding auction efficiency in the low-cost treatment.[25]

Result 8. *The English auction is more efficient than the second-price auction for low cost of information acquisition.*

The advantage of the English auction in terms of efficiency in the low-cost treatments is most likely due to the higher frequency of information acquisition.

5. Analysis of Individual Level Behavior

In this section, we support our experimental findings by taking a closer look at the dynamics of the subjects' information acquisition and bidding behavior.

[23]For low cost treatments Mann-Whitney test: p-value=0.88, for high cost treatments Mann-Whitney test: p-value=0.88. As we have seen in Subsection 4.1, the frequencies of information acquisition are very similar in both formats. Moreover, in the English auction the subjects fail to wait before acquiring information. Thus, similar revenues were to be expected across formats.

[24]Mann-Whitney test: p-value<0.001 for both auctions.

[25]Mann-Whitney test: p-value<0.01.

5.1. **Information acquisition behavior.** We analyze the switches in information acquisition strategies on an individual player level.[26] Over all of the treatments, players switched their information acquisition strategy in 266 out of a possible 2280 cases. This indicates that the subjects followed their strategies consistently. In the two low-cost treatments, 38 (second-price auction) and 33 (English auction) strategy switches were observed overall, with only two players changing frequently from one round to another. In the high-cost second-price auction, 72 changes were observed, with only 2 players exceeding 5 changes over the course of the experiment. A slightly different picture was found in the English auction with high cost of information acquisition, where 123 changes were made with 33% of players exceeding five changes, and thus not following a clear information acquisition strategy.

We run a probit model for the information acquisition behavior to corroborate the robustness of the results presented thus far. The results can be found in Table 8. For both formats, we find that only the cost of information influences the probability of acquiring information, whereas the round of the experiment does not have a significant effect.

TABLE 8. Probit model for the second-price and English auction (standard errors in parentheses).

Dependent variable: information acquisition		
Variables	**Second-price auction**	**English auction**
Intercept	1.08***	1.72***
	(0.098)	(0.117)
High cost	−0.97***	−1.58***
	(0.084)	(0.099)
Auction rounds (1–20)	0.01	−0.01
	(0.007)	(0.008)
Nobservations	1200	1200
Pseudo R^2	0.10	0.23

5.2. **Bidding strategies.** Figure 2 shows scatterplots of the bids of the subjects who acquired information. To understand the dynamics of the bidding behavior in more depth, we run two separate regression models for the different auction formats.

[26]We define that a bidder has switched the information acquisition strategy in round k if he had acquired information in Round $k-1$ but not in k, or if he had not acquired information in Round $k-1$ but in Round k.

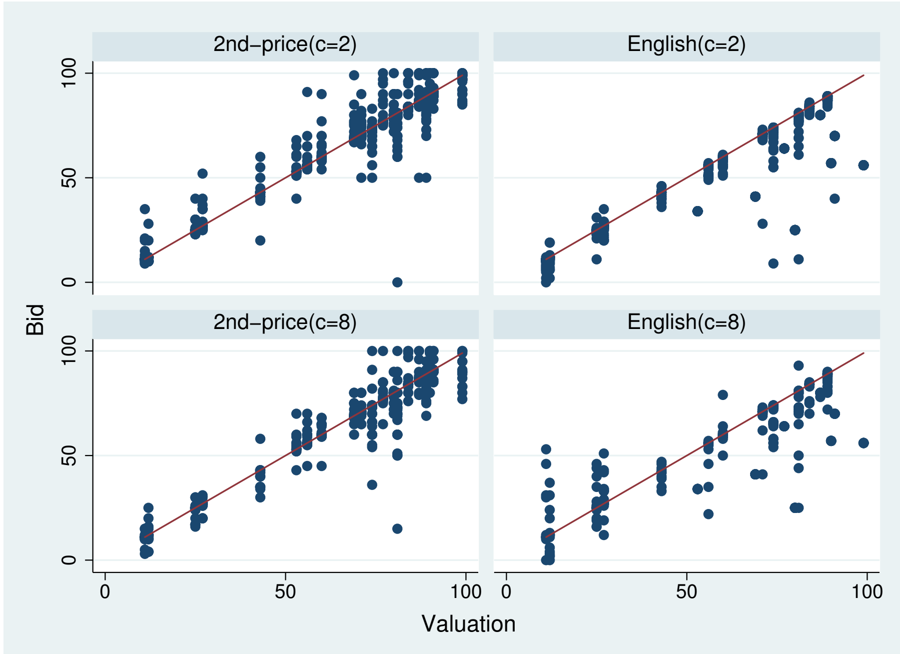

FIGURE 2. Observed bidding of informed subjects.

We start our analysis with a fixed-effects regression for the second-price auction (Table 9). Model 1 shows that information acquisition is the main influence on the bids. In comparison, the valuation has significant but much smaller effect. Also, the impact of the auction round is marginal. Hence, we can conclude that learning does not strongly impact the strategies employed in our experiment. In Model 2 we additionally control for the number of switches in player's information acquisition strategy. Here, we find no significant impact on the bids.

The analysis of the English auction requires a different approach as the auction finished instantly whenever all but one bidder dropped out. Hence, in such cases the true final bid does not materialize in the dataset. To account for this, we specify a random effects tobit model for which we censor the bids in cases where we cannot observe the true final bid (See Table 10).[27] The effect of information acquisition has a major and highly significant impact on the bids. Valuation of the players also has a significant but comparatively smaller effect. In contrast to the second price auction, the effect of the auction round is only weakly significant (see Model 1). Furthermore, we control for the price clock in the English format and find no significant effect on bids, underlining the result that subjects in the experiment fail to use the dynamic feature of the auction in deriving their bidding strategies (Model 2).

[27]In our case this means a right-censoring of 448 bids.

Table 9. Fixed effect regression for the second-price auctions (standard errors in parentheses).

Dependent variable: bid		
Variables	**Model 1**	**Model 2**
Intercept	-6.413***	-6.34***
	(2.048)	(2.091)
Information acquisition	22.99***	22.96***
	(1.762)	(1.769)
Valuation player	0.705***	0.705***
	(0.018)	(0.018)
Auction_rounds (1–20)	0.237***	0.234***
	(0.082)	(0.084)
Number of switches in IA strategy		-0.305
		(1.796)
N observations	1200	1200
ρ	0.405	0.404
σ_μ	13.281	13.278
n clusters	60	60

Finally, the number of switches in player's information acquisition strategy has a weakly significant impact on the bids (Model 3).

This strengthens our conclusions, as we can now exclude learning as a main driver of the observed behavior in any of the auction formats.

6. Alternative hypotheses

As we have seen, the experiment results contradict the predictions derived in Section 2. The main deviations from the predictions were that bidders acquired more information than predicted, and that uninformed bidders bid significantly below $E[v_1]$. In what follows, we explore alternative explanations for subject's behavior that have worked well in other settings. More precisely, we will consider three different explanations that are frequently used to explain subjects' behavior in experimental auctions: regret avoidance, risk aversion, and ambiguity aversion.[28] Regret avoidance will explain our results, whereas the other theories fail to explain at least one of the major observations. As our experiment was not initially designed to test different theories, everything in the following chapter is an ex-post

[28] Those are the most prominent theories that are brought forward to explain overbidding in first-price auctions. Moreover, those theories also seem to fit our setting well due to the fact that the underlying distribution of the lottery that our subjects face is convoluted.

TABLE 10. Random effects tobit regression for the English auction (standard errors in parentheses)

Dependent variable: bid			
Variables	**Model 1**	**Model 2**	**Model 3**
Intercept	-3.452	-3.288	-2.648
	(2.711)	(2.734)	(2.778)
Information acquisition	17.876***	17.509***	17.054***
	(1.749)	(1.956)	(1.983)
Valuation player	0.772***	0.723***	0.723***
	(0.021)	(0.021)	(0.021)
Auction_rounds (1-20)	0.187*	0.186*	0.182*
	(0.098)	(0.098)	(0.098)
Price clock at information acquisition		0.028	0.105
		(0.068)	(0.639)
Number of switches in IA strategy			-2.569**
			(1.954)
N observations	1200	1200	1200
ρ	0.303	0.302	0.304
σ_μ	11.272	11.240	11.279
n clusters	60	60	60

insight, and possibly needs further experimental evaluation. A summary of the results can be found in Table 11.

TABLE 11. Predictions of alternative models.

Theory/Observation	**Prohibitive cost of information acquisition**	**Bidding of uniformed bidders**
Observation	$\hat{c} > 3.4$	$b < E[v_1]$
Standard	$\hat{c} = 3.4$	$b = E[v_1]$
Regret avoidance	$\hat{c} > 3.4$	$b < E[v_1]$
Risk aversion	$\hat{c} < 3.4$	$b < E[v_1]$
Ambiguity aversion	$\hat{c} < 3.4$	$b < E[v_1]$

6.1. **Regret avoidance.** A bidder who acquires information and bids his valuation in the second-price auction always bids optimally—not only from the ex-ante point of view but also from the ex-post point of view.[29] In contrast, without acquiring information, the bidding decision may turn out suboptimal ex-post. If the bidding decision is not optimal

[29]In the English auction, dropping out when the price reaches a bidder's valuation is ex-post optimal for any realization of the other bidders' valuations.

ex-post, the bidder may experience regret. Moreover, if the bidder anticipates a feeling of regret, this concern will be reflected in his information acquisition and bidding decisions.

Regret enters the bidding decision in two dimensions: winner's regret and loser's regret. For example, suppose the bidder does not acquire information and places a bid of $E[v_1] = 50$ ECU in the second-price auction. At the end of the auction, he learns that the second highest bid is 40 ECU, but his valuation is 10 ECU. In this case, the bidder loses 30 ECU. If he had acquired information and bid his valuation, this loss could have been avoided. The fact that the ex-ante best bid is no longer the best bid ex-post will make the bidder regret his decision.

On the other hand, suppose that at the end of the auction the same bidder learns that the second highest bid is 60 ECU, but his valuation is 90 ECU. In this case, the bidder would have won 30 ECU if he had acquired information and placed a bid equal to his valuation. Again, the best bid ex-ante is no longer the best bid ex-post and the bidder will regret his decision.

Filiz-Ozbay and Ozbay (2007) and Engelbrecht-Wiggans and Katok (2007) showed that the influence of regret on equilibrium bidding depends strongly on the feedback given to bidders. In our set up, we did not reveal the true valuation to bidders who did not acquire information and lost the auction. Hence, losing bidders were not able to observe whether their bidding decision was optimal ex-post. Thus, regret from losing the auction could *not* influence their bidding decisions.[30]

Second-price auction. Suppose bidder 1 did not acquire information and placed a bid based on his expected valuation in the subsequent second-price auction. In this case, shading his bid below $E[v_1]$ would minimize regret from winning the item at an unfavorable price. Moreover, if bidder 1 acquires information, he bids his valuation and his bid is ex-post optimal which means he would not experience regret. Hence, his willingness to pay for information would be larger than a regret-neutral bidder's willingness to pay. We summarize this finding in Fact 3. A more formal treatment can be found in Appendix B

Fact 3. *In the second-price auction with regret, a cutoff $c^r > c^e$ exists, such that bidder 1 acquires information if $c \leq c^r$. He refrains from information acquisition whenever $c > c^r$. If bidder 1 remains uninformed in the second-price auction with regret, he bids $b^* < E[v_1]$.*

This implies that a range of information cost exists such that bidder 1 acquires information in the second-price auction if and only if he anticipates the feeling of regret. Moreover,

[30] Anticipated regret in auctions was originally brought forward as an explanation for overbidding in first-price auctions (see, e.g., Filiz-Ozbay and Ozbay, 2007, or Engelbrecht-Wiggans and Katok, 2007).

if the feeling of regret is anticipated, bidders who remain uninformed bid below the expected valuation. Hence, with the appropriate definition of the regret function $r(\cdot)$, a theory of regret accounts for the departure from risk-neutral expected-surplus maximization in the second-price auction as described in Results 1 and 5.

English auction. By the same reasoning as in the second-price auction, an uninformed bidder in the English auction who anticipates winner's regret optimally leaves the auction before the price reaches $E[v_1]$. Moreover, his willingness to pay for information is greater than a regret-neutral bidder's willingness to pay. This implies that bidders that are sensitive to regret acquire information at an earlier stage. This finding is summarized in Fact 4. A more formal treatment can be found in Appendix C.

Fact 4. *In the English auction with regret, the following exist:* $p_r^*(c) < p^*(c)$, $p_r^{**}(c) > p^{**}(c)$, *and* $b^* < E[v_1]$ *given by equations* (11) and (12) *such that:*

- *(i) If there are at least two other competing bidders left in the auction at price* p, *bidder* 1 *does not acquire information and stays in the auction as long as* $p < \max\{p_r^*(c), b^*\}$.
- *(ii) If only one other competing bidder is left in the auction, two cases are relevant:*
  - *(a) If* $p_r^*(c) > p_r^{**}(c)$, *bidder* 1 *never acquires information and drops out as soon as the price reaches* $E[v_1]$.
  - *(b) If* $p_r^*(c) < p_r^{**}(c)$, *no information has been acquired by bidder* 1, *and*
    - *(i)* $p \in [p_r^*(c), p_r^{**}(c)]$, *bidder* 1 *acquires information, drops out immediately if* $p > v_1$, *or stays in the auction if* $p \leq v_1$;
    - *(ii)* $p > p_r^{**}(c)$, *bidder* 1 *drops out;*
    - *(iii)* $p < p_r^*(c)$, bidder 1 stays in the auction.

The information acquisition strategy in the English auction with regret has the same structure as the strategy in the English auction without regret as depicted in Figure 1. However, as $p_r^*(c) < p^*(c)$ and $p_r^{**}(c) > p^{**}(c)$, the range of prices on the price-clock for which the uninformed bidder acquires information in equilibrium is greater for any c if regret is an issue. Hence, a range of information cost $[\underline{c}, \bar{c}]$ exists such that $p^*(c) \geq p^{**}(c)$ and $p_r^*(c) < p_r^{**}(c)$ for all $c \in [\underline{c}, \bar{c}]$. This implies that for $c \in [\underline{c}, \bar{c}]$, bidder 1 acquires information with positive probability in the English auction if, and only if, he anticipates the feeling of regret. Moreover, if the feeling of regret is anticipated, bidders who remain uninformed drop out of the auction before the price reaches their expected valuation. Hence, with the appropriate definition of the regret function $r(\cdot)$, a theory of regret accounts for the observed high rates of information acquisition as described in Result 1, and the underbidding effect of the uninformed bidders as described in Result 5.

Assuming bidders' regret also explains Result 3. Due to $p_r^*(c) < p^*(c)$, we should observe earlier information acquisition dates in the English auction. This would explain why bidders buy information prematurely.

It remains to be argued why subjects acquire information if more than one competitor is left in the auction. One possible explanation is as follows: suppose the regret concerns are of such a high magnitude that $p_r^{**}(c)$ is close to 100. In this case, to avoid regret the bidder would surely acquire information at some point in the auction once the price reaches $p_r^*(c)$. Hence, bidders are indifferent about acquiring information right away, or after all but one competitor has dropped out. In the experiment, the valuations of the other bidders were drawn from a discrete distribution. Therefore, all remaining competitors could drop out at the same price with positive probability. In this case, the bidder strictly prefers to buy information as soon as the price reaches $p_r^*(c)$ even if more than one competitor is left in the auction.

Estimation of the regret function. If we assume a linear form

$$r(x) := \begin{cases} \alpha x & \text{if } x < 0, \\ 0 & \text{otherwise,} \end{cases}$$

we can use the experimental data to estimate the regret function.[31] Solving equation (7) for $N = 4$ with valuations uniformly distributed on $[0, 100]$ yields

$$b^* = \frac{\sqrt{1+\alpha} - 1}{\alpha} 100. \tag{4}$$

The results of our experiment for the high-cost treatment of the second-price auction suggest that the average bid amounts to 40.6 if the bidder remains uninformed. Solving equation (4) with $b^* = 40.6$ for α yields $\alpha = 1.25$.[32] The regret coefficient in our experiment is therefore in line with previous results on regret in auctions. For example, Filiz-Ozbay and Ozbay (2007) found a regret coefficient of 1.23 and Engelbrecht-Wiggans and Katok (2008) found a regret coefficient of 0.623.

[31] A formal definition for the utility function of a regret-averse subject can be found in Appendix B.

[32] We cannot use the data from the English auction for a precise estimation of the regret parameter. This is due to the fact that the estimated average bid in the English auction is merely the lower boundary of the actual bid. However, we can estimate the upper boundary of the regret coefficient which amounts to $\alpha = 1.97$.

6.2. **Risk aversion.** Risk-averse subjects dislike zero mean risks. Thus, loosely speaking, if a risk-averse subject is faced with two lotteries with the same expectation, he prefers the lottery with less variance. It follows that to reduce variance, risk-averse bidders optimally shade their bids below $E[v_1]$ if they remain uninformed. This is consistent with our observations. However, the willingness of a risk-averse bidder to pay for information is less than the willingness to pay of a risk-neutral bidder. To see this, recall that a risk-neutral subject's maximum willingness to pay for information is defined such that the expected value of the lottery of becoming informed and participating in the auction minus the information cost, is equal to the expected utility of the lottery of bidding uninformed. However, the former lottery is more dispersed, and one can show that it is more volatile. Thus, a risk-averse bidder would strictly prefer the latter lottery.[33] Risk-averse subjects consequently prefer not to buy information, and thus risk-aversion fails to explain the observed excessive information acquisition by the subjects in our experiment.

6.3. **Ambiguity aversion.** Our setting does not involve true ambiguity, as the probabilities of all events in the experiment can be calculated from the information given to the subjects. However, some authors have claimed that ambiguity can also arise if the distribution of the probabilities of the relevant events is convoluted and subjects cannot fully access these probabilities.[34] In the setting at hand, this implies that the valuation of the subjects is ambiguous when they are faced with the decision as to whether to acquire information. An ambiguity-averse subject then places higher probabilities on events that are unfavorable for him, i.e., on lower valuations. This implies that the subject expects to place lower bids and receive smaller profits from participating in the auction. However, this diminishes the incentive to acquire information and fully participate in the auction. Thus, ambiguity aversion fails to explain the observed excessive information acquisition by the subjects.

7. Conclusion

We used a risk-neutral expected profit maximization model for auctions with the opportunity for information acquisition and designed the first laboratory experiment to study information acquisition strategies and bidding behavior in such auctions. We found excessive information acquisition in two different formats: the second-price sealed-bid, and the English auction. Moreover, bidders who remained uninformed bid significantly below the optimal bid. Nevertheless, the general predictions concerning revenue and efficiency remain

[33] A more formal argument can be found in Appendix D.

[34] See, e.g., Salo and Weber (1995).

valid, as higher information acquisition costs led to lower revenues and lower efficiency rates.

Our results indicate that for an auction designer who is concerned about revenues, the cost of information acquisition is something to worry about, albeit to a lesser degree than theory would suggest. This is due to the fact that with a high information acquisition cost , the subjects overinvested in information and increased revenues. Moreover, our results suggest that the auction designer should be indifferent to English or second-price auctions. However, this could easily change with a different number of uninformed bidders, as the difference in information acquisition frequencies then has a higher impact on revenue.

If the auction designer is concerned about efficiency, the cost of information acquisition should be a consideration. Even though the allocative efficiency was better than theoretically predicted, the over-investment in information significantly hurt efficiency to a high extent. Our results suggest that the English auction is a slightly better choice when it comes to efficiency: with a low information acquisition cost, there is a significantly higher allocative efficiency, whereas with a high information acquisition cost, the subjects invest significantly less in inefficiently costly information.

Overall, bidders' willingness to pay for information is surprisingly high. Hence, an auction designer who controls the information (for example, through due diligence fees) can price information aggressively.

References

Bergemann, D., X. Shi, and J. Välimäki (2009): "Information acquisition in interdependent value auctions," *Journal of the European Economic Association*, 7(1), 61–89.

Compte, O., and P. Jehiel (2000): "On the virtues of the ascending price auction: New insights in the private value setting," *mimeo*.

——— (2007): "Auctions and information acquisition: Sealed bid or dynamic formats?," *RAND Journal of Economics*, 38(2), 355–372.

Cooper, D. J., and H. Fang (2008): "Understanding overbidding in second price auctions: An experimental study," *Economic Journal*, 118(532), 1572–1595.

Davis, A., E. Katok, and A. Kwasnica (2011): "Why sellers should prefer sequential mechanisms," *mimeo*.

Engelbrecht-Wiggans, R. (1988): "On a possible benefit to bid takers from using multi-stage auctions," *Management Science*, 34(9), 1109–1120.

——— (1989): "The effect of regret on optimal bidding in auctions," *Management Science*, 35(6), 685–692.

Engelbrecht-Wiggans, R., and E. Katok (2007): "Regret in auctions: Theory and evidence," *Economic Theory*, (33), 81–101.

Engelbrecht-Wiggans, R., and E. Katok (2008): "Regret and feedback information in first-price sealed-bid auctions," *Management Science*, 54(4), 808–819.

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

Fischbacher, U. (2007): "z-Tree: Zurich toolbox for ready-made economic experiments," *Experimental Economics*, 10(2), 171–178.

Garratt, R., M. Walker, and J. Wooders (2012): "Behavior in second-price auctions by highly experienced eBay buyers and sellers," *Experimental Economics*, 15(1), 44–57.

Greiner, B. (2004): "An online recruitment system for economic experiments," in *Volker Macho, Kurt Kremer (Ed.), Forschung und wissenschaftliches Rechnen 2003, GWDG Bericht 63. Ges. für Wiss. Datenverarbeitung, Göttingen, Germany*, no. 13513, pp. 79–93.

Gretschko, V., and A. Wambach (2014): "Information acquisition during a descending auction," *Economic Theory*, 50(2), 79–85.

Guzman, R., and C. Kolstad (1997): "Auction equilibrium with costly information acquisition," *Working Paper*.

Hausch, D. B., and L. Li (1993): "A common value auction model with endogenous entry and information acquisition," *Economic Theory*, 3(2), 315–334.

Hernando-Veciana, A. (2009): "Information acquisition in auctions: Sealed bids vs. open bids," *Games and Economic Behavior*, 65(2), 372–405.

Kagel, J., and D. Levin (1993): "Independent private value auctions: Bidder behaviour in first-, second-and third-price auctions with varying numbers of bidders," *Economic Journal*, 103(419), 868–879.

Lee, T. (1985): "Competition and information acquisition in first price auctions," *Economics Letters*, 18(2), 129–132.

Levin, D., J. H. Kagel, and J.-F. Richard (1996): "Revenue effects and information processing in English common value auctions," *American Economic Review*, 86(3), 442–460.

Matthews, S. (1984): "Information acquisition in discriminatory auctions," *Bayesian Models in Economic Theory*, 5, 181–207.

Parkes, D. (2005): "Auction design with costly preference elicitation," *Annals of Mathematics and Artificial Intelligence*, 44(3), 269–302.

Persico, N. (2000): "Information acquisition in auctions," *Econometrica*, 68(1), 135–148.

Rasmusen, E. (2006): "Strategic implications of uncertainty over one's own private value in auctions," *BE Journal of Theoretical Economics*, 6(1), 1–21.

Rezende, L. (2005): "Mid-auction information acquisition," *mimeo*.

Salo, A. A., and M. Weber (1995): "Ambiguity Aversion in First-Price Sealed-Bid Auctions," *Journal of Risk and Uncertainty*, 11, 123–137.

Shi, X. (2012): "Optimal auctions with information acquisition," *Games and Economic Behavior*, 74(2), 666–686.

Appendix A. Valuations

Table 12 provides an overview of the valuations of the bots, and the subjects that were drawn for the experiment.

Table 12. Valuations during the experiment.

Round	**Bot 1**	**Bot 2**	**Bot 3**	**Player**
1	73	83	92	81
2	54	34	76	74
3	87	51	89	89
4	54	55	4	99
5	56	43	45	43
6	39	18	18	12
7	32	69	23	91
8	21	24	3	80
9	19	18	68	25
10	30	79	34	87
11	96	15	26	71
12	95	78	81	60
13	0	40	2	69
14	87	77	55	56
15	23	2	33	53
16	77	14	80	11
17	29	63	60	77
18	81	32	27	27
19	9	23	56	90
20	9	49	90	84

Appendix B. Formal treatment of fact 3

Taking into consideration winner's regret, bidder i's utility function in the second-price auction can be expressed using the following formulation:

$$u_i(v_i, b^{(1)}) := \begin{cases} v_i - b^{(1)} & \text{if } v_i \geq b^{(1)} \text{ and } i \text{ wins,} \\ v_i - b^{(1)} - r(b^{(1)} - v_i) & \text{if } v_i < b^{(1)} \text{ and } i \text{ wins,} \\ 0 & \text{if } i \text{ loses,} \end{cases} \tag{5}$$

where $b^{(1)}$ is the highest bid of the competitors and $r(\cdot) : \mathbb{R} \to \mathbb{R}_+$is the regret function, which is assumed to be non-negative and non-decreasing. For the informed bidders, it is a weakly dominant strategy to bid their valuation. Hence, those bidders never experience regret. If the uninformed bidder remains uninformed, his best reply b^* to the bidding strategies of the informed bidders is the solution to[35]

$$(6) \qquad \max_b \int_0^b \int_0^1 (v_1 - v^{(1)}) - \chi_{\{v_1 \le v^{(1)}\}}(v_1) r(v^{(1)} - v_1) dF(v_1) dF^{N-1}(v^{(1)}).$$

The first-order condition for this problem amounts to

$$(7) \quad \left(\int_0^{b^*} (v_1 - b^*) - r(b^* - v_1) dF(v_1) + \int_{b^*}^1 (v_1 - b^*) dF(v_1) \right) (N-1) f(b^*) F^{N-2}(b^*) = 0.$$

If r is strictly positive on a subset of $[0, 50]$ with Lebesgue measure larger than 0, it directly follows that $b^* < E[v_1]$ and that

$$(8) \quad \int_0^{b^*} \int_0^1 (v_1 - v^{(1)}) - \chi_{\{v_1 \le v^{(1)}\}} r(v^{(1)} - v_1) dF(v_1) dF^{N-1}(v^{(1)}) \le E\left[\max\left\{ E[v_1], v^{(1)} \right\} - v^{(1)} \right].$$

If bidder 1 acquires information, he bids his valuation and his bid is ex-post optimal, which means he does not experience regret. Hence, he acquires information before the auction starts if the expected utility of acquiring information is higher than the expected utility of remaining uninformed:

$$(9) \quad E\left[\max\{v_1, v^{(1)}\} - v^{(1)} \right] - c \ge \int_0^{b^*} \int_0^1 (v_1 - v^{(1)}) - \chi_{\{v_1 \le v^{(1)}\}} r(v^{(1)} - v_1) dF(v_1) dF^{N-1}(v^{(1)}).$$

Comparing inequation (9) and (1) using inequality (8) yields the result.

Appendix C. Formal treatment of fact 4

Taking into consideration winner's regret, bidder i's utility function in the English auction can be expressed using the following formulation:

[35] $\chi_M(\cdot)$ denotes the indicator function with $\chi_M(x) = 1$ if $x \in M$ and $\chi_M(x) = 0$ otherwise.

$$u_i(v_i, b^{(1)}) := \begin{cases} v_i - p & \text{if } v_i \geq b^{(1)} \text{ and } i \text{ wins,} \\ v_i - p - r(p - v_i) & \text{if } v_i < b^{(1)} \text{ and } i \text{ wins,} \\ 0 & \text{if } i \text{ loses,} \end{cases} \tag{10}$$

where p is the price at which the last competitor left the auction and $r(\cdot) : \mathbb{R} \to \mathbb{R}_+$is the regret function as defined above. As before, for bidders who are informed about their valuation v_i, it is a weakly dominant strategy to drop out whenever $p = v_i$. Hence, those bidders never experience regret.

With the same argument as in Section 2, it remains weakly dominant for the uninformed bidder to consider information acquisition if and only if one competitor is left in the auction. If bidder 1 remains uniformed, his optimal drop out point $b^* < E[v_1]$ is the solution to problem (6) and is given by equation (7). We proceed in the same manner as in Section 2. To formalize the trade-off between the cost of information acquisition, the probability of winning, and the risk of buying at an unfavorable price, we define the following:

$$H_r(p, c) := E[\max\{v_1, v_2\} - v_2 | v_2 \geq p] - c,$$
$$K_r(p) := \int_0^{b^*} \int_0^1 (v_1 - v_2) - \chi_{\{v_1 \leq v_2\}} r(v_2 - v_1) dF(v_1) dF(v_2 | v_2 \geq p),$$

$$p_r^{**}(c) := \sup\{p \in [0, 1] | H_r(p, c) \geq K_r(p)\}, \text{ and} \tag{11}$$

$$p_r^*(c) := \inf\{p \in [0, 1] | E[\max(p, v_1) - v_1 + r(\max(p, v_1) - v_1)] - c \geq 0\}. \tag{12}$$

Therein v_2 denotes the valuation of the last remaining competitor. Comparing equations (11) and (12) to equation (2) and (3) using inequality (8) yields the result.

Appendix D. Formal treatment of risk aversion

Suppose bidder 1 is risk averse with a concave utility function $u(x)$. We start by showing that if bidder 1 decides not to buy information, his bid in a second-price auction b^* will be lower than $E[v_1]$. To see this, consider the maximization problem of bidder 1 once he decided not to buy information:

$$\max_b \int_0^b \int_0^{100} u(v_1 - v^{(1)}) dv_1 dv^{(1)}.$$

The first-order condition for this problem is:

$$\int_0^{100} u(v_1 - b^*)dv_1 = Eu(v_1 - b^*) = 0.$$

Within the parameters of the experiment, it holds that $E(v_1 - 50) = 0$. By the definition of risk aversion, all risk-averse individuals dislike zero-mean risks. Hence, $Eu(v_1 - 50) \leq 0$ and therefore $b^* < 50$.

Given the equilibrium behavior of the informed bidders and the choice of b^*, the decision as to whether to buy information or not is the choice between two random variables $\tilde{x} - c$ and $\tilde{y}$. If bidder 1 decides to buy information, his pay off is:

$$\tilde{x} - c = \max(v_1 - v^{(1)}, 0) - c.$$

If bidder 1 decides not to acquire information, the pay-off is:[36]

$$\tilde{y} = \chi_{\{v^{(1)} \leq b^*\}}(v_1 - v^{(1)}).$$

The highest c^* for which a risk-neutral bidder would acquire information is defined by $c^* = E[\tilde{x}] - E[\tilde{y}]$. To demonstrate that risk-averse bidders may refrain from information acquisition in situations where a risk-neutral bidder would have acquired information, we show that $E[u(\tilde{x} - c^*)] - E[u(\tilde{y})] \leq 0$.

Define $\tilde{x}_0 := \tilde{x} - E[\tilde{x}]$, $\tilde{y}_0 := \tilde{y} - E[\tilde{y}]$ and denote by $\pi(\omega, u, \tilde{x}_0)$ the risk premium of $\tilde{x}_0$ at a wealth level of ω. It follows:

$$\begin{aligned}
& E[u(\tilde{x} - c^*)] - E[u(\tilde{y})] \leq 0 \\
\Leftrightarrow & E[u(\tilde{x} - E[\tilde{x}] + E[\tilde{y}])] - E[u(\tilde{y})] \leq 0 \\
\Leftrightarrow & E[u(\tilde{x_0} + E[\tilde{y}])] - E[u(\tilde{y})] \leq 0 \\
\Leftrightarrow & E[u(E[\tilde{y}] - \pi(E[\tilde{y}], u, \tilde{x}_0))] - E[u(E[\tilde{y}] - \pi(E[\tilde{y}], u, \tilde{y}_0))] \leq 0 \\
\Leftrightarrow & \pi(E[\tilde{y}], u, \tilde{x}_0)) \geq \pi(E[\tilde{y}], u, \tilde{y}_0). \qquad (13)
\end{aligned}$$

For small risks, we can use the Arrow-Pratt approximation. Hence, inequality (13) holds true whenever $\mathrm{Var}[\tilde{y}_0] \leq \mathrm{Var}[\tilde{x}_0]$. For the parametrization of the experiment, we get $\mathrm{Var}[\tilde{y}_0] \leq 1.354$ and $\mathrm{Var}[\tilde{x}_0] = 1.6$ whenever $b^* < 50$. We can conclude that risk-averse bidders have a smaller willingness to pay for information than risk-neutral bidders in a second-price auction.

[36] χ denotes the indicator function.

Appendix E. Instructions

Welcome and thank you for participating in today's experiment. Please read the following instructions thoroughly. These are the same for all participants. Please do not hesitate to ask if you have any questions. However, we ask you to raise your hand and wait for us to come and assist you. We also ask that you refrain from communicating with the other participants from now on until the end of the experiment. Please ensure that your mobile phone is switched off. Violating these rules can result in your expulsion from this experiment. You will be able to earn money during this experiment. The amount of your payout depends on your decisions. Each participant will receive his payout individually in cash at the end of the experiment. You will receive 2.50 EUR for participating as well as payouts from each round. Potential losses at the end of the experiment will be deducted from the participation fee (if you accumulated losses on top of that, you will be required to pay these in cash at the end of the experiment). During the experiment payouts will be stated in the currency "ECU" (Experimental Currency Unit). 10 ECU are equivalent to 1 Euro (10 ECU = 1 EUR). The experiment consists of 20 payout relevant rounds.

Course of a Round (Treatment: 2nd Price Auction). During this experiment you will take part in an auction of a fictional product. You will be bidding in a group of four with three other participants. These three participants are pre-programmed bid robots. Their exact functioning will be described in more detail in the following.

Information prior to the Auction: The fictional product has a different value for each bidder. Therefore prior to each round a valuation is determined for each participant. This valuation is between 0 and 100 ECU and each number has the same probability. However, during this auction you will not have any initial information about your valuation. Nevertheless, at the cost of 2 ECU/ 8ECU, you can acquire knowledge as to your exact valuation at any time. In contrast, the bid robots know their exact valuation of the fictional product. Their valuation, just as your own valuation, is between 0 and 100 ECU and each number has the same probability. The three bid robots will always have different valuations.

Profits and Losses during the Auction: All bidders simultaneously make an offer for the fictional product. The bidder with the highest offer wins the auction. The price for the fictional product is set at the amount of the second highest bid. The winner of the auction has to pay this price for the product. If multiple bidders make the same offer during the round, then the winner is randomly determined. (Please note: You will not be able to revoke an offer or buy any information, once an offer has been submitted.) The payout for the winner of an auction is calculated from his previous, randomly determined product valuation minus the price at the end of the auction. (Please note: You will incur a loss if your offer is higher than your valuation of the product. Losses at the end of the experiment will be deducted from the participation fee. However, if you accumulate losses on top of that, you will be required to pay these in cash at the end of the experiment.) Additionally, if you have bought information at the cost of 2 ECU/ 8 ECU, then this amount will be deducted from your profit, or entered as a loss.

Feedback after an Auction Round: At the end of an auction round you will be informed, as to whether you won the fictional product with your bid. Additionally, you will be informed as to the second highest bid, and therefore the price of the fictional product as well as your individual profit for this round.

Course of a Round (Treatment: English Auction). During this experiment, you will take part in an auction of a fictional product. You will be bidding in a group of four, with three other participants. These three participants are pre-programmed bid robots. Their exact functioning is described in more detail in the following.

Information Prior to the Auction: The fictional product has a different value for each bidder. Therefore, prior to each round, the valuation is determined for each participant. This valuation is between 0 and 100 ECU, and each number has the same probability. However, during this auction you do not initially have any information about your valuation. Nevertheless, at the cost of 2 ECU/ 8ECU you can acquire knowledge of your exact valuation at any time. In contrast, the bid robots know their exact valuation of the fictional product. Their valuation, just as your own valuation, is between 0 and 100 ECU and each number has the same probability. The three bid robots will always have different valuations.

Profits and Losses during the Auction: The auction begins at 0 ECU for the fictional product. The bid will increase every 2 seconds by 1 ECU. A price clock indicates the current bid in ECU during the auction. You will also be able to see at any time how many bidders are still active and you will be able to buy information on your exact valuation. You can pause the price clock as you wish by clicking the button "Pause/ Continue". All participants automatically continue bidding until they leave the auction round by clicking the button "Quit" on their screen. The auction ends automatically once only one bidder is left active. The last active bidder wins the auction and has to pay the last price on the price-clock, i.e. the price when the second to last bidder dropped out. If multiple bidders quit simultaneously, then the winner of the round is randomly determined. The payout for the winner of an auction is calculated from his previous, randomly determined valuation of the good minus the price at the end of the auction. (Please note: You will incur a loss if your offer is higher than your valuation of the product. Losses at the end of the experiment will be deducted from the participation fee. However, if you accumulate losses on top of that, you will be required to pay these in cash at the end of the experiment.) Additionally, if you have bought information at the cost of 2 ECU/ 8 ECU, then this amount will be deducted from your profit, or entered as a loss.

Feedback after each Auction Round: At the end of an auction round you will be informed, as to whether you won the fictional product with your bid. Additionally, you will be informed as to the second highest bid, and therefore the price of the fictional product as well as your individual profit for this round.

End of Experiment. All auction rounds in this experiment are payout relevant. After completion of all 20 auction rounds, your payouts for each round as well as your overall result will be presented to you in a summary on your screen. After that we will ask you fill out a short questionnaire concerning the experiment. Please raise your hand if you have any further questions.

University of Cologne, Albertus Magnus Platz, 50923 Cologne, Germany
E-mail address: gretschko@wiso.uni-koeln.de