The Chopstick Auction: A Study of the Exposure Problem in Multi-Unit Auctions

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Summary

Multi-unit auctions are sometimes plagued by the so-called exposure problem. In this paper, we analyze a simple game called the 'chopstick auction' in which bidders are confronted with the exposure problem. We analyze the chopstick auction with incomplete information both in theory and in a laboratory experiment. In theory, the chopstick auction has an efficient equilibrium and is revenue equivalent with the second-price sealed-bid auction in which the exposure problem is not present. In the experiment, however, we find that the chopstick auction is slightly less efficient but yields far more revenue than the second-price sealed-bid auction.

Keywords: Chopstick auction, Exposure problem, Laboratory experiment, Second-price sealed-bid auction

JEL Classification: C9, D44

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1 Introduction

Multi-unit auctions are sometimes plagued by what is called the 'exposure problem'. We speak of an exposure problem when bidders aim at winning several objects in a multi-object auction but are *exposed* to the risk of buying too few as competition on some of these objects turns out to be tougher than expected.[1] Several economists have argued that the exposure problem in auction should be prevented as it leads (1) to an inefficient outcome of the auction and (2) to low revenue. In this paper, we will investigate whether these claims are true, both using a game theoretical model and a laboratory experiment.

Economic theory sketches a mixed picture about these two claims. Theoretical papers of Robert Rosenthal and coauthors include situations in which the exposure problem is present. Szentes and Rosenthal (2001a, 2001b) find efficient equilibria in multi-unit auctions of homogeneous objects. However, Krishna and Rosenthal (1996), and Rosenthal and Wang (1996) construct inefficient equilibria in the case of heterogeneous objects. In these papers, they analyze multi-unit auctions with two types of bidders, namely 'local bidders' who are interested in only one object, and 'global' bidders who try to acquire several. The global bidders, in competition with the local ones, face the exposure problem when attempting to realize synergies between the objects. In line with this, Bykowsky et al. (1998) give an illustrative example in which the equilibrium outcome is such that either the allocation is inefficient or at least one of the bidders ends up paying more for the purchased items than they are worth to her.

Other theorists have investigated the relationship between efficiency and revenue. Ausubel and Cramton (1998, 1999) stress the importance of efficiency of the auction outcome in terms of revenues for the seller in auctions of perfectly divisible objects. Ausubel and Cramton (1999) show that efficiency of the auction outcome is necessary for revenue maximization when the auction is followed by a perfect resale market and when the seller cannot commit to not selling some objects. However, usually there is a trade-off between efficiency and revenue. In Myerson's (1981) model, the seller maximizes his expected revenue by imposing a reserve price and hence excluding bidders with low values from winning the object. Milgrom (2000) constructs an example in which there is a trade-off

[1] See also Bykowsky et al. (2000), and Milgrom (2000).

between efficiency and revenue in the case of multi-unit auctions: the seller realizes a less efficient outcome when using larger packages but gets a higher revenue.

In practice, it is also not clear whether the exposure problem is a major issue. At least Klemperer (2001) does not include the warning 'avoid the exposure problem' in his list of issues that are of practical importance in the design of (multi-unit) auctions. However, Van Damme (2000) claims that the exposure problem lead to low bids and an inefficient outcome in the Dutch DCS-1800 auction. In February 1998, the Dutch government auctioned licenses for second generation mobile telecommunication using an auction with almost the same rules as the FCC auctions in the US.[2] A difference between the Dutch DCS-1800 auction and the American auctions was that in the American auctions, the exposure problem was not seriously present as bidders were allowed to withdraw there bids. Van Damme argues that the FCC auction format would have lead to a higher revenue and a more efficient outcome.

Does the exposure problem indeed lead to inefficient outcomes and low revenues? In order to answer this question, we confronted subjects with a simple auction game called 'the chopstick auction' (CSA).[3] In this auction, a seller simultaneously sells three chopsticks. There are 2 bidders in the auction, who independently submit a bid, which is the price for one chopstick. Call the second highest bid p. The outcome of CSA is such that the highest bidder gets two chopsticks for a price of $2p$ and the second highest bidder gets one chopstick for p. We compared CSA with the second-price sealed-bid auction in which two chopsticks are sold as one bundle (SPSB). The only difference with the 'usual' second-price sealed-bid auction is that the winning bidder has to pay his bid twice, once for each chopstick. We investigated bidding behavior in CSA and in SPSB in the following setting. Bidder i's ($i = 1, 2$) marginal values are zero on the first chopstick, v_i on second, and zero on the third. The signals v_i's are drawn independently from the same distribution function. As the second highest bidder wins a worthless chopstick for a positive price, bidders face the exposure problem in CSA.

[2] See McMillan (1994), Cramton (1995, 1998), McAfee and McMillan (1996), and Milgrom (2000) for descriptions and discussions of these auctions.

[3] The credit for the name of this auction game goes to Mary Lucking-Reiley. Thanks to Balasz Szentes and Robert Rosenthal for pointing this out to us.

A game closely related to CSA is the dollar auction. In the dollar auction, two bidders play an ascending auction in order to win $1. The highest bidder wins the dollar, but both bidders pay the price at which the second highest bidder decided to step out. Note that the exposure problem is present here: the second highest bidder pays a positive price, and gets nothing. In equilibrium, bidders play a mixed strategy in which both independently pick a price level at which they leave the auction. This price level follows an exponential distribution with mean 1. The expected revenue for the seller of the dollar is exactly one dollar. However, when Shubik (1971) and others confronted subjects with this game in the lab, the average revenue was significantly larger than $1.

There are two main differences between Shubik's experiment and ours. First, subjects in the dollar auction are completely informed about the value of the auctioned object (which is $1 for both bidders), whereas in our experiment, subjects are only incompletely informed about the value of the other bidder. Moreover, the winner in Shubik's experiment pays the same amount as the loser, whereas in CSA, the winner pays twice the loser's bid.

In this paper, we study CSA in a laboratory experiment and confront the outcomes with theoretical predictions. In section 2, we will give theoretical properties of CSA and SPSB in terms of equilibrium behavior and expected revenue.[4] Assuming that both bidders are risk neutral and draw their value v_i from a uniform distribution on $[0, 100]$, we find that CSA has an efficient Bayesian Nash equilibrium. From standard auction theory, we learn that SPSB has an efficient equilibrium in dominant strategies in which each bidder submits a bid equal to half her value for each chopstick. The revenue equivalence theorem (Myerson, 1981) then implies that CSA is revenue equivalent with SPSB. In other words, in this theoretical setting, auctions in which the exposure problem is present perform as well as auctions in which it is not. That makes this setting a useful benchmark to test the two claims we started with.

In section 3, we describe the experimental design and present the results of the experiment. Our first result is the striking difference between the obtained revenue in CSA and SPSB. In line with the outcomes of the dollar auction, revenue tends to be higher when bidders are confronted with the exposure problem than if they are not. Our second

[4] See Onderstal (2002) for a more detailed theoretical investigation of the chopstick auction.

finding is that there is a significant but small difference between the efficiency of CSA and of SPSB. Both auctions turn out to be reasonable efficient. Although we observe some learning during the experiment, these results seem to be robust.

The third outcome may seem somewhat surprising: in SPSB, the average revenue was about 20% above the theoretical outcome assuming that the bidders play a weakly dominant strategy, i.e., bidding half her value. This finding is in contrast to what is found in experiments by Kagel et al. (1987), Kagel and Levin (1993), and Harstad (2000) on the 'standard' second-price sealed-bid auction. In these experiments, the average revenue was only about 10% above the dominant strategy.[5] A possible explanation of this result is that we have complicated the game somewhat: when winning, a bidder has to pay *twice* the second highest bid, once for each chopstick. This is different than what happens in the usual second-price sealed-bid auction, in which the winner pays the second highest bid only once. This framing effect shows that even a slight complication of the environment may make it harder for people to act rationally.

We conclude that our experiment does not give a convincing reason why the warning 'avoid the exposure problem' should be added to Klemperer's list of practical issues in the design of auctions. CSA is virtually as efficiency as SPSB and turns out to yield much more revenue.

2 Theory

Consider a situation with 2 bidders, labeled 1 and 2, who wish to eat Chinese food. However, none of the bidders has anything to eat with. Suppose that a seller sells 3 chopsticks in the chopstick auction (CSA) which has the following rules. The price starts at zero and is continuously raised. Bidders have the opportunity to quit the auction at any price they desire. The auction ends when one bidder quits. She wins one chopstick and pays the price at which she quits. The remaining bidder wins two chopsticks and

[5] See Kagel (1995) for an overview of laboratory experiments on the second-price sealed-bid auction.

pays two times the price at which the second highest bidder quits.[6]

The value $V_i(s)$ bidder i attaches to owning s chopsticks is given by

$$V_i(s) = \begin{cases} v_i & s = 2, 3 \\ 0 & s = 0, 1, \end{cases} \tag{1}$$

where v_i is a private signal for bidder i. In words, a bidder attaches a value of v_i to winning two chopsticks and no value to winning only one chopstick or to winning a third one. We assume that the v_i's are drawn independently from a uniform distribution on the interval $[0, 100]$.

Each bidder is a risk neutral expected utility maximizer. Suppose that the price realized in CSA is equal to p. The utility for bidder i having drawn a value equal to v_i is given by

$$u_i(v_i, s, p) = \begin{cases} v_i - 2p & s = 2 \\ -p & s = 1 \end{cases} . \tag{2}$$

Proposition 1 gives equilibrium bidding in CSA. By a standard argument, this bid function must be strictly increasing and continuous. Let $U(v, w)$ be the utility for a bidder with signal v who behaves as if she has signal w, whereas the other bidders play according to the equilibrium bid function. A necessary equilibrium condition is that

$$\frac{\partial U(v, w)}{\partial w} = 0$$

at $w = v$. From this condition, a differential equation is derived, from which the equilibrium bid function is uniquely determined.

Proposition 1 *Let $B(v)$, the bid of a bidder with signal v, be given by*

$$B(v) = v + [100 - v] [\log (100 - v) - \log 100] .$$

Then B is a symmetric Bayesian Nash equilibrium of CSA. The outcome of the auction is efficient. The bidder with the lowest possible value obtains zero utility.

[6] In this auction, ties are broken as follows. When a tie takes place at a price of p, a fair coin is tossed. If tails comes up, the bidder with the lowest label wins two chopsticks for a price of $2p$, and the other bidder wins one chopstick for a price of p. If heads come up, the outcome is reversed.

Proof. See the appendix. ∎

Let us compare the outcomes of CSA with the second-price sealed-bid auction in which two chopsticks are sold as one bundle (SPSB). The only difference with the 'usual' second-price sealed-bid auction is that the winning bidder has to pay his bid twice, once for each chopstick. Proposition 2 gives the equilibrium properties of SPSB.

Proposition 2 *Let $b(v)$, the bid of a bidder with signal v, be given by*

$$b(v) = \frac{1}{2}v.$$

Then b is the unique symmetric Bayesian Nash equilibrium in weakly dominant strategies of SPSB. The outcome of the auction is efficient. The bidder with the lowest possible value obtains zero utility.

Proof. Standard. ∎

Propositions 1 and 2 show that both auctions are efficient. In other words, a seller who is concerned about efficiency is indifferent between the two auction type.

Moreover, both auctions turn out to be revenue equivalent, and generate the same expected utility for the bidders. This is a direct consequence of the revenue equivalence theorem (Myerson, 1981), using the following two observations. First, CSA is an auction of a single object, namely a set of two chopsticks. Second, according to Propositions 1 and 2, both auctions are efficient and the utility of the bidder with the lowest possible value is equal to zero. The interpretation is that a risk neutral seller interested in revenue is indifferent between using CSA and SPSB to sell the chopsticks. Proposition 3 summarizes this finding, and gives the expected revenue and the expected utility for the bidders.

Proposition 3 *Suppose that bidders play CSA and SPSB according to the strategies given in Propositions 1 and 2 respectively. Then for both CSA and SPSB, expected revenue equals* $33\frac{1}{3}$ *and ex ante expected utility for a bidder is* $16\frac{2}{3}$.

Proof. Expected revenue in SPSB can be calculated as follows. As in equilibrium, each bidder submits a bid equal to 50% of his value, the winner is the bidder with the highest value. She pays twice the bid of the lowest bidder. In other words, revenue is equal to the lowest possible value. Therefore, expected revenue is equal to $33\frac{1}{3}$ as this is the expectation of the lowest from two numbers independently drawn from a uniform distribution on the interval $[0, 100]$. The utility for the winner of SPSB equals the value obtained minus the price paid. The expected value of two chopsticks for the winner is equal to the maximum of two numbers drawn independently from the uniform distribution on the interval $[0, 100]$, i.e. $66\frac{2}{3}$. Given that he pays $33\frac{1}{3}$ in expectation, the winner's expected utility equals $33\frac{1}{3}$. As ex ante both bidders have probability $\frac{1}{2}$ to be the winner, ex ante expected utility for a bidder equals $16\frac{2}{3}$. CSA yields the same expected revenue and the same ex ante expected utility for each bidder as SPSB. This follows immediately from the revenue equivalence theorem (Myerson, 1981), as in equilibrium, both auctions are efficient and yield zero expected utility for the bidder with the lowest possible value. ■

3 Laboratory experiment

We present the results of our laboratory experiment in three parts. In the first part, we describe the experimental design. In the second part, we analyze total revenue generated by the auctions. In the third part, we focus on efficiency.

3.1 Experimental design

In a computerized laboratory experiment, we studied CSA and SPSB in a setting that is closely related to the theoretical setting.[7] The main differences are the following. First

[7] The experiment has been programmed and conducted with the software Z-tree (Fischbacher, 1999).

of all, the subjects in the lab were confronted with the one-shot version of CSA. Subjects did not see the price rise until one of them indicated to leave the auction. Instead, subjects were asked at which price they would desire to quit. However, the two games are strategically equivalent, so that we did not expect much differences in the outcomes.[8]

Secondly, subjects drew their values from a finite grid between 0 and 100, with 1 as the smallest step. Our theoretical results have been based on the assumption that bidders draw their signals from the interval [0,100]. Moreover, subjects could choose prices from a finite grid between 0 and 999, with 1 as the smallest step. The theory has been based on the assumption that bidders can choose their bids from a continuous action space. However, both grids are sufficiently fine to approximate the continuous signal and action space.

The experiments were conducted at the faculty of economics and social sciences at Innsbruck University between 15 May and 3 June 2002.[9] We conducted four sessions, each consisting of 24 subjects. We had between-subject treatments. In two sessions, subjects played CSA, and in the other two sessions, subjects were confronted with SPSB. In all sessions, the subjects were separated in groups of four. We ran three practice periods, followed by 40 paid trading periods. Before the start of each period, the subjects were randomly re-matched to an opponent in their group of four resulting in 12 independent observations per treatment. In each period, all subjects drew a new value for two chopsticks. At the beginning of each session, subjects read the instructions (see the appendix). Questions were answered privately.

Subjects were paid a lump sum transfer (5 euros) for showing up and an additional reward which depended on their average gains in the auctions. They earned points which were calculated as the difference between the value of the chopsticks they won minus the price they paid. Points were exchanged into cash according to the exchange rate

$$100 \text{ points} = 3 \text{ Euro.}$$

[8]Still, we should be somewhat cautious, as 'framing effects' may occur. For instance, in experiments by Coppinger et al. (1980) and Cox et al. (1982), the first-price sealed-bid auction turned out to generate higher prices than the Dutch auction, despite the fact that both games are strategically equivalent.

[9]We conducted a test-experiment at the BEAUTY2001 summer school at the University of Amsterdam. We took the point earnings from this experiment as guideline how to choose the lump-sum payment and the rate according to which points are exchanged.

In CSA, the winner of just one chopsticks gets a negative score equal to the amount he paid for it. The maximum score in a period is 100 points, i.e., the maximum value (100) minus the minimum payment (0). If subjects played according to the bidding strategies in Propositions 1 and 2, they would have earned 25 euros on average.[10] The experiments lasted about 45 minutes, so that the subjects could earn a salient amount of money. Paying every period as we did induces behavior towards risk neutrality. Paying according to a randomly selecting one period, instead, may increase subjects' willingness to take risks (Davis and Holt, 1993).

3.2 Results: revenue

What is the average revenue in the auctions? In CSA, revenue equals three times the price: the winner of two chopsticks pays this price twice, the winner of one chopstick once. In SPSB, revenue is equal to twice the price. See figure 1 for the average revenue in each period.

Figure 1: Revenue in CSA and SPSB.

Subjects turned out to bid much more in CSA than predicted by the theory. Proposition 3 predicts that the average revenue is $33\frac{1}{3}$ points per period. In reality, the average revenue was 68 points. As a consequence, the average payments to a subject was very low,

[10] The calculation is as follows. According to Proposition 3, subjects earn on average $16\frac{2}{3}$ points per period. Given than they play 40 periods, and the exchange rate of 100 points = 3 Euro, they expect to earn $16\frac{2}{3} * 40 * \frac{3}{100} = 20$ Euro. Add to this number the 5 Euro lump sum transfer in order to end up with 25 Euro.

i.e., about 60 eurocents. Of course, it could be that the subjects experienced difficulties in understanding the auction. We tested for this by making statistical comparisons separately for the first and last 20 periods in order to account for learning effects. We found some learning in the sense that the average payment in the last 20 periods was lower that in the first 20. However, it is still much higher that $33\frac{1}{3}$.

Result 1 *CSA yields more revenue than predicted by the theory.*

Also for SPSB, the theory predicts that revenue equals $33\frac{1}{3}$ points on average per period. In the experiment, average revenue was equal to about 39 points, 20% more than the theoretical prediction. The subjects earned 19.1 euros on average, which is clearly less than the 25 euro they could have earned if they had played the weakly dominant strategy. A substantial subset of the bidders bid more than its value, playing a weakly dominated strategy. A possible explanation of this result is that we have complicated the game somewhat: when winning, a bidder has to pay *twice* the second highest bid, once for each chopstick. This is different than what happens in the 'usual' second-price sealed-bid auction, in which the winner pays the second highest bid only once. Overbidding in SPSB may be driven by the framing.

Result 2 *SPSB yields more revenue than predicted by the theory.*

Our third result is the striking difference between the obtained revenue in CSA and SPSB. In line with the outcomes of the dollar auction, revenue tends to be higher when bidders are confronted with the exposure problem than if they are not. A Mann-Whitney test reveals that the difference in revenue between CSA and SPSB is significant at a 1% level (p=0.0005). For both CSA and SPSB we observe a trend towards the prediction by the theory ($33\frac{1}{3}$ for both auctions). In periods 1-20, the average revenue in CSA is 71 and in SPSB 40. In periods 21-40, we observe 66 for CSA and 38 for SPSB. The difference is still large and significant at a 1% level for the later periods.

Result 3 *CSA and SPSB are not revenue equivalent: CSA yields much more revenue than SPSB.*

3.3 Results: efficiency

Efficiency is defined as follows

$$\text{Efficiency} = \frac{\text{value of the winning bidder}}{\max\{v_1, v_2\}}.$$

Figure 2 shows the development of efficiency over the periods in both CSA and SPSB.

Figure 2: Efficiency of CSA and SPSB.

Propositions 1 and 2 predict that both auctions are 100% efficient. In a worst case scenario, if the two chopsticks are assigned using a lottery, expected efficiency equals 75%.[11] In CSA, we observed an average efficiency equal to 91%, which means that

[11] The calculation for this number is the following. As both bidders are ex ante symmetric, we may assume without loss of generality, that the lottery always assigns two chopsticks to bidder 1. Expected efficiency is then given by

$$\begin{aligned} \text{Expected efficieny} &= \int_0^{100} \left[\int_0^{v_2} \frac{v_1}{v_2} * \frac{1}{100} dv_1 + \int_{v_2}^{100} 1 * \frac{1}{100} dv_1 \right] \frac{1}{100} dv_2 \\ &= \frac{3}{4}. \end{aligned}$$

The first term in the inner integral refers to the case that bidder 2 has a higher value than bidder 1 (so that efficiency equals $\frac{v_1}{v_2}$). In the second term, bidder 1 has the higher value (so that efficiency equals 1).

Result 4 *CSA is reasonably efficient.*

The efficiency of CSA is closer to the theoretical prediction of 100% than the outcome of a lottery.

The same holds true for SPSB in which efficiency was 95%. This finding is probably explained by the fact that several subjects bid their value instead of half of it. Still,

Result 5 *SPSB is reasonably efficient.*

Using a Mann-Whitney test, we observe that the difference in efficiency between CSA and SPSB is significant at a 5% level ($p = 0,0209$). Still the difference is not large, so that we conclude that

Result 6 *SPSB is only slightly more efficient than CSA.*

We have checked whether these results change during the course of the experiment. This turns out not to be the case. For the first 20 periods, we observed 91% efficiency in CSA versus 94% in SPSB. In the final 20 periods (periods 21-40) we observe virtually no difference (91% in CSA and 95% in SPSB). In both the early periods and the late periods, the difference between CSA and SPSB is significant at a 5% level.

4 Conclusions

In this paper, we have investigated the effect of the exposure problem on bidding behavior in auctions. In contrast to some theoretical papers and concerns raised by the outcome of the Dutch DCS-1800 auction, we feel that auction designers do not have to worry that the exposure problem leads to low revenue and inefficiency. On the contrary: our experiment has shown that auctions in which the exposure problem is present may yield far more revenue for the seller than auctions in which it is not. Moreover, the difference in efficiency is rather small.

Does this mean that we recommend governments to design auctions in which the exposure problem is present? Probably not: especially if large amounts of money are at stake, bidders are wise enough to hire experts in auction theory who we expect to convince bidders to correctly take the risks into account associated with the exposure problem. Still, in the case that a government is not sure about the conditions on the demand side, it may safely split up supply in small parts. The bidders could sort out themselves how many small parts they need to obtain sufficient value. Depending on the shape of demand, the government may design an auction in which the exposure problem is present. Our experiment has shown that this need not have a detrimental effect on the outcome.

What has remained somewhat puzzling to us is the observation that subjects in SPSB do not play weakly dominant strategies. We conclude that we have touched a broader topic in experimental economics or even in economics in general: slight complication of the environment has significant effect on the outcomes. This may be important for many applications/situations, from the introduction of elaborate pricing schemes to new currencies like the euro.

5 Appendix

5.1 Proof of Proposition 1

Let $B(v)$, the bid of a bidder with signal v, be given by

$$B(v) = v + [100 - v] [\log (100 - v) - \log 100] .$$

Then B is a symmetric Bayesian Nash equilibrium of CSA. The outcome of the auction is efficient.

Proof. The following observations imply that a symmetric equilibrium bid function must be strictly increasing. First, a higher-value type of a bidder cannot exit before a lower-value type of the same bidder would exit. (Suppose the lower type is indifferent between two different strategies, giving her two different probabilities of being the ultimate winner of two chopsticks. The higher type then strictly prefers the strategy with the higher probability to win. Therefore, she will never quit earlier than the lower type.) Furthermore, there is no range in which the bid function is flat. (Suppose there is the bid function is flat at a price level of p. Then each bidder being in the range of signals that bid p exits the auction with positive probability at p. But if this is the case, then each bidder strictly prefers staying just a bit longer.)

Let $\tilde{B}$ be a symmetric and strictly increasing equilibrium bid function. If the other bidder bids according to $\tilde{B}$, the expected utility of a bidder with signal v who bids as if she has signal w is given by

$$U(v,w) = -(1-\frac{w}{100})\tilde{B}(w) + \int_0^w (v - 2\tilde{B}(x))\frac{1}{100}dx.$$

The first (second) term of the RHS refers to the case that the bidder makes the second highest (highest) bid.

The FOC of the equilibrium is

$$\frac{\partial U(v,w)}{\partial w} = -(1-\frac{w}{100})\tilde{B}'(w) - \frac{\tilde{B}(w)}{100} + \frac{v}{100} = 0 \tag{3}$$

at $w = v$. Rearranging terms we find

$$\frac{(100-v)\tilde{B}'(v) + \tilde{B}(v)}{(100-v)^2} = \frac{v}{(100-v)^2},$$

which is equivalent to

$$\frac{\tilde{B}(v)}{100-v} = \int_0^v \frac{x}{(100-x)^2}dx + C,$$

for some C. C must be zero (C must be at least zero, otherwise a bidder with signal 0 submits a negative bid; if C is larger than zero, a bidder with signal 0 submits a strictly positive bid. As $\tilde{B}$ is (by assumption) strictly increasing, this bidder submits the lowest bid with probability one, and has to buy one chopstick for a positive price. Clearly, she is strictly better off by bidding zero.) Also the SOC is fulfilled as $sign(\frac{\partial U(v,w)}{\partial w}) = sign(v-w)$. It is readily checked that B is a solution.

What remains to be checked it that B is strictly increasing. From (3), B is strictly increasing if and only if $B(v) < v$ for almost all $v \in [0, 100]$. This is true, as

$$
\begin{aligned}
B(v) &= v + [100 - v] [\log (100 - v) - \log 100] \\
&< v
\end{aligned}
$$

for all $v \in (0, 100)$. As B is strictly increasing, CSA is efficient. ■

5.2 Instructions for the experiment

Original Instructions were in German. These are instructions for treatment CSA.

General information for participants

You are taking part in an economics experiment funded by the *Jubilaeumsfonds der Oesterreichischen Nationalbank*. The purpose of the experiment is to analyze decision behavior in markets.

You will receive 5 Euro for showing up. If you carefully read the instructions and follow the rules you can earn a fair amount of money. During the experiment you can earn additional amounts of money. In this experiment you earn points. These points will be converted with a conversion rate of

100 points = 3 Euro.

Your final payoff consists of the initial 5 Euro given to you at the beginning of the experiment and the money you earn in the course of the experiment. You will be paid immediately after the experiment in cash.

During the experiment communication is forbidden. If you have questions, please ask us. We will gladly answer your questions individually. It is very important that you follow this rule. Otherwise the results of the experiment will be of no value from a scientific perspective.

Detailed instructions

In this experiment each participant is a buyer. You and one other buyer will participate in an auction in order to obtain units of a good. There are two possible outcomes. Either you obtain one unit, or you obtain two units. If you obtain only one unit, this is of no value for you. If you obtain two units, this will have a positive value for you. You will be informed about your value of obtaining two units. This value is a number between 0 and 100. Your value of obtaining two units of the good is randomly determined such that each number is equally likely to occur. This value is private information, i.e. neither you know the other buyer's value nor does the other buyer know your value.

The experiment consists of 3 practice periods and 40 trading periods. The practice periods will not account for your final earnings. But you should take these periods seriously since you will gain valuable experience for the trading periods that are paid.

In each period you will participate in an auction with a second buyer. In each period you are randomly matched with another buyer. You will never know whom you are matched with and it may be that you are matched with somebody more often than once.

In each period you and every other buyer are assigned new values for obtaining two units of the good. Notice that your value is very likely to be different from other buyers' valuations.

The auction rules

The good is sold according to the following rules:
Each buyer is asked to submit a bid. This bid is the maximum amount the bidder is willing to pay for one unit of the good. The buyer who submitted the higher bid is the

winner and obtains two units of the good. The buyer who submits the lower bid obtains only one unit.

For every unit you obtain you have to pay a price. This price equals the lower of the two submitted bids. The price and your value determine what you earn.

If you are the winner, i.e. you have obtained 2 units, this has a positive value for you but you have to pay the price for each of those units, i.e. you earn a number of points equal to your value minus two times the price.

If you have obtained only 1 unit this is of no value for you but you have to pay the price for this unit, i.e. you lose a number of points equal to the price.

Note that you can, dependent on the price and your value, make losses.

Example

The following examples shall help you to become familiar with the auction and the design of the interface. You will first see the Decision Screen and then the Result Screen.

– *Here the instructions contained a screenshot of the Decision Screen.* –

In this case your valuation for obtaining two units of the good is 74. Your bid is 32.

Important:

If you do not submit a bid within the prespecified time the computer will assign you a bid of 0.

When the time is elapsed you will see the Result Screen. *(Notice that the numbers given in the screens serve illustrative purposes only.)*

– *Here the instructions contained a screenshot of the Result Screen of a winner.* –

From the screen above you see that you submitted the highest bid. You obtain 2 units, realize a value of 63 and you pay 2 times the price. Check that you earned 33 point.

– *Here the instructions contained a screenshot of the Result Screen of a loser.* –

Here you see that the other buyer submitted the winning bid and you obtain only 1 unit of the good. You do not realize your value of 68 but you have to pay the price for one unit. Therefore you lose 30 points.

Good Luck!

Original Instructions were in German. These are instructions for treatment SPSB.

General information for participants

You are taking part in an economics experiment funded by the *Jubilaeumsfonds der Oesterreichischen Nationalbank*. The purpose of the experiment is to analyze decision behavior in markets.

You will receive 5 Euro for showing up. If you carefully read the instructions and follow the rules you can earn a fair amount of money. During the experiment you can earn additional amounts of money. In this experiment you earn points. These points will be converted with a conversion rate of

$$100 \text{ points} = 3 \text{ Euro} .$$

Your final payoff consists of the initial 5 Euro given to you at the beginning of the experiment and the money you earn in the course of the experiment. You will be paid immediately after the experiment in cash.

During the experiment communication is forbidden. If you have questions, please ask us. We will gladly answer your questions individually. It is very important that you follow this rule. Otherwise the results of the experiment will be of no value from a scientific perspective.

Detailed instructions

In this experiment each participant is a buyer. You and one other buyer will participate in an auction in order to obtain units of a good. There are two possible outcomes. Either you obtain one unit, or you obtain two units. If you obtain only one unit, this is of no value for you. If you obtain two units, this will have a positive value for you. You will be informed about your value of obtaining two units. This value is a number between 0 and 100. Your value of obtaining two units of the good is randomly determined such that each number is equally likely to occur. This value is private information, i.e. neither you know the other buyer's value nor does the other buyer know your value.

The experiment consists of 3 practice periods and 40 trading periods. The practice periods will not account for your final earnings. But you should take these periods seriously since you will gain valuable experience for the trading periods that are paid.

In each period you will participate in an auction with a second buyer. In each period you are randomly matched with another buyer. You will never know whom you are matched with and it may be that you are matched with somebody more often than once.

In each period you and every other buyer are assigned new values for obtaining two units of the good. Notice that your value is very likely to be different from other buyers' valuations.

The auction rules

The good is sold according to the following rules:
Each buyer is asked to submit a bid. This bid is the maximum amount the bidder is willing to pay for one unit of the good. The buyer who submitted the higher bid is the winner and obtains two units of the good. The buyer who submits the lower bid obtains only one unit.

For every unit the winner obtains, she has to pay a price. This price equals the lower of the two submitted bids. The price and your value determine what you earn.

If you are the winner, i.e. you have obtained 2 units, this has a positive value for you but you have to pay the price for each of those units, i.e. you earn a number of points equal to your value minus two times the price. Note that you can, dependent on the price and your value, make losses.

If you have obtained only 1 unit this is of no value for you and you don't have to pay the price for this unit, i.e. your income in this period is equal to 0.

Example

The following examples shall help you to become familiar with the auction and the design of the interface. You will first see the Decision Screen and then the Result Screen.

– Here the instructions contained a screenshot of the Decision Screen. –

In this case your valuation for obtaining two units of the good is 96. Your bid is 88.

Important:

If you do not submit a bid within the prespecified time the computer will assign you a bid of 0.

When the time is elapsed you will see the Result Screen. *(Notice that the numbers given in the screens serve illustrative purposes only.)*

– Here the instructions contained a screenshot of the Result Screen of a winner. –

From the screen above you see that you submitted the highest bid. You obtain 2 units, realize a value of 96 and you pay 2 times the price of 40. Check that you earned 16 point.

– Here the instructions contained a screenshot of the Result Screen of a loser. –

Here you see that the other buyer submitted the winning bid and you obtain only 1 unit of the good. You do not realize your value of 68 and you don't have to pay the price for this unit. Therefore your income in this period is 0.

Good Luck!

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