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Abstract

In any market, the amount of feedback provided to its participants is one of the most important design choices. In the last couple of decades, several studies on feedback information in games and its role in learning have been conducted. Some of the most notable ones are the results in learning direction theory (Selten & Stoecker, 1986), impulse balance theory (Ockenfels & Selten, 2005), and the findings by Weber (2003). All these approaches have been validated experimentally in single-unit first price auctions (e.g. Dufwenberg & Gneezy, 2002). As the focus of previous studies has been on this specific type of auction, there is little research on information feedback in multi-unit or divisible good auctions. A natural extension to the current literature is to examine the effect of auction round feedback in the latter auction formats. We contribute to this field of research by conducting such a feedback information experiment with an energy market framing. Sellers are endowed with a portfolio of various quantities at different costs. The auctioneer is a single buyer who needs to procure a fixed quantity. We investigate two treatment variables: the strength of competition and, more importantly, the amount of information provided. With regard to previous findings from single-unit first price auctions, we can confirm the influence of feedback on learning and the change in bidder behavior for the divisible good auction case. However, the impact of the competitive situation was generally stronger than the feedback effect. Also, we observe significant differences for socio-demographic factors such as gender and educational background.

Keywords: feedback information, divisible good auction, laboratory experiment, reserve energy market

JEL Classification: C91, D03, D44, D83

1 Introduction

To date, research on feedback has mainly focused on general learning theories and theories applied to first-price auctions. Feedback, i.e. information on the results of individual behavior, is the crucial factor that enables learning and fosters convergence to the theoretically predicted (equilibrium) behavior. In a market environment, this means that determining the amount of information provision is an important design variable. However, many real-world markets are not set-up as first-price auctions, but rather as multi-unit or divisible good auctions. In order to be able to use theoretical and experimental results from existing approaches on learning behavior in these important markets, with goods such as treasury bonds or energy, it is crucial to verify their applicability to the relevant auction types.

In the context of energy markets, this notion is especially distinguished. In recent years, energy markets have been challenged by the introduction of fluctuating renewable energy sources. While technically motivated research has already found some technology-based solutions, to date they are still too expensive for a large-scale roll-out. For a possibly preferable market-based solution, critical adjustments to accommodate rapidly changing supply situations are missing. Recently, capacity markets have been suggested as a way to improve the situation in wholesale markets. Their introduction involves many risks and uncertainties, especially as some design ideas are irreversible after implementation. The associated difficulties encompass the adequate determination of the necessary amount of capacity, the technologies to be supported, as well as the timing and details of the implementation process itself. Considering the relatively high financial burden the German electricity consumers have to bear due to the costs the renewable energy levy (amounting to more than €28 bn in 2013), it does not seem reasonable to introduce a new monetary constraint. A less extreme solution that serves similar goals could be more favorable. To this end we have developed a market mechanism for a local reserve energy market, where private households, thus small prosumers, can trade their self-produced energy. The central administrator of such a market is the balance group responsible party (BGRP), i.e., for example, a utility or an energy service company. The already existing institution of the BGRP is empowered and can take over a variety of new tasks, while using its experience of procuring compensation energy for system losses.

A local reserve energy market has several advantages. Beyond being a tool to enhance customer relationships and giving home-owners a platform where they can put their self-produced energy to use, it helps integrating renewable energy sources extensively. Furthermore, it offers a market-based incentive scheme that can replace the currently installed guaranteed feed-in tariff scheme in Germany. In doing so, the installation of new generation units slows down when the market has sufficient supply and competition depresses profits, while installations are triggered by high profits in times of short supply and competition. The mechanism, thus, offers flexible adjustment to market conditions. Due to its expected size, deciding about the right amount of information that is provided to market participants is even more essential. As shown in an agent-based simulation (Rosen & Madlener, 2013a), this can have long-term effects on the market outcome. Building upon these results and in order to validate them, we now examine the reserve energy market, i.e. a divisible good auction, experimentally. In our computerized laboratory, human bidders can interact with each other and thereby experience market dynamics. The goal of our current research is to find out how feedback information impacts this process. To this end, we analyze four treatments differing in the amount of information provided and the competitive strength of the market, i.e. the number of market participants. It has been framed as a local reserve energy market, where sellers submit offers to a single buyer. We expect similar results as shown in our simulation study from the experiment.

To our knowledge, information has so far not been studied as a treatment variable in divisible good auctions. In the context of electricity auctions, its role in policy decisions has been established theoretically by Ray & Cashman (1999). With this study we contribute to the literature on divisible good auctions and procurement auctions, while examining a topic of practical relevance for the transformation of the energy system.

We proceed as follows: Section 2 gives an overview of relevant related research. Section 3 introduces the experimental design and procedure. Section 4 presents the results obtained, which are further discussed in Section 5. Section 6 evaluates the questionnaire, while Section 7 concludes.

2 Related work

As already mentioned, we have analyzed the short and long-term influences of information in several degrees or aggregation types in an agent-based simulation (Rosen & Madlener, 2013a). The result is that with very detailed information, the equilibrium market price is lowest and reached very early. When no information on the behavior of other bidders is provided, but only feedback on the individual success, the convergence process takes more than twice the time and the equilibrium market price remains on a higher level indefinitely. We will later see whether this holds in an experimental setting with human bidders as well. First, we will examine what role information has played in other experiments to gain a deeper understanding of the topic in general.

Nikiforakis (2010) conducts an experiment in the context of public goods. In each treatment he provides the same information in a different format. First, he only shows the contributions of each individual, then the earnings of each individual (with equal endowments being the endowment less the contribution plus the share of the public good) and then both the contributions and the earnings. He finds that the information format has an influence on the behavior of individuals. When earnings are displayed, participants tend to punish peers more harshly.

Danz et al. (2012) examine a two-player game under varying extents of information provision. In the baseline treatment they give full information, whereas in the other two treatments information either on previous performance or on the opponent's payoff is withheld. They find that a lack of either kind of information leads to less strategic behavior. Furthermore, performance-related feedback is essential for learning during the course of the experiment and also enhances strategic behavior over time.

Weber (2003) challenges common learning theories and claims that learning also takes place when no feedback is provided. He proves this idea in an experiment of a repeated game with and without priming. Primes are meant to induce participants to think about strategic aspects of the game. Convergence to equilibrium outcomes can be observed in all treatments, which means that learning takes place in all cases. It is, of course, most distinctive in the control treatment with feedback, but shows the same direction in all other treatments. Priming did not have an unambiguous effect in the sense that stronger priming would lead to faster learning.

The main relevance of feedback is explained by its impact on learning processes that can ultimately drive individual behavior in a specific direction. In addition to, or as a result from, experiments, several theories have been developed that try to explain the behavioral pattern both qualitatively and quantitatively. Learning processes in auctions and other games have been analyzed theoretically and experimentally. For auctions, the main research subject has been single-unit first-price auctions.

Ockenfels & Selten (2005) find that in repeated sealed-bid first-price auctions bids are lower when feedback on losing bids is given compared to situations where it is not provided. They are able to explain the bidding pattern with their impulse balance theory, which states that bids are a reaction to impulses experienced from the feedback. The lower bid curves are a result of the different weights attached to downward and upward impulses.

Dufwenberg & Gneezy (2002) conduct an experiment on competition in first-price procurement auctions. This auction is repeated 10 times and offers a different amount of information for each treatment. They have a full information feedback, a semi-full information feedback, and a no information feedback treatment. In the first treatment, bidders were informed about all bids that had been submitted, in the second only about the winning bids and in the third only about their own payoff. They find that when all (winning and losing) bids are announced, bids remain on a much higher level than is predicted by theory. In the other two treatments, bids converged to the theoretical prediction. The authors explain this with signaling, which only makes sense when it can be observed by other bidders. This kind of observation is merely possible in the full information treatment. In comparison to an earlier publication (Dufwenberg & Gneezy, 2000), the authors also find that with three and four competitors, bids always approach the Nash equilibrium.

Isaac & Walker (1985) consider a discriminative sealed-bid auction where bidders have unit demand. They implement a full information and a limited information treatment, where the full information treatment displays all submitted bids including the identification number of the bidder. In the limited information feedback, bidders only obtain the winning bid with the identification number. Prices in the limited information treatment are greater than those in the full information treatment, but efficiency is not affected. Also, all prices are higher than predicted in equilibrium for risk-neutral bidders.

Engelbrecht-Wiggans & Katok (2008) differentiate between two types of regret that can be observed in a first-price sealed-bid auction. When a bidder wins an auction and learns that the second highest bid was substantially lower, he can suffer from "money-left-on-the-table" regret, because he has paid too much for the item. On the other hand, if he does not win, but learns that the highest bid was still smaller than his valuation, he can suffer from "missed-opportunity-to-win" regret. They show that in case of the first type of regret, bids decrease when the second highest bids are displayed. For the second type of regret, bids increase when winning bids are displayed.

Neugebauer & Selten (2006) perform an experiment on the effect of information in a first-price sealed-bid auction with single demand. They find that information feedback in the form of achieved prices leads to overbidding in first-price auctions. They explain this result qualitatively with the learning direction theory and quantitatively with the impulse balance theory.

Neugebauer & Perote (2007) extend these findings and introduce a no information treatment. In contrast to all other treatments, absolutely no feedback is provided. They find that this results in average bids below the risk-neutral Nash equilibrium, while feedback leads to overbidding. They explain this with anchoring of the bidders on the published market prices.
When talking about feedback (information) in the context of auctions, one should keep in

mind that depending on the auction format, different degrees of information are per se provided to the bidders. Comparing two standard formats, the English (open cry) and the Dutch (descending clock) auction, it becomes obvious that in the former type all bidders hear all bids, whereas in the latter only the final price is called out. This means that although there is a lack of experimental studies examining the effect of feedback in multi-unit auctions, existing studies which investigate different auction formats can offer some limited insights into the learning pattern when multiple items are bought or sold at the same time.

One of the first studies of this kind is Plott & Smith (1978), who implicitly examine two kinds of information treatment due to the choice of auction design. In their open-cry auction they inform bidders only about the highest and the lowest bid of the previous round and total quantity available. In contrast, in their posted-bid market all bids from the previous (but not the current) round are known. However, the authors assume this informational difference to be minor. They establish that the open-cry design leads to overbidding, whereas the posted-offer design leads to underbidding. One should also note that bidders in their multi-unit auction have single-unit demand, whereas in the posted-offer market several units are traded at the same time.

Cox et al. (1984) investigate a discriminatory-price sealed-bid auction, where bidders each demand a single unit. They compare the auction outcome when the highest rejected bid and the highest accepted bid are displayed to the auction outcome when this information is not displayed. In both cases, they observe underbidding relative to the risk neutral Nash equilibrium. Underbidding was enhanced when information was blocked, which resulted in 60% of the bidders bidding too low, whereas when the relevant information was available, only 48% bid too low.

Kagel & Levin (2001) use computer bidders with single demand that followed the dominant strategy (i.e. bid their value). They restricted bidders to bidding the same or lower on the second unit and examine (among others) a clock auction with and without feedback, i.e. the clock pauses as soon as one of the computer rivals drops out or not. They find significant behavioral differences when feedback is missing, as bidders have better chances to adjust their behavior when information flows continuously. The clock auction without feedback, therefore, has very similar outcomes to the sealed bid auction, where intermediate information gathering is hindered.

Kagel & Levin (2005) examine the behavior of bidders in multi-unit auctions with a sealed-bid and an ascending-bid (open-cry) design. However, they used the same information feedback throughout the entire experiment, namely all bids, ranked according to price, highlighting the winning bids. Their design has one more important difference to the one at hand. As in their earlier experiment, they let computers with single-demand compete against individual human bidders with demand for multiple units. They find that bidders are closer to the predicted behavior in the open-cry design, confirming the finding of Ockenfels & Selten (2005) that feedback reduces overbidding.

Engelmann & Grimm (2009) conduct an experiment with two units and two bidders, where bidders can either observe drop-out prices or bids, depending on the auction format (open vs. sealed-bid). They implement different pricing rules, namely uniform and discriminatory pricing as well as the Ausubel and the Vickrey auction. Auctioneer's revenue is then less dependent on the pricing rule, but more on whether it is open or sealed-bid, hinting again at a behavioral impact of the implicit information provision.

Cummings et al. (2004) examine several types of auctions to determine the design best-suited for the Georgia irrigation reduction auction. The most important similarity is that it is also a procurement auction, as farmers sell their permits. A very significant difference, however, is that the buyer does not buy a prespecified amount or number of permits, but has a fixed budget. Valuation has a common and a private element and their market is much larger than ours (9 to 42 participants). To our knowledge, they are the only ones that applied an information treatment to an experiment on multi-unit auctions. However, the authors do not implement repeated bidding, but allow bidders to revise their offers upon knowledge of the competing bids. This continues until no one wants to change his offer any more or until the auctioneer chooses to terminate the auction. Cummings et al. observe that after participants receive a provisional acceptance, they often increase prices. On the other hand, when not being accepted in a round, they decrease prices again. In a couple of additional sessions with a smaller number of bidders, the experiment was repeated while not announcing the cut-off-price, but only the ID numbers of accepted permits. However, as each bidder holds three different permits, they are able to deduce the approximate cut-off-price nonetheless and game with their offers. Altogether, the different settings of the information treatment make the results not fully comparable. In this study, we want to fill this gap by creating a very reliable experimental design. It is important to note that when revision rounds are announced before the start of the auction, incentives are quite different to those in repeated bidding auctions. This means that the results from Cummings et al. (2004) cannot fully be transferred to our case either way.

3 Methodological approach

A simulation study such as Rosen & Madlener (2013a) is a good way to test a mechanism on the appropriate scale. However, such studies are always limited by the input the model is fed with and can approach human behavior only to some extent. An experiment is therefore the logical next step for validating a theoretical framework. A standard laboratory experiment with isolated variables appears to be the most suitable way. Treatments differed in the amount of information made available to the participants and the number of bidders, i.e. the competitive situation. The first treatment is meant to investigate the observation put forward by Ray & Cashman (1999) that a lower degree of information can help to foster competition in an imperfect market that might otherwise give rise to market power. The central idea hereby is that scarce information hampers collusion as well as learning over several rounds. This means that equilibrium, if at all, can only be reached in a later stage. Rosen & Madlener (2013a) already validated this notion using a simulation and found that the equilibrium is

Table 1: Details of studies on multi-unit or divisible good auctions

Study	**Auction format**	**Treatment**	**Value distribution**
Cox et al. (1984)	sealed-bid auction with and without information on rejected bids	discriminatory pricing	independent private values
Cummings et al. (2004)	sealed-bid auction with revision rounds	discriminatory pricing (uniform pricing only in 2 initial rounds)	independent private values
Engelmann & Grimm (2009)	open and sealed-bid	uniform pricing, discriminatory pricing, Vickrey, Ausubel	independent private values
Kagel & Levin (2001)	ascending bid clock auction with and without feedback, sealed-bid auction	uniform pricing and dynamic Vickrey auction	independent private values
Kagel & Levin (2005)	ascending bid clock auction vs. sealed-bid auction	uniform pricing	independent private values
Plott & Smith (1978)	oral and sealed-bid (posted-offer)	discriminatory pricing	independent private values

indeed reached at a later point in time and remains on a higher level forever. The second treatment manipulates the extent of competition directly and thereby allows us to estimate the relative size of the competitive impact of information.

The experiment has been programmed in z-Tree (Fischbacher, 2007). This is a common toolbox for laboratory experiments, which allows implementation of a large variety of experiments. It runs extremely reliably, but this comes at the cost of a few restrictions or rather complications on the side of possible algorithms.

3.1 Experimental design and procedure

The experiment was conducted in four sessions over two weeks in December 2012. In total, 120 subjects participated in the experiment, meaning 30 in the four treatments and sessions. The low competition session accommodated ten bidding groups of three bidders and the high competition session five bidding groups of six bidders. Bidding groups describe the competitors in one market, i.e. they comprise all sellers that bid competitively to one auctioneer. Both competition scenarios were held with and without feedback (hereafter: information and no information treatment).

The experiment took place in the AIXperiment lab at the School of Business and Economics, RWTH Aachen University. The lab is run by five Chairs of the School, which have established a database of possible candidates for experiments. This database and the recruitment in general are managed using ORSEE (Online Recruitment System for Economic Experiments), developed by Greiner (2003). It allows control over what type of participants are invited, and provides feedback on their reliability concerning show-ups. Most participants were students with either an engineering or a business studies background, or both. Each subject could only participate once.

Upon arrival, participants were asked to draw their seating number from a randomized stack. This ensured random seating, especially preventing close friends - who can be assumed to have higher incentives for and lower barriers to collaboration - from cheating. They were seated at terminals that are protected by dividers on three sides. In addition to random participant seating, the distribution of the group IDs on the terminals was also randomized, such that bidding group members would not sit close to each other. At no point in time did participants know their competitive situation or who was part of their bidding group. Print-outs of the instructions were handed out and read aloud giving ample time for questions. To ensure that everyone really understood the auction mechanism and the resulting bidding possibilities, the first four screens consisted of test questions that had to be answered individually. Only when every participant had answered all questions correctly did the experiment start. Prices and quantities for the quiz differed from the prices and quantities in the experiment with a factor of at least 20, to prevent any anchoring effect.

For the auction, participants were asked to imagine they lived in a household with typical decentralized, small-scale energy generation and storage equipment, for example photovoltaics, micro-combined heat and power, micro-wind turbines, or storage batteries. Having different technical properties, the resulting differences in cost structures are obvious. Available capacities were presented as a portfolio of three quantities at different (production) costs (see Table 2). Each first, second, and third price and quantity pair were drawn from the same distribution. For reasons of fairness, the portfolios were then constructed in a way that ensured the most similar total amount of available capacity for each bidder.

Participants could determine the amount (in kW) they wanted to offer and the price (per kW) they wanted to receive in each auction round. The amount could be freely chosen as long as it was not larger than the sum of their capacities. For any smaller amount, the function determining the profit assumed that the amount produced by the technology with the lowest costs was sold first, thereby maximizing the individual's profit. The average costs of the quantity offered were at the same time the minimum price limiting the possible bids from below. This procedure prevented losses on the side of the participants during the entire session. There was also a maximum, or reservation, price for the bids, which was set at 100

ECU (experimental currency units). Above this price, bids were not accepted by the system, i.e. participants faced an error message asking them to observe the reservation price. For the auction process, this upper limit was non-binding. If a bidder decided not to participate in an auction round, he or she could simply enter an amount of 0. The bidding groups, i.e. the competitive field, as well as individual price and quantity schedules remained fixed during all 20 identical auction rounds. Bidders had no knowledge of the portfolio of their competitors, except that it was "similar".

The auctioneer was a single buyer with fixed demand, which was not made public. It was set at 40% of the total supply, amounting to 56 units (kW) in the low competition scenario and to 112 units (kW) in the high competition scenario. In each auction round, bids were ranked according to price and accepted until the auctioneer's demand was at least fulfilled. Marginal bids were completely accepted without rationing. Being framed as a reserve market, this procedure makes sense, as it ensures some safety margins. Also, market participants are assumed to be small (household) producers with a generation capacity of up to 50 kW (cf. Rosen & Madlener, 2013a). With this lack of market power, they would, therefore, not be able to abuse the situation in a real-world setting. Details of the auction mechanism can be found in the appendix.

The information provided to the participants was always direct feedback on their bids, i.e. whether their bid had won, and the resulting profit for the current round. In the information treatment prices of all accepted bids, ranked from lowest to highest, were additionally displayed. The no information treatment did not offer such a display. Bidders were not made aware of their informational status. Nevertheless, when asked what kind of feedback to expect, participants got the true answer corresponding to the treatment they took part in.

After the laboratory experiment, participants were asked to fill out a questionnaire to evaluate whether they enjoyed participating in the auction and whether they would like to participate in such an auction also in reality. For the questionnaire we used a five-point Likert-scale on three fields of interest. The first concerns the attitudes towards the presented market and its mechanism, as well as participants' expected intentions to trade on such a market in reality. The second field covers the experiment and its procedures in more detail, including the presentation of input and output on the screen. The third block encompasses earlier experience and enjoyment of other auction markets for trading.

Participants received 10 Euros as a base pay and an additional variable pay, which was equal to their total profit, summed over all 20 auction rounds, divided by 1000, and rounded to the nearest Euro. Final payouts ranged from 15 to 22 Euros. The experiment took about 90 minutes.

3.2 Theoretical benchmark and expected results

Table 2 shows the capacity portfolio of the bidders. For the high competition scenario, each bidder type was assigned to two participants.

In a competitive market, theory predicts that prices are set at the marginal cost level. From the cost structure determined by the cumulative portfolio, we can determine the marginal cost as the cost of generators 4-6 (the medium-cost generators in the low competition scenario) and 7-12 (the medium-cost generators in the high competition scenario). This amounts to 12 ECU. In principle, both treatments should eventually reach this price level. Expectations are that it is more stable in the no information treatment, but will be reached in fewer rounds in the information treatment.

Table 2: Cost and quantity portfolios per bidder

Bidder 1		Bidder 2		Bidder 3	
Quantity	**Cost**	**Quantity**	**Cost**	**Quantity**	**Cost**
10	6	12	6	14	7
16	10	14	12	16	12
23	15	18	15	17	15

As we did not impose any rationing, bidders have an incentive to bid their total capacity. If they did not do that, bidding full truncations, i.e. the entire capacity of the generators with costs lower than the price bid, is optimal and always preferable to any other strategy. This results in two possible market-clearing solutions (I and II). In solution I, all bidders bid the capacities of their first and second generators. In solution II, all bidders bid their total capacity. Both solutions generate a relatively stable market outcome when competition is not sufficiently strong, but solution I is, of course, more efficient, as the high-cost generators are excluded. Solution II, however, offers higher expected profits for the bidders. For more details, see also the discussion in (Rosen & Madlener, 2013b). For the experiment, the information treatment should foster competition and thereby support solution I.

4 Results

The Statistics Toolbox of MATLAB offers several functions to analyze data. In order to examine the data produced by the experiment we use hypothesis tests and regression analysis. Specifically, deploying the functions provided by MATLAB we develop a program for a Kruskal-Wallis test, a Wilcoxon rank sum test and a regression analysis. These programs allow us to flexibly investigate the data obtained.

In the experiment, results show that, with no information, capacity withholding decreases. This is irrespective of the accepted capacity, or from the point of view of the seller the amount sold, but only takes into account the sum of the bid quantities.

Capacities offered in the market slightly increased over time, especially in the low competition treatment without information (see Figure 1). It should also be noted that capacity bids were generally on a higher level when no feedback was provided. Capacities in the low competition information treatment ranged from 2 to 49 kW, although 2 kW was probably entered by mistake, the next lowest value would then be 8 kW. The mean was 33.2 kW and the standard deviation of 11.7 kW. In the low competition no information treatment, the capacities ranged

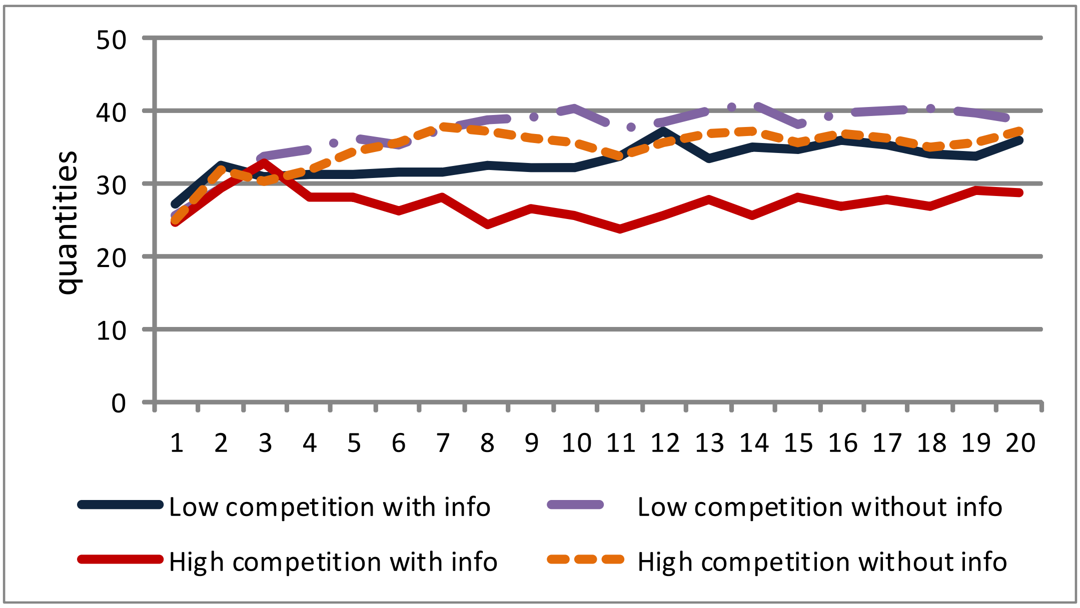

Figure 1: Development of mean capacities

from 4 to 49 kW, with a mean of 37.3 kW and a standard deviation of 10.6 kW. In the high competition information treatment, capacities ranged from 1 to 49 kW, with a mean of 27.3 kW and a standard deviation of 10.3 kW. Again, it is unclear whether 1 kW was entered on purpose or by mistake. The high competition no information treatment produced values of 0 to 49 kW, with a mean of 34.8 kW and a standard deviation of 13.0 kW. The differences between the information and the no information treatment were statistically significant at the 1% level (see Table 3). If higher quantities can be translated as higher levels of competition, then less information does indeed support the competitive situation as suggested by Ray & Cashman (1999). In contrast, we argue that the higher capacity bids observed here hint at reduced competition in the no information treatment. With competitive pressure, higher-cost generators should be driven out of the market, reducing total capacity offered, as can also be observed in the high competition scenarios.

The development of the auctioneer's expenditure can be seen in Figure 2. In particular, in the low competition no information treatment, the capacity-weighted expenditures range from 9.5

to 52.3 ECU/kW, with a mean of 18.3 ECU/kW and a standard deviation of 6.1 ECU/kW. In the control treatment with information, the weighted expenditures have a similar range with 9.0 to 51.6 ECU/kW, also with a mean of 18.3 ECU/kW and a standard deviation of 8.7 ECU/kW. It should be noted, however, that the extreme values could only be observed during the first rounds; in later rounds, some convergence took place, but full convergence could never be reached. Although the values and the development look very similar, Kruskal-Wallis (see Table 4) and Wilcoxon rank sum tests do not confirm this, i.e. treatments produce results that are significantly different.

In the high competition information treatment, values of 9.6 to 37.3 ECU/kW were obtained, with a mean of 13.7 ECU/kW and a mean of 3.9 ECU/kW. The high competition no information treatment produced values of 12.3 to 25.8 ECU/kW, with a mean of 15.6 ECU/kW and a standard deviation of 2.5 ECU/kW. It can thus be seen that the low competition scenario resulted in significantly higher (at the 1% level) expenditures per unit than the high competition scenario. This result is not surprising, but shows that the mechanism works in the anticipated way. Transferred to the scenario analyzed in Rosen & Madlener (2013a), which emphasizes the use of such a mechanism as an incentive scheme for renewable energy, the necessary goal of attracting market participants in an early phase with little competition is accomplished.

Prices develop very similar in all treatments except for the high competition information treat-

Table 3: Kruskal-Wallis ANOVA for capacities

	Source	**SS**	**df**	**MS**	**Chi-sq**	**Prob>Chi-sq**
Low competition	Columns	4.02984e+06	1	4029843	34.01	5.47767e-09
	Error	1.38032e+08	1198	115218.5		
	Total	1.42062e+08	1199			
High competition	Columns	1.42823e+07	1	14282281	121.36	3.19076e-28
	Error	1.26825e+08	1198	105863.9		
	Total	1.41107e+08	1199			

Table 4: Kruskal-Wallis ANOVA for auctioneer's expenditure

	Source	SS	df	MS	Chi-sq	Prob>Chi-sq
Low competition	Columns	227719.8	1	227719.8	17.04	3.66701e-05
	Error	5105580.2	398	12828.1		
	Total	5333300	399			
High competition	Columns	230928.1	1	230928.1	68.93	1.01827e-16
	Error	435721.9	198	2200.6		
	Total	666650	199			

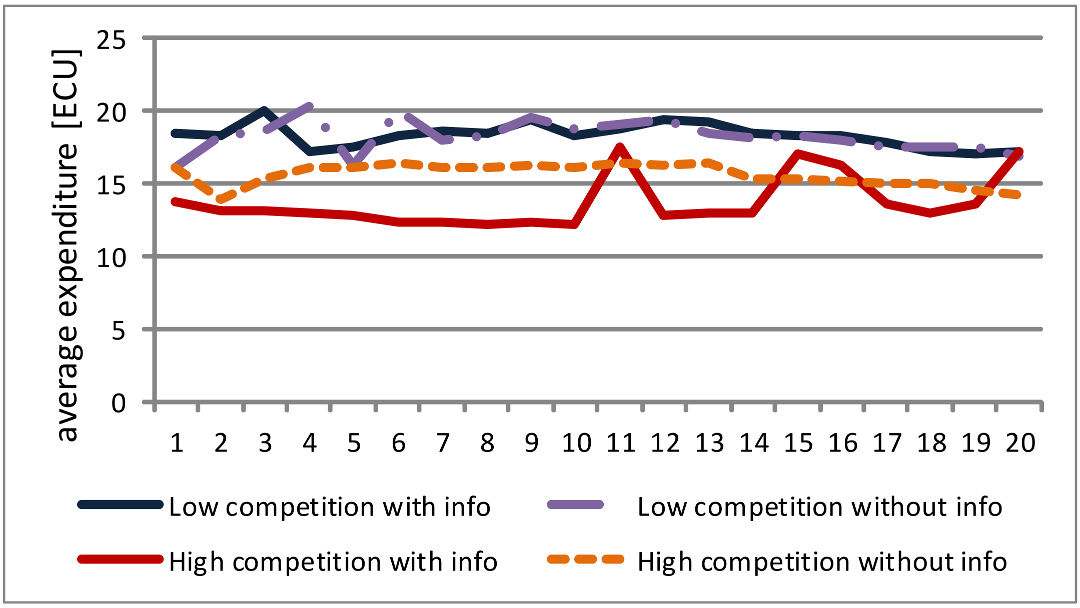

Figure 2: Development of weighted auctioneer's expenditures

ment (see Figure 3). The no information treatment seems to have a slight tendency to produce higher values than the information treatments. In particular, bid prices range from 7 to 100 ECU/kW, both in the information and in the no information treatment in the low competition case. Means are also very close with 19.0 ECU/kW (standard deviation: 11.5 ECU/kW) in the information treatment and 19.1 ECU/kW (standard deviation: 10.4 ECU/kW) in the no information treatment. Although both samples seem extremely similar, the Wilcoxon rank sum test (p=9.1032e^{-8}) as well as the Kruskal-Wallis ANOVA (Table 5) show that they do not come from the same distribution.

In the high competition case, the range of values remains about the same as in the low competition case, with 6 to 100 ECU/kW in the information treatment and 7 to 100 ECU/kW in the no information treatment, but the mean values change considerably. They reduce to 15.7 ECU/kW (standard deviation: 13.4 ECU/kW) in the information treatment and 18.1 ECU/kW (standard deviation: 11.6 ECU/kW) in the no information treatment. Here, the samples obviously do not come from the same distribution, as both Kruskal-Wallis (Table 5) and Wilcoxon rank sum tests confirm. Overall, there are no significant trends in the data, but sellers on average seem to submit the same prices in each round.

Over the rounds, the development of bidders' profits mirrors that of prices to some extent. The difference between low competition and high competition scenarios, however, is more

Table 5: Kruskal-Wallis ANOVA for prices

	Source	**SS**	**df**	**MS**	**Chi-sq**	**Prob>Chi-sq**
Low competition	Columns	3.41013e+06	1	3410134.1	28.56	9.09904e-08
	Error	1.3977e+08	1198	116669.1		
	Total	1.4318e+08	1199			
High competition	Columns	3.21615e+07	1	32161484.3	272.85	2.71496e-61
	Error	1.09167e+08	1198	91124.8		
	Total	1.41329e+08	1199			

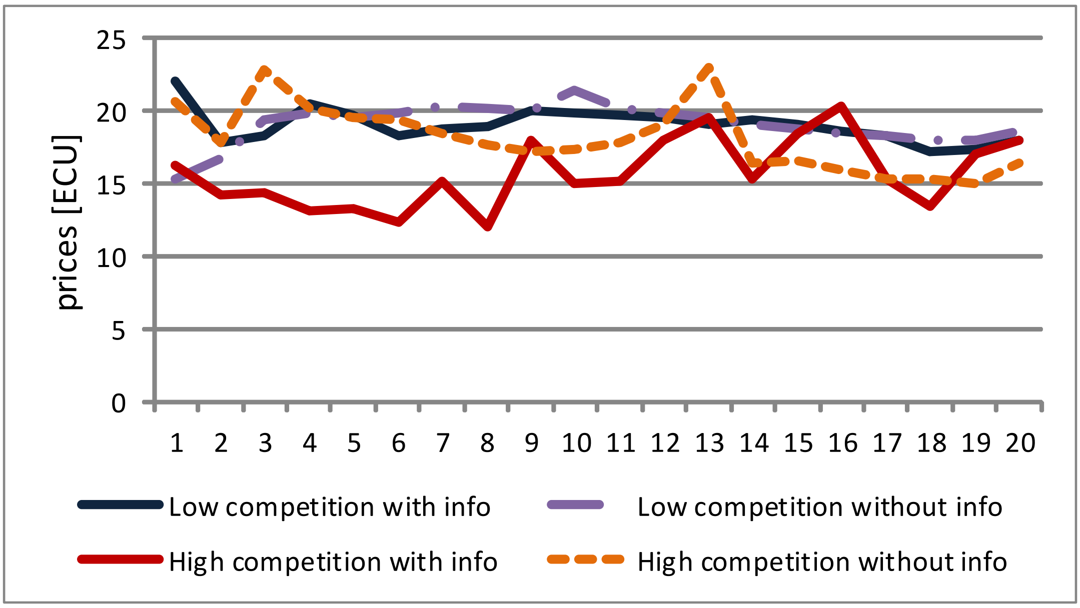

Figure 3: Development of prices

Table 6: Kruskal-Wallis ANOVA for profits

	Source	**SS**	**df**	**MS**	**Chi-sq**	**Prob>Chi-sq**
Low competition	Columns	854026.8	1	854026.8	7.22	0.0072
	Error	140923394.7	1198	117632.2		
	Total	141777421.5	1199			
High competition	Columns	1.14868e+06	1	1148678.4	9.77	0.0018
	Error	1.39791e+08	1198	116687.3		
	Total	1.4094e+08	1199			

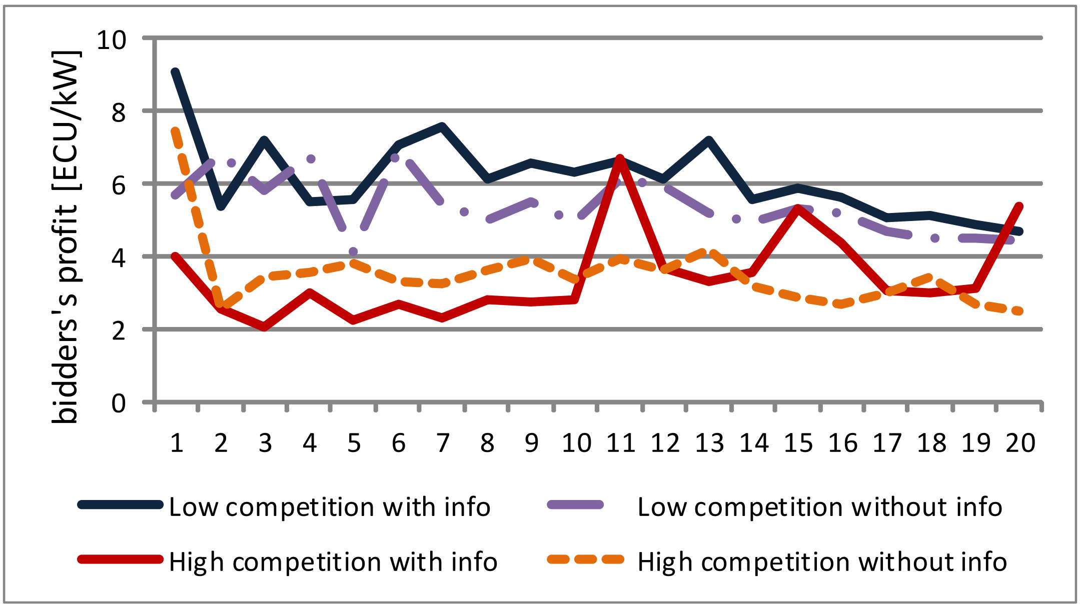

Figure 4: Development of capacity-weighted profits

pronounced. For the low competition scenario, profits obtained range from 0 to 3450 ECU (mean: 210.9 ECU, standard deviation: 356.9 ECU) in the information treatment, while the no information treatment produced values of 0 to 4155 ECU (mean: 209.8 ECU, standard deviation: 365.8 ECU). In the high competition scenario, profits ranged from 0 to 3890 ECU (mean: 92.4 ECU, standard deviation: 241.0 ECU) in the information treatment and from 0 to 1744 ECU (mean: 111.7 ECU, standard deviation: 135.1 ECU) in the no information treatment. For better comparability, we also calculated the capacity-weighted profits. Mean values here are relatively low because we do not discriminate between bidders that won an auction but did not make any profit, and bidders that did not win an auction and therefore made no profit by definition. In the low competition scenario, we found weighted profits of 0 to 78.4 ECU/kW (mean: 6.2 ECU/kW, standard deviation: 9.2 ECU/kW) for the information treatment and 0 to 88.4 ECU/kW (mean: 5.4 ECU/kW, standard deviation: 8.0 ECU/kW) for the no information treatment. In the high competition scenarios, corresponding values were 0 to 88.4 ECU/kW (mean: 3.4 ECU/kW, standard deviation: 5.7 ECU/kW) in the information treatment and 0 to 91.8 ECU/kW (mean: 3.5 ECU/kW, standard deviation: 5.2 ECU/kW) in the no information treatment. The three peaks that can be observed for the high competition information treatment in rounds 11, 15, and 20 (Figure 4) are outliers that result from three individual bidders who were lucky or able to game the system with bidding prices close to or at the reservation price, while offering their entire capacity. All in all, the impact of the competitive situation is much more pronounced than the effect of feedback information.

In all variables examined here, differences are significant between the two informational treatments. We have seen that without information feedback, capacities withholding decreases, i.e. more generators enter the market. However, this also means that efficiency suffers because more expensive units are offered. At the same time and as a result of the inclusion of higher-cost generators, prices increase, and therefore also the auctioneer's expenditures. Profits, however, are not necessarily positively influenced by a lack of information, only by decreasing intensity in the competitive situation.

5 Discussion

The results can be explained by two diverging trends: On the one hand, competitive forces move prices downwards over time. On the other hand, bidders tried to gradually approach higher prices wherever possible. In the information treatment, they used the published prices and oriented their own bids towards the upper end. In the no information treatment, they concluded the market prices from their own accepted or rejected bids. Furthermore, they seem to have applied different strategies in the two treatments. When prices were displayed, two thirds of the participants included this information in their decision process to react with their own price bid appropriately. This is evidence for the anchoring effect observed by Neugebauer & Perote (2007), and explains why no clear trend can be observed in the data. Although more bidders anchored on the higher accepted bids, some anchored on the lower accepted bids, suggesting a continuous replication of the preceding prices. While in the no information treatment, prices are also an important decision variable, quantity-driven considerations are relatively more important than in the information treatment. The high competition information treatment was the only one where bidders became very competitive. Some stated that they tried to drive others out of the market, or were bidding in a specific way just to hinder others from gaining higher profits, even if their own profits were suffering. Others tried to bring down prices until their competitors were not able to offer sufficient supply at the prevailing price level. At this point, they would step in and offer a large amount at very high prices to maximize their own profits. It should be noted that, in general, bidders in the high competition information treatment understood very quickly that they had to reduce their quantity offers to stay profitable.

Even though several bidders strictly oriented their bidding prices towards the upper end of the accepted price scale, explicit attempts at collusion were unsuccessful. The bidders do not seem to have understood the signals their competitors were trying to send to the market. As we do not display losing bids, this result is in line with Dufwenberg & Gneezy (2002).

6 Evaluation of the questionnaire

The questionnaire is meant to assess the chances of success of a market, such as the one introduced in a real-world setting, and to provide some background to the results observed during the experiment. After asking socio-demographic questions, the first block of items concentrates on the auction process and the market idea. The second block investigates the participants' experience during the experiment and the third block earlier experience with online auction markets. The evaluation is also structured in three parts, which are a general analysis, a gendered analysis and an analysis with respect to educational background.

The general part reveals that participants enjoyed bidding in the auction, although most participants did not engage in any kind of online trading, particularly not in selling, in real life.

They found the market mechanism transparent and easy to understand. In terms of usability, interfaces as well as input and output masks were very highly rated.

Some surprising differences appear when comparing questionnaire results for each sex. While males evaluated bidding in the auction and participating in the experiment almost equally (correlation 0.80), females also showed a significant, albeit much weaker correlation between these two items. That is, when they liked bidding in the auction, they liked participating in the experiment even more. Another interesting difference in the gendered evaluation is that males liked participating when they found the remuneration scheme motivating. For females, this correlation is not significant. In the context of experience with other auction formats, we find that they use auction platforms like eBay and others when they have fun buying things on those platforms. Here the correlation is only significant for females, not for males. However, males (mean: 1.9, standard deviation 0.94) enjoy selling things on those platforms more than females do (mean: 2.2, standard deviation: 0.99). One should note, though, that males (mean: 1.7, standard deviation: 0.9) also seem to use these platforms somewhat more intensively for shopping than females do (mean: 1.8, standard deviation: 0.8), which might be due to a generally higher affinity with computers and online business.

There are also differences according to the educational background. Participants with a technical background are much more inclined to participate in such a market in reality than participants with an economic background ($p = 0.02$). At the same time, they also claimed to have better understood the market mechanism ($p = 0.03$) and found the written instructions more comprehensible ($p = 0.04$), which might be an explanation for their more positive attitude towards participating in reality. Interestingly, the same differences can be observed in a gendered analysis, most at an even higher significance level. The reason could be that most participants with a technical background were male, while participants with an economics background tended to be female.

The merits of the local reserve energy market were not well evaluated, most likely because we were not able to explain them in enough detail. Therefore, participants did not show an intention to recommend such a market (significant correlation with a coefficient of 0.73 between own participation in a real market and recommendation). During the instructions and the experiment, the focus was always on the market mechanism to validate its functioning. For this reason, we expect no difficulties in acceptance in a real-world setting, where possible market entrants can be much better informed. Also, possible market participants would actually possess generation technology, which makes it likely for them to have a much stronger interest and, therefore, an even more proactive attitude toward a market (designed in whatever way) where they can sell their self-produced energy.

7 Conclusion

We observed that quantities submitted were larger in the no information treatment, in both competition scenarios. The same is true for the auctioneer's expenditure, which is higher for no information and a lower level of competition. This means that holding back information hinders competition, as anticipated in Rosen & Madlener (2013a). For prices we could not find a large difference in the low competition case, but in the high competition case the no information treatment produces much higher prices. Nevertheless, also in the low competition scenario, differences were significant and the data reveal a positive trend for the no information treatment, while the information treatment follows the expected negative trend, i.e. prices converge to costs. The results for profits are contradictory in the sense that the two competitive settings produce different outcomes. In the low competition scenario, profits were lower for the no information treatment, while they were higher in the high competition scenario.

The evaluation of the questionnaire shows that there are significant differences in attitudes towards and handling of the market for the educational background and the gender.

Further research should validate the current findings with respect to their robustness. This concerns the pricing and the rationing rule as well as the auction format.

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Appendix

Part A - Auction mechanism

There is a set I of n potential bidders, with $n \in \left\{ 3;\ 6 \right\}$, depending on the treatment. Each bidder $i \in I$ can submit one bid $b_i(p)$, which is composed of a price p_i and a quantity q_i. These bids are ranked according to price, with $b_{i;1}$ being the lowest offer and $b_{i;k_{max}}$ being the highest offer, k_{max} being either 3 or 6. Each bidder knows his costs as a function of quantity, $c_i(q)$. Costs follow a discrete step function and are drawn from a common distribution, as are available quantities.

In the following, we ignore the source of the bid, i.e. neglect the i. Let p be the vector of prices that the auctioneer faces due to the submitted sets of offers $p = \left(p_1;\ p_2;\ ...;\ p_{kmax} \right)$. Further, let $q = \left(q(p_1);\ q(p_2);\ ...;\ q(p_{kmax}) \right)$ be the corresponding quantity vector, as emerging from the bids $b_{i;k}$ ranked according to price. Considering the reservation price p_R enforced in the auction, total expenditure of the auctioneer becomes

$$
\begin{aligned}
&\min_p \sum_i x_i q_i p_i \\
\text{s.t.}\quad &\sum_i q_i \geq Qs \\
\text{with}\quad & s = \begin{cases} 0 \text{ if } \sum_i q_i < Q \\ 1 \text{ otherwise} \end{cases} \\
& x_i \in \{0, 1\} \text{ with } x_i = \begin{cases} 0 \text{ if bid } i \text{ is accepted} \\ 1 \text{ otherwise} \end{cases} \\
& p_R \geq p_i.
\end{aligned}
\tag{1}
$$

Part B - Questionnaire

PERSONAL ITEMS

Age: ____________________ Study course: ________________________________

Sex: ☐ m ☐ f

THE MARKET	Strongly agree	Agree	No opinion	Disagree	Strongly disagree
Bidding in the auction was fun for me	☐	☐	☐	☐	☐
The auction mechanism was transparent	☐	☐	☐	☐	☐
The bidding procedure was motivating	☐	☐	☐	☐	☐
I tried to maximize my profit during the auction rounds	☐	☐	☐	☐	☐
I could imagine participating in a real electricity market of this kind	☐	☐	☐	☐	☐
I would recommend participation in a real electricity market of this kind to others	☐	☐	☐	☐	☐
I succeeded in applying an efficient bidding strategy	☐	☐	☐	☐	☐
I participated in the market with success	☐	☐	☐	☐	☐
The market mechanism was easy to understand	☐	☐	☐	☐	☐
The market helps to protect the environment	☐	☐	☐	☐	☐
The market supports sustainability	☐	☐	☐	☐	☐

Imagine such an electricity market existed in reality and you already possessed the necessary generation equipment to participate in the market. Would you do it?

☐ yes, because ______________________________

☐ no, because ______________________________

THE EXPERIMENT	Strongly agree	Agree	No opinion	Disagree	Strongly disagree
Participating in the experiment was fun for me	□	□	□	□	□
Written instructions for the bidding procedure were easy to understand	□	□	□	□	□
Written instructions for the bidding procedure were complete	□	□	□	□	□
Input fields for entering the bids were well-arranged	□	□	□	□	□
The payout system was motivating	□	□	□	□	□
The display of the results after an auction round was easy to understand	□	□	□	□	□
The time consumed by an entire auction round including the display of results was reasonable	□	□	□	□	□

AUCTIONS IN GENERAL	Strongly agree	Agree	No opinion	Disagree	Strongly disagree
I use auction platforms (e.g. Ebay, hood.de, centgebote.de) as a private buyer	☐	☐	☐	☐	☐
I use auction platforms (e.g. Ebay, hood.de, centgebote.de) as a private seller	☐	☐	☐	☐	☐
I have fun selling something at auctions	☐	☐	☐	☐	☐
I have fun buying something at auctions	☐	☐	☐	☐	☐

How often do you use auction platforms on average?

☐ once a week or more

☐ two to three times a month

☐ once a month

☐ every two months

☐ once a year or less

☐ never

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