

Excess information acquisition in auctions

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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.

Keywords Dynamic auctions · Information acquisition · Bidding behavior

JEL classification C91 · D44 · D80

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 one's valuation. If the cost of information is high, bidders may prefer to place bids based on partial information.

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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 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 one's 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

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 et al. (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, 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.

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

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, 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.

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.

2.1 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

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

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 $c^e = E[\max\{v_1, v^{(1)}\} - v^{(1)}] - E[\max\{E[v_1], v^{(1)}\} - v^{(1)}]$ exists such that bidder 1 acquires information if $c \leq c^e$. He refrains from information acquisition whenever $c > c^e$. If bidder 1 remains uninformed in the second-price auction, he bids his expected valuation.

2.2 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

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

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

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

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

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

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

$p^{**}(c)$ 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 Fig. 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-

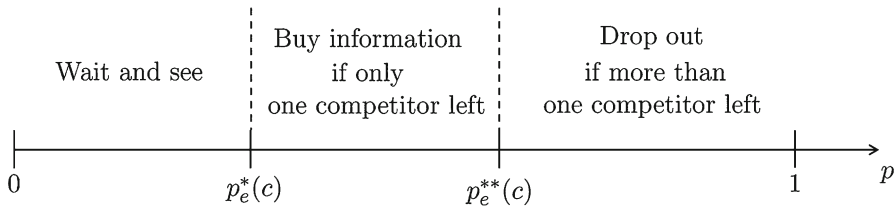


Fig. 1 Structure of the information acquisition and drop out decisions of the uninformed bidder

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.

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 one's 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

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.

⁹ ECU is the Experimental Currency Unit. 10 ECU are equivalent to 1 Euro (10 ECU = 1 EUR).

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

3.1 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:

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 et al. 1996).

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 $E[v_1] = 50$.

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

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 of Electronic Supplementary Material) to calculate the prediction in Table 2.

¹⁴ T-test: p -value < 0.0001 .

Table 1 Predictions for information acquisition in the English auction

Treatment	Information acquisition		Bidding	
	$p^*(c)$	$p^{**}(c)$	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

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,

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.

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 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 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 et al. (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 the difference in the experimental designs. In contrast to Kagel and Levin (1993) and Garratt et al. (2012) sensitized their subjects to possible losses in the second-price auction. This was also the case in our design (see Appendix E of Electronic Supplementary Material). 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.

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.

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

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

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.

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

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

In Sect. 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.

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

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

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

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 Sect. 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.

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

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)

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.

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.

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

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

²⁵ Mann–Whitney test: p -value < 0.01 .

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 .

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

acquisition strategy in 266 out of a possible 2,280 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.

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.

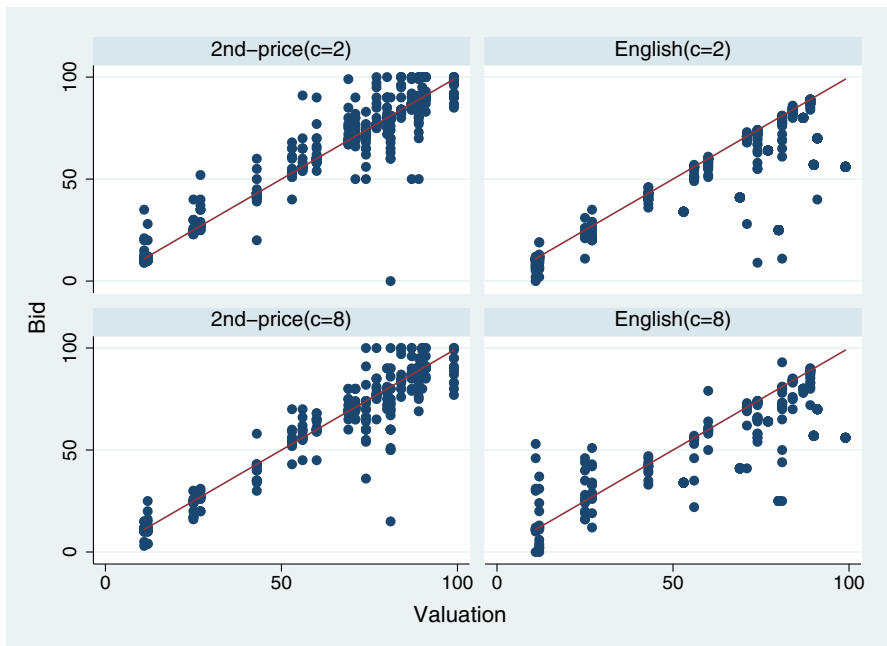
We start our analysis with a fixed-effects regression for the second-price auction (Table 9). Model 1 shows that information acquisition is the main influence on the bids. In comparison, the valuation has significant but much smaller effect. Also, the impact of the auction round is marginal. Hence, we 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

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

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*** (0.098)	1.72*** (0.117)
High cost	−0.97*** (0.084)	−1.58*** (0.099)
Auction rounds (1–20)	0.01 (0.007)	−0.01 (0.008)
<i>N</i> observations	1,200	1,200
Pseudo R^2	0.10	0.23

**Fig. 2** Observed bidding of informed subjects

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). 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 Sect. 2. The main deviations from the predictions were that bidders acquired more

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*** (2.048)	−6.34*** (2.091)
Information acquisition	22.99*** (1.762)	22.96*** (1.769)
Valuation player	0.705*** (0.018)	0.705*** (0.018)
Auction_rounds (1–20)	0.237*** (0.082)	0.234*** (0.084)
Number of switches in IA strategy		−0.305 (1.796)
<i>N</i> observations	1,200	1,200
ρ	0.405	0.404
σ_μ	13.281	13.278
<i>n</i> clusters	60	60

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

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 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

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.

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.

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 (2.711)	−3.288 (2.734)	−2.648 (2.778)
Information acquisition	17.876*** (1.749)	17.509*** (1.956)	17.054*** (1.983)
Valuation player	0.772*** (0.021)	0.723*** (0.021)	0.723*** (0.021)
Auction_rounds (1–20)	0.187* (0.098)	0.186* (0.098)	0.182* (0.098)
Price clock at information acquisition		0.028 (0.068)	0.105 (0.639)
Number of switches in IA strategy			−2.569** (1.954)
<i>N</i> observations	1,200	1,200	1,200
ρ	0.303	0.302	0.304
σ_μ	11.272	11.240	11.279
<i>n</i> clusters	60	60	60

Table 11 Predictions of alternative models

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

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

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).

6.1.1 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 of Electronic Supplementary Material.

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, 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.

6.1.2 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 of Electronic Supplementary Material.

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 Eqs. (11) and (12) of Electronic Supplementary Material 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 Fig. 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 $p^*(c) \geq p_r^{**}(c)$ 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.

6.1.3 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 Eq. (7) of Electronic Supplementary Material for $N = 4$ with valuations uniformly distributed on $[0, 100]$ yields

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

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

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 Eq. (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.

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

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 $\alpha = 1.97$.

³³ A more formal argument can be found in Appendix D of Electronic Supplementary Material.

³⁴ See, e.g., Salo and Weber (1995).

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 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.

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