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An Externality-Robust Auction: Theory and Experimental Evidence

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Abstract

An auction is externality-robust if unilateral deviations from equilibrium leave the other bidders' payoffs unaffected. The equilibrium and its outcome will then persist if certain types of externalities arise between bidders. One example are externalities due to spiteful preferences, which have been used to explain overbidding in the second-price auction (SPA). Another example are cross-shareholdings between companies that compete in an auction. We derive an auction that coincides with the SPA in terms of efficiency and revenue but, in contrast to the SPA, is externality-robust. The externality-robust auction (ERA) is a first-price auction in which truthful bidding is encouraged by bonus payments. We test the robustness property experimentally by comparing SPA and ERA. We replicate the earlier finding of significant average overbidding in the SPA, but we find that bidders bid on average their value in the ERA. We conduct additional treatments where bidders play against the computer and we use controls for cognitive skills and joy of winning to further pin down the reasons behind the subjects' bidding behavior.

JEL-Code: C910, D030, D440, D820.

Keywords: second-price auction, spitefulness, mechanism design, experimental auctions.

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1 Introduction

When Vickrey (1961) first described the second-price sealed-bid auction (SPA), his goal was to devise a selling mechanism that achieves Pareto efficiency in private information environments, without requiring too much strategic sophistication of the agents. Since truth-telling is a dominant strategy in the SPA, every "bidder can confine his efforts and attention to an appraisal of the value the article would have in his own hands, at a considerable saving in mental strain" (Vickrey, 1961, p. 22). Hence a certain notion of robustness – with respect to knowledge and beliefs, see Bergemann and Morris (2005) – is an important argument in favor of the SPA.

Experimental studies reveal, however, that the actual performance of the SPA can differ substantially from the theoretical prediction (Kagel, 1995): overbidding is regularly observed, such that Pareto efficiency of the outcome is not guaranteed. Explaining this finding is intricate. Most behavioral models that predict overbidding in auction formats like the first-price sealed-bid auction (FPA) fail to do so in the SPA, precisely because of its dominance property.[1] Among the candidates that can explain overbidding in the SPA, spiteful preferences have received much attention (e.g. Morgan et al., 2003; Brandt et al., 2007). Spiteful bidders have an incentive to overbid because the own bid can affect the price that a winning opponent has to pay in the SPA. The experimental literature has presented evidence for the presence of a spite motive among bidders in auctions (Andreoni et al., 2007; Cooper and Fang, 2008; Nishimura et al., 2011).[2] Given these empirical findings, robustness with respect to interdependent preferences might not be of lesser importance than robustness as captured by dominant strategies. The contribution of this paper is, first, to formally derive such a robust auction format and, second, to test its predicted properties in a laboratory experiment.

In a mechanism design framework with independent private values and quasilinear payoffs, Bierbrauer and Netzer (2014) have introduced the concept of externality-robustness.[3] Suppose that the Bayes-Nash equilibrium of a mechanism satisfies that unilateral deviations (e.g. to overbidding in an auction) leave the expected payoffs of all non-deviating agents unaffected. Such

[1] This holds for models of risk aversion (Cox et al., 1988), anticipated regret (Filiz-Ozbay and Ozbay, 2007), level-k thinking (Crawford and Iriberri, 2007; Crawford et al., 2009), quantal response equilibrium (Goeree et al., 2002), impulse balance equilibrium (Ockenfels and Selten, 2005), or interim rationalizability (Battigalli and Siniscalchi, 2003).

[2] Cooper and Fang (2008) show that, in addition to spitefulness, both joy of winning (Roider and Schmitz, 2011) and imperfect learning help to explain their findings. Lange and Ratan (2010) propose a specific form of loss aversion as a driver of overbidding and discuss resulting differences between lab experiments and the field.

[3] Bierbrauer and Netzer (2014) focus on intention-based social preferences, but their concept is applicable to a wider range of externalities.

an equilibrium will continue to exist for general preference interdependencies, because the bidders cannot manipulate each others' payoffs. In addition to spitefulness, the class of externalities for which robustness is implied also contains motives such as inequality aversion (Fehr and Schmidt, 1999; Bolton and Ockenfels, 2000), intention-based social preferences (Rabin, 1993; Dufwenberg and Kirchsteiger, 2004), or altruism (Andreoni, 1989). Bierbrauer and Netzer (2014) show that externality-robustness is implied by an insurance property of the (incentive-compatible) social choice function to be implemented, i.e., the agents' payoffs have to be ex-ante insured against the randomness in the other agents' types. This property is similar to concepts of insurance in auctions with risk-averse agents (e.g. Maskin and Riley, 1984) and with ambiguity-averse agents (e.g. Bose et al., 2006), but it serves a different purpose here. Insurance is relevant with risk-averse agents (albeit not generally optimal, see Matthews, 1983, and Maskin and Riley, 1984) for the conventional reasons, and it is relevant with ambiguity-averse agents (and also optimal, see Bose et al., 2006) because providing insurance on the worst-case prior allows the seller to extract revenue from the agents. In the present context, insurance is relevant because it protects an agent against other agents' attempts to manipulate her payoffs, and hence it protects the equilibrium against payoff externalities.[4]

Given the degrees of freedom in designing ex-post transfers of Bayesian incentive-compatible mechanisms, it is possible to make any mechanism externality-robust without changing either its allocation rule or its expected revenue. In the first part of this paper, we formally derive the robust counterpart to the SPA, the externality-robust auction (ERA). We show that the ERA corresponds to a first price auction which is augmented by bonus payments to elicit larger bids. Specifically, every bidder obtains a bonus that is increasing in the own bid but independent of the others' bids and the event of winning or losing. The bonus schedule is designed so as to induce truthful bidding. Unilateral deviations from truthful bidding then have no effect on the other bidders' payoffs, because (*i*) their bonus payment is unaffected and (*ii*) winning the auction generates no additional rents that can be manipulated. We will discuss the relation of the ERA to several previously described auction formats in Section 2.6.

The hypothesis that payoff externalities are the reason for overbidding in the SPA, together with the externality-robustness of the ERA leads to several predictions about bidding behavior,

[4]See Bose et al. (2006, p. 424f) for a careful discussion of the different concepts of insurance in auctions. Bellemare and Sebald (2011) apply a related invariance property to experimentally infer about belief-dependent preferences. Esö and Futo (1999) have investigated the different problem of insuring the auctioneer against randomness in the revenue (see also Börgers and Norman, 2009).

which we test experimentally in the second part of the paper. First and foremost, we expect to find overbidding in the SPA but not in the ERA, since spitefulness among experimental subjects can manifest itself in overbidding in the SPA but not in the ERA. We conducted treatments for both auction types, relying on a between subjects design. Participants are anonymously and randomly rematched in groups of two bidders in each of 24 rounds. Their private values are determined anew every round by an independent draw from a uniform distribution. The results confirm our main hypothesis. In the SPA, bids are on average about 10 percent above values. Average overbidding in the ERA, by contrast, is not different from zero. This difference in average overbidding between SPA and ERA is highly significant.

To put the theoretical arguments to further testing, we conducted control treatments where subjects interact with a computer instead of another subject. The important property of these control treatments is that interaction with a computer directly eliminates the possibility that a bidder can influence the payoff of another bidder.[5] If payoff externalities are indeed the (only) reason for overbidding in the SPA, we should not observe overbidding in the SPA against the computer. For the ERA, in contrast, where no externality exists by design, we should observe no change in bidding behavior when the human opponent is replaced by the computer. Our data show that average overbidding is significantly reduced (to about 4 percent) in the SPA against the computer. We also find that average overbidding remains indistinguishable from zero in the ERA against the computer. Even though some overbidding persists in the SPA against the computer, these results provide unambiguous evidence that a large part of the difference in average bidding behavior between the SPA and the ERA is driven by the property of externality-robustness of the ERA.

To capture further possible motives for bidding behavior in the different auction formats, and also to understand individual heterogeneity, we administered a Raven Progressive Matrices test (Raven et al., 2007), which measures cognitive skills. We also collected a measure of the subjects' joy of winning, using a procedure due to Sheremeta (2010) where money can be invested to win a contest with no monetary prize. Joy of winning turns out to be positively correlated with bidding in all four treatments, although significantly so only in two of the four treatments. Cognitive skills have a significant impact on bidding only in the SPA, where better cognitive

[5]Replacing human opponents by a computer is a standard experimental technique to eliminate social contexts, see e.g. Bohnet and Zeckhauser (2004) for a trust game and van den Bos et al. (2008) for a common value auction. Note that the SPA against the computer bidder is a variant of the Becker-DeGroot-Marschak mechanism (Becker et al., 1964), which is often used to elicit the willingness to pay of a single buyer.

skills are associated with less overbidding. The distinguishing feature of the SPA from the other three treatments is the existence of another bidder whose payoff can be manipulated. This observation lends support to the possibility that cognitive skills serve as a proxy measure for less spiteful preferences in our analysis, which is supported by existing evidence that has documented a positive correlation between cognitive skills and pro-social behavior (e.g. Burks et al., 2009; Millet and Dewitte, 2007).

The primary goal of this paper is to derive and test a behaviorally motivated auction format. We do this by focussing on the externality of spitefulness that occurs naturally in the laboratory, and we thus also contribute to the literature on overbidding and the spite motive in auctions. An alternative approach for testing the externality-robustness of the ERA would be to induce interdependencies in the laboratory. For example, in several real-world auctions, bidders are firms who hold shares of their competitors (Ettinger, 2003; Dasgupta and Tsui, 2004; Chillemi, 2005; Ettinger, 2008). Such cross-shareholdings imply that firms take into account the effect of their behavior on other bidders' profits – yet another externality that is resolved by the ERA and that could be induced and studied in an experimental setting. Importantly, cross-shareholdings are predicted to lead to underbidding. While overbidding might not be perceived as a problem by a seller whose interest is not efficiency but to maximize revenue, employing the ERA can be very attractive even for such a seller if cross-shareholdings among bidders exist.

In a bilateral trade context, the recent study by Bierbrauer et al. (2014) compares theoretically and experimentally a mechanism that is revenue-optimal and ex-post implementable if there are no externalities between the agents, to one that is constrained optimal under the additional requirement of externality-robustness.[6] In line with our findings, they report systematic deviations from predicted behavior in the former but not in the latter mechanism.

2 Theoretical Analysis

2.1 Formal Framework

Framework and notation introduced below are a special case of the mechanism design approach in Bierbrauer and Netzer (2014). The problem is to allocate one unit of an indivisible object among risk-neutral bidders with private information about their willingness to pay. The set of bidders is $I = \{1, \ldots, n\}$, $n \geq 2$. Bidder i's valuation of the object is denoted by $\theta_i \in \Theta_i$.

[6]Netzer and Volk (2014) investigate ex-post implementation for the model of intention-based social preferences.

Let $\theta = (\theta_1, \ldots, \theta_n) \in \Theta = \Theta_1 \times \ldots \times \Theta_n$ denote the profile of valuations of all bidders. The expression $\theta = (\theta_i, \theta_{-i})$ will be used when convenient. Bidder i's valuation is drawn randomly from the set $\Theta_i = \{\theta^1, \ldots, \theta^m\} \subset \mathbb{R}$, where $m \geq 2$ and $0 \leq \theta^1 < \theta^2 < \ldots < \theta^m$. Valuations are drawn independently and identically across bidders, according to strictly positive probabilities $p^1, p^2, \ldots, p^m$. Cumulated probabilities are denoted by $P^k = \sum_{j=1}^{k} p^j$, $k = 0, 1, \ldots, m$, so that $P^0 = 0$ and $P^m = 1$. Let $Q = \{(q_1, \ldots, q_n) \in [0,1]^n | \sum_{i=1}^{n} q_i = 1\}$ be the set of possible outcome decisions, where $q = (q_1, \ldots, q_n) \in Q$ are the winning probabilities for each bidder. Let $T = \mathbb{R}^n$ be the set of all possible transfers, where $t = (t_1, \ldots, t_n) \in T$ prescribes the transfers paid to each bidder (negative transfers amount to payments made by the corresponding bidder). Altogether, $A = Q \times T$ is the set of possible allocations. Bidder i's material payoff from an allocation is given by $\pi_i(q_i, t_i, \theta_i) = q_i\theta_i + t_i$.

In this environment, a social choice function (SCF) is a mapping $f : \Theta \to A$ which assigns an allocation $f(\theta) \in A$ to every profile $\theta \in \Theta$. The notation $f = (q_1^f, \ldots, q_n^f, t_1^f, \ldots, t_n^f)$ will also be used, so that $q_i^f(\theta)$ is the winning probability and $t_i^f(\theta)$ is the transfer to bidder i under the SCF f, given valuations θ. The SCF f^{SPA} which is underlying the second-price sealed-bid auction is described as follows. For any given profile of valuations θ, let $W(\theta) \subseteq I$ be the set of bidders with maximal valuation in $\theta = (\theta_1, \ldots, \theta_n)$. Furthermore, let $s(\theta)$ be the second-largest valuation in θ. Whenever $|W(\theta)| = 1$, so that there is a single bidder with largest valuation, $s(\theta)$ is strictly smaller than this largest valuation. Whenever $|W(\theta)| > 1$, so several bidders have the same largest valuation, $s(\theta)$ is identical to this largest valuation. Now define

$$q_i^*(\theta) = \begin{cases} 1/|W(\theta)| & \text{if} \quad i \in W(\theta), \\ 0 & \text{if} \quad i \notin W(\theta), \end{cases} \tag{1}$$

which implies that the object is allocated with equal probabilities among all bidders with largest valuation. Transfers are defined by

$$t_i^{SPA}(\theta) = \begin{cases} -s(\theta)/|W(\theta)| & \text{if} \quad i \in W(\theta), \\ 0 & \text{if} \quad i \notin W(\theta), \end{cases} \tag{2}$$

which states that the winner has to pay the second-largest valuation (adjusted for randomly broken ties). The direct mechanism for $f^{SPA} = (q_1^*, \ldots, q_n^*, t_1^{SPA}, \ldots, t_n^{SPA})$, where each bidder is asked for a bid from Θ_i and the outcome is determined by f^{SPA}, is called the second-price sealed-bid auction, or the Vickrey auction (Vickrey, 1961). It is a special case from the class of Vickrey-Clarke-Groves mechanisms (e.g. Mas-Colell et al., 1995, ch. 23), so that truthful bidding (making bids equal to the true value) is a weakly dominant strategy for every bidder.[7]

2.2 Externality-Robustness

While the dominance of truthful bidding is an important advantage of the SPA, it has the disadvantage of being vulnerable to externalities. This can be illustrated in a simple example. Assume $n = 2$ and $m = 2$. Let $\Theta_i = \{1, 2\}$ be the set of possible valuations, and write $p^1 = p$ and $p^2 = 1 - p$, where $0 < p < 1$. Assume also that bidder 2 in fact bids truthfully. It is an easy exercise to derive the ex-ante expected payoff pairs that bidder 1 can induce for herself and the opponent by varying her own strategy. Truthful bidding yields the maximal expected payoff $p(1 - p)$ for bidder 1. Deviations to always bidding low (underbidding) or always bidding high (overbidding) reduce this expected payoff to $p(1 - p)/2$. The effect on bidder 2 is as follows. Truthful bidding yields $p(1-p)$ also for bidder 2. If bidder 1 deviates to underbidding, however, the expected payoff of bidder 2 increases to $(1 - p)$. Overbidding, on the other hand, reduces bidder 2's expected payoff to 0. Now suppose that bidder 1 is not selfish but maximizes a weighted sum of the own and the opponent's payoff, with weight α placed on the opponent. Then underbidding will be preferable to truthful bidding whenever $\alpha > [p/(1 - p)]/2$. This could correspond to a case with a sufficiently large share α of holdings in the opponent firm (Ettinger, 2003; Dasgupta and Tsui, 2004; Chillemi, 2005). Overbidding, on the other hand, becomes more attractive than truth-telling whenever $\alpha < -1/2$, which could correspond to a case of sufficiently strong spitefulness (Morgan et al., 2003; Brandt et al., 2007).

The problem arises because bidder 1's strategy choice affects the payoff of bidder 2. Suppose that, in a different auction format, bidder 1 did not have the opportunity to manipulate the payoff of bidder 2 through a unilateral deviation from truthful bidding, and suppose further that truthful bidding was still a selfish best response for bidder 1. In such an auction, the incentive to bid truthfully would not be destroyed by pro- or anti-social concerns.[8] Following Bierbrauer and Netzer (2014), we say that an SCF is externality-robust if it is (i) Bayesian incentive-compatible,

[7] Truthful bidding is, however, not the unique equilibrium. See Blume and Heidhues (2004) for a complete characterization of the equilibrium structure. The focus on equilibrium existence but not uniqueness in mechanism design theory is often justified by the argument that the mechanism designer can suggest a particular equilibrium to the agents.

[8] This argument applies to a large class of interdependent preference models, including essentially all the models commonly used in the literature. For a more detailed discussion see Bierbrauer and Netzer (2014) or Bierbrauer et al. (2014), and the related arguments in Segal and Sobel (2007) and Dufwenberg et al. (2011).

i.e., truth-telling is a Bayes-Nash equilibrium in the direct mechanism, and (*ii*) it satisfies that unilateral deviations from this equilibrium have no impact on the expected payoffs of all other agents. Bierbrauer and Netzer (2014, Proposition 2) show in an abstract framework that it is possible to start from any Bayesian incentive-compatible SCF f and construct an externality-robust SCF $\bar{f}$ that coincides with f in terms of the decision rule $(q_1^f, \ldots, q_n^f)$, the expected revenue, and the interim expected payoffs of all agents. In the next section, we apply this result to our auction setup, where the construction of the new transfers $(t_1^{\bar{f}}, \ldots, t_n^{\bar{f}})$ reduces to

$$t_i^{\bar{f}}(\theta) = \mathbb{E}_{\theta_{-i}}\left[q_i^f(\theta_i, \theta_{-i})\,\theta_i + t_i^f(\theta_i, \theta_{-i})\right] - q_i^f(\theta)\,\theta_i. \tag{3}$$

Bose et al. (2006) and Bodoh-Creed (2012) apply an analogous construction in a model framework where bidders have ambiguous beliefs about the other bidders' values. The expectation in (3) is then taken with respect to bidder i's worst-case prior, which provides insurance to the bidder and at the same time increases revenues to the seller.

2.3 The Externality-Robust Auction

We now apply the construction described in the previous section to $f = f^{SPA}$ to derive its externality-robust counterpart $\bar{f} = f^{ERA}$. Since the efficient decision rule $(q_1^*, \ldots, q_n^*)$ is adopted without modification, the following proposition describes only the modified transfers.

Proposition 1. *In the externality-robust auction f^{ERA}, transfers are given by*

$$t_i^{ERA}(\theta) = B(\theta_i) + \begin{cases} -\theta_i/|W(\theta)| & \text{if} \quad i \in W(\theta), \\ 0 & \text{if} \quad i \notin W(\theta), \end{cases} \tag{4}$$

where

$$B(\theta_i) = \sum_{j=1}^{k-1} \left(P^j\right)^{n-1} \left(\theta^{j+1} - \theta^j\right) \tag{5}$$

for k such that $\theta_i = \theta^k$.

Proof. See Appendix A.1. □

Consider the simultaneous sealed-bid auction induced by the direct mechanism for f^{ERA}. Without the additional term $B(\theta_i)$ in the transfers (4), it would correspond to an FPA where bidders are required to submit bids and the winner pays the own bid. In the simple FPA, bidders would shade their bids (report less than their true valuation) with the goal of earning rents in case of winning, but the bonus function $B(\theta_i)$ defined in (5) restores incentives to report the valuation truthfully. The bonus takes a value of zero for the smallest possible bid, it is strictly increasing, and it does not depend on the opponents' bids or the event of winning or losing the auction. Externality-robustness now holds because, first, the bonus $B(\theta_i)$ received by bidder i cannot be influenced by any opponent, and, second, there are no additional rents that can be manipulated by manipulating the identity of the winner, as the true valuation is paid by the winner in equilibrium.

Three qualifications are appropriate. First, our approach relies on an idea of robustness, not of optimal auction design. If the exact nature of externalities between bidders is known, an auction tailored to the situation can achieve larger revenues. Our analysis applies to situations where such information requirements are excessive, for instance due to unobserved heterogeneity in bidders' (anti-)social preferences or firm ownership structures that are hard to disentangle or unobservable to the outsider.[9] Second, a disadvantage of the ERA is that the optimal bonus schedule depends on the prior distribution of values, and it no longer has dominant strategies. This reflects the fact that there is a trade-off between the different notions of robustness of a mechanism. In light of the discussion in the introduction, this trade-off might have to be resolved differently from case to case.[10] Third, the literature has investigated a large range of different externalities in auctions (Jehiel and Moldovanu, 2006). Not all of them are captured by the notion of externality-robustness considered here, which only eliminates externalities based on overall payoffs.[11]

[9]See e.g. Chillemi (2005) and Loyola (2007) for optimal auctions with known cross-shareholdings, Lu (2012) for financial externalities, and Tang and Sandholm (2012) for spiteful bidders. As an alternative to externality-robustness, a multi-dimensional mechanism design problem could be considered if externalities are not observable. These problems are often intractable, and they still require substantial knowledge of the class of externalities.

[10]Segal and Sobel (2007) propose a concept which speaks to both notions of robustness at once, by requiring the opponent in a two-player game to be indifferent between the conventionally defined dominated and dominating strategy for all own strategies. For the purpose of mechanism design, this concept appears overly demanding. Bierbrauer et al. (2014) impose externality-robustness on top of ex-post implementability, which requires to sacrifice revenues.

[11]Bidders still have the discretion to manipulate the identity of the winner, which can be relevant in other applications (Jehiel et al., 1996). The same holds for externalities arising from types to the losers of an auction (Jehiel and Moldovanu, 2000) and directly from prices (Engelbrecht-Wiggans, 1994; Maasland and Onderstal, 2007) as in knockout auctions (Graham and Marshall, 1987; McAfee and McMillan, 1992) or auctions that are used to finance public goods (Goeree et al., 2005; Engers and McManus, 2007). Finally, externalities can arise from toeholds in takeovers (Burkart, 1995; Singh, 1998; Bulow et al., 1999; Ettinger, 2008), which is also not addressed by the ERA.

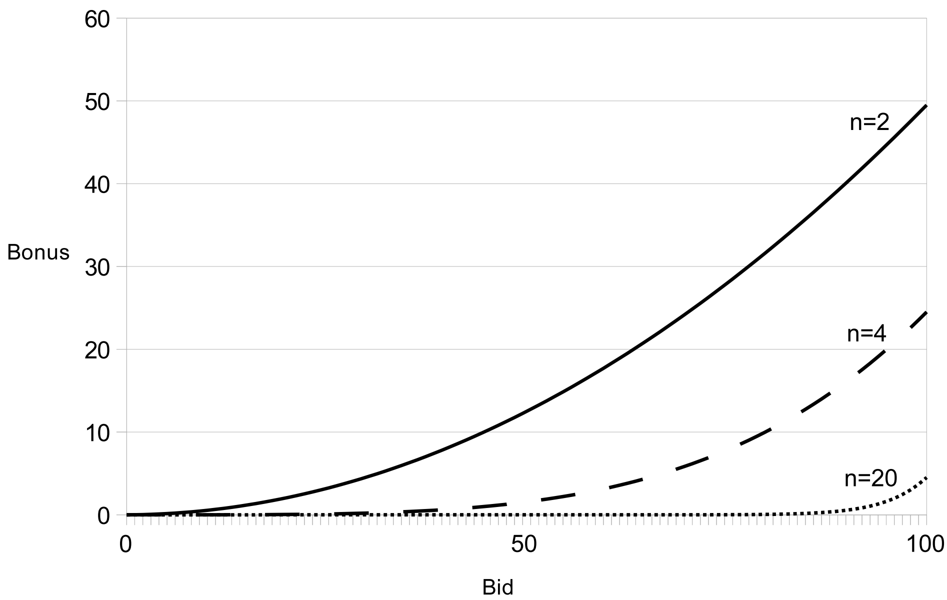
2.4 Example

To get a better understanding of the properties of $B(\theta_i)$, suppose that $\Theta_i = \{1, ..., m\}$ and that values are uniformly distributed. The bonus function can now be written as

$$B(k) = \sum_{j=1}^{k-1} \left(\frac{j}{m}\right)^{n-1},$$

which is a strictly convex function of the bid k. For $m = 100$, as in our following experiment, it is depicted in Figure 1 for the three cases of $n = 2$, $n = 4$ and $n = 20$. With two competing bidders, as in the experiment, a bid of 50, for instance, is rewarded by a bonus of 12.25, a bid of 80 is rewarded by a bonus of 31.6, and the maximal bid of 100 is rewarded by a bonus of 49.5.

Figure 1: Bonus Function



Returning to the example from Section 2.2 ($n = m = 2$, $p^1 = p$, $p^2 = 1 - p$), it follows that $B(1) = 0$ and $B(2) = p$. Table 1 compares the SPA to the ERA for this case. Each row in the table corresponds to one of the four possible profiles of values. The efficient decision rule is identical for both auctions. The table then contains the transfers of the SPA and the ERA, as well as their generated ex-post revenues. For the ERA, straightforward calculations show that, conditional on bidder 2 bidding truthfully, bidder 1 still achieves the maximal own expected payoff of $p(1-p)$ by also bidding truthfully, while both over- and underbidding reduce this payoff to $p(1-p)/2$. In contrast to the SPA, however, bidder 2 can always expect to obtain $p(1 - p)$, irrespective of bidder 1's behavior.

Table 1: Comparison of SPA and ERA

θ_1	θ_2	q_1^*	q_2^*	t_1^{SPA}	t_2^{SPA}	Revenue	t_1^{ERA}	t_2^{ERA}	Revenue
1	1	1/2	1/2	$-1/2$	$-1/2$	1	$-1/2$	$-1/2$	1
1	2	0	1	0	-1	1	0	$p-2$	$2-p$
2	1	1	0	-1	0	1	$p-2$	0	$2-p$
2	2	1/2	1/2	-1	-1	2	$p-1$	$p-1$	$2(1-p)$

2.5 Ex-Post Revenues

The ERA generates the same expected revenue as the SPA with selfish bidders, but their ex-post revenues differ. In particular, the ex-post revenue of the SPA is always non-negative. This is not necessarily the case for the ERA where the auctioneer makes payments to the bidders, so that ex-post deficits might become possible. It will be shown in the following that deficits remain impossible in the case with uniformly distributed values, but cannot be ruled out in some more general environments.

Recall that $B(\theta_i)$ is increasing in θ_i. To rule out deficits for all possible valuation profiles $\theta \in \Theta$, it therefore suffices to check the cases where all bidders have the same valuation: $\theta_i = \theta^k$ for some $k \in \{1, \ldots, m\}$ and all $i \in I$. These are worst-case scenarios for the auctioneer, because overall bonus payments are maximal among all valuation profiles that yield a gross revenue of θ^k. Hence it suffices to check whether or not

$$n\, B(\theta^k) \leq \theta^k \tag{6}$$

holds for all $k \in \{1, \ldots, m\}$, where the LHS captures the bonus sum and the RHS is gross revenue collected. As a next step, it can be shown that condition (6) is most stringent for the largest possible value θ^m, a consequence of convexity of the bonus function (see Appendix A.2). Thus, the ERA never runs a deficit if and only if

$$n\, B(\theta^m) \leq \theta^m. \tag{7}$$

For the framework introduced in Section 2.4, condition (7) can be verified (see again Appendix A.2), which shows that ex-post deficits are impossible with uniformly distributed (equidistant) values. Deficits become possible in more general frameworks, however. For instance, assume $n = 2$ and $m = 3$ within the previous framework, but deviate from the assumption of a uniform distribution. For concreteness, let $p^1 = 1 - \epsilon$, $p^2 = \epsilon/2$ and $p^3 = \epsilon/2$. It can be shown that (7) is violated whenever $\epsilon < 1/3$. If high valuations are unlikely, the bonus payments must be especially large for high bids, to ensure incentive-compatibility. Otherwise, high-value bidders would be tempted to underbid and still win with sufficiently large probability. If several bidders simultaneously have such high valuations, this leads to a deficit.

2.6 Existing Auction Formats

To illustrate revenue equivalence beyond the usual class of auctions, Riley and Samuelson (1981) describe, among other examples, a "Santa Claus auction." It turns out that the ERA corresponds to this auction format. However, Riley and Samuelson do not examine the Santa Claus auction any further and, in particular, they do not describe its desirable properties in the presence of externalities, which is the focus in our paper.[12] Bose et al. (2006, p. 422) describe an analogous auction with a bonus schedule that depends on the degree of ambiguity, and which converges to the Santa Claus auction as ambiguity vanishes. Also related, Matthews (1983) describes an auction where a bonus is paid to high bidders, while low bidders have to make payments to the auctioneer.

The distinguishing feature of the ERA is that bonus payments are made to all bidders. In this regard it is also related to several real-world auction formats in which the transfers to non-winning bidders are different from zero.[13] First, this also holds in all-pay auctions (Goeree et al., 2005), albeit with opposite sign. There, non-winning bidders have to pay their bid, while they receive a payment related to their bid in the ERA. Second, in some auctions a share of the revenue is distributed back to the bidders (Graham and Marshall, 1987; McAfee and McMillan, 1992; Engelbrecht-Wiggans, 1994; Maasland and Onderstal, 2007). Engelbrecht-Wiggans (1994), for instance, describes how the heirs bid for an estate and divide the winner's payment among themselves. In such auctions, however, the transfer to an unsuccessful bidder depends on the winning bid instead of the own bid, which reinforces the opportunity to affect each others' payoffs by over- or underbidding. Finally, the literature has investigated premium auctions such as the different versions of the Amsterdam auction (Goeree and Offerman, 2004; Hu et al., 2011). They are closely related to the ERA because they reward a premium to a non-winning bidder

[12] Technical differences are the reserve price and the continuous valuations in their paper. The bonus function for $n = 2$ in Riley and Samuelson (1981, p. 387) is $\int_{v_*}^{b} F(v)dv$, where b is the bid, v_* is the reserve price, and F is the cdf of the valuations. Riley and Samuelson (1979) contains the generalization to $n \geq 2$ bidders.

[13] The literature has also investigated bonus auctions in which an individual-specific bonus is awarded only to the winner, in form of a discount on the price that has to be paid (Mares and Swinkels, 2011).

with the goal of raising equilibrium bids. In the first-price Amsterdam auction, for instance, the highest bidders wins and pays the own bid, while both winner and second-highest bidder receive a premium that is increasing in the second-highest bid.[14] There are two main differences to the ERA. First, not all bidders obtain the premium, and, second, the size of the premium does not depend on the own bid alone. Unilateral deviations from equilibrium behavior will therefore again influence the payoffs of the other bidders.

3 Experimental Design

We conducted four different treatments, a second-price auction, an externality-robust auction, and two corresponding auction formats in which subjects interacted with a computer instead of interacting with another subject.

3.1 Second-Price Auction (SPA)

Treatment SPA is a standard second-price auction, repeated for 24 rounds. Subjects are anonymously and randomly rematched in two-person groups in each round.[15] Each bidder first observes her private value but not the value of the matched bidder. Values are drawn independently across bidders and rounds according to a uniform distribution from $\Theta_i = \{1, \ldots, 100\}$, which is common knowledge. Both bidders in a group then simultaneously submit their bids, which can be any value from Θ_i. The bidder who submits the higher bid wins the auction. She receives her private value and pays the bid of the losing bidder. The payoff of the losing bidder is zero. Ties are resolved randomly with equal probability. Feedback is given at the end of each round, where each bidder is reminded of her own valuation, the own bid, the bid of the competing bidder, and the resulting own payoff in the period. Then the next round begins.

3.2 Second-Price Auction against the Computer (SPA-C)

Subjects in treatment SPA-C face a single-agent decision problem. In contrast to treatment SPA, bidders are not matched in two-person groups but interact with the computer that draws random numbers from $\Theta_i = \{1, \ldots, 100\}$. Otherwise, the two treatments are identical. If the bid

[14] More precisely, an elimination stage takes place first, where the price increases until only two bidders are left. An FPA is then conducted among these two bidders, where the premium depends linearly on the difference between the second-highest bid and the price at which the first stage concluded. There also exists a second-price version of the Amsterdam auction. See Goeree and Offerman (2004) for more details and a formal analysis.

[15] Since we had between 30 and 36 subjects per session, repeated game effects should be absent.

of a subject exceeds the random number, the subject wins the auction. She receives her private value and pays a price that equals the random number. The subject's payoff is zero if her bid falls short of the random number. Ties are resolved randomly with equal probability. Bidders are informed in the beginning that the random numbers of the computer correspond to the bids of subjects in a past auction that was identical except for the fact that two bidders competed for winning. Indeed, we conducted one session of SPA-C for each session of SPA with the exact same realization of own values and others' bids. That is, for each subject in SPA-C there is a subject in SPA who had the same sequence of values in the 24 rounds. Moreover, the subject in SPA-C receives a sequence of random numbers from the computer that equals the sequence of bids that the corresponding subject in SPA received from the respective other bidders.

3.3 Externality-Robust Auction (ERA)

Treatment ERA is an implementation of the externality-robust auction. As in SPA, the auction is repeated with random rematching for 24 rounds, and values are drawn independently and uniformly from $\Theta_i = \{1, \ldots, 100\}$. The only difference between SPA and ERA are the auction rules that determine the payoffs. In ERA, the bidder with the highest bid wins and receives her private value as in SPA, but now she pays her own bid and receives the bonus that corresponds to her own bid as given in (5). The bidder with the lower bid also receives the bonus that corresponds to her own bid.

3.4 Externality-Robust Auction against the Computer (ERA-C)

Subjects in treatment ERA-C again face a single-agent decision problem because they interact with the computer. The treatments ERA and ERA-C are identical otherwise, so that the relation between ERA and ERA-C is the same as the relation between SPA and SPA-C.

3.5 Additional Measurements

In each session we elicited two additional individual characteristics after the 24 rounds of the respective auction format were completed. To measure a subject's "joy of winning," we conducted a short treatment in which the subject could win a contest against the computer. Each subject received an additional endowment of 20 points that could be spent to win the contest. After the subject's decision how many points to spend, the computer draws an integer from $\{0, \ldots, 20\}$ according to a uniform distribution. The subject wins the contest if the number of points spent exceeds the randomly drawn integer. Ties are randomly resolved with equal probability. Importantly, winning is merely symbolic, i.e., it does not carry a financial gain. A subject's payoff is thus given by 20 points minus the number of invested points, irrespective of the outcome of the contest. We take the number of points spent to win as a measure of the subject's joy of winning. This approach of measuring joy of winning follows Sheremeta (2010).[16]

To measure the subjects' "cognitive skills," we administered a computerized 12-item Raven Progressive Matrices test (Raven et al., 2007). The Raven test is a widely used IQ test, based on problems the solutions to which neither depend on knowledge nor on verbal skills. Each item presents a 3×3 matrix of abstract figures, where one figure is missing. Subjects have to determine the missing figure out of eight given solution possibilities. Identifying the correct solution requires reasoning about patterns across both rows and columns. The problems become more difficult over the course of the 12 items. Before the subjects could start working on the test, they first had to correctly solve two practice items to ensure the understanding of the test. After a subject correctly solved the two test items, she had 12 minutes to complete the 12 main items. Feedback for the main items was given only in the end. The performance in the Raven test and the measure of joy of winning serve as control variables in our analysis of the subjects' bidding behavior.

3.6 General Procedures

We conducted two sessions for each of the four treatments, with 272 subjects in total. 70 subjects participated in treatment SPA, 70 subjects participated in treatment ERA, and 64 and 68 subjects participated in the respective computer treatments. In each session we implemented three matching groups of size 10 to 12, depending of the number of subjects in a session, which varied due to no-shows between 30 and 36. The experiment was computerized with the software z-Tree (Fischbacher, 2007) and took place at the decision laboratory of the Department of Economics at the University of Zurich in 2013. Subjects were mainly students from the University of Zurich and the Swiss Federal Institute of Technology in Zurich. Students majoring in economics or psychology were not recruited. Each subject participated in only one session, which lasted about 90 minutes.

[16] In Sheremeta (2010), two subjects compete with each other to win a contest with no monetary reward. We implemented a contest against the computer to separate our measure of joy of winning from more complicated motives, such as spiteful attempts to interfere with another subject's joy of winning.

The instructions for the auctions were handed out to the subjects. They included comprehension questions that had to be answered correctly before the experiment could begin. A summary of the instructions was read aloud to ensure common knowledge. The bonus function of the externality-robust auction was presented to the subjects on a supplementary information sheet, both in form of a table and as a diagram. An English translation of the original German instructions for all four treatments can be found in Appendix A.3. The instructions for the two measurement tasks were provided directly on the computer screens. Payoffs from the auctions, denominated in "points," were converted into money at the rate of 4 points to CHF 1 (about \$ 1.05). Four rounds were randomly selected for payment at the end of the experiment. In the joy of winning task, points were converted into CHF at a rate of 10 to 1. We incentivized the Raven test by paying CHF 1 for each correctly solved item, in order not to confound our measure of cognitive skills with a subject's intrinsic motivation to participate in the test. On average, subjects earned CHF 33.30 in total, which includes a show-up fee of CHF 10.[17]

4 Hypotheses

If spiteful preferences are one (or the only) reason for overbidding in the SPA, we should observe less (or no) overbidding in the ERA, which is designed such that bidders cannot influence each others' payoffs. Spiteful preferences should therefore not affect the subjects' bidding behavior in the ERA. This observation gives rise to our main hypothesis:

Hypothesis 1. *There is less overbidding in ERA than in SPA.*

To test for the role of spiteful preferences more directly, subjects face non-strategic decision-making problems in our computer treatments. Spiteful preferences should not affect their behavior in these treatments because a competing player is absent. This gives rise to the following two hypotheses:

Hypothesis 2. *There is less overbidding in SPA-C than in SPA.*

Hypothesis 3. *There is no difference in bidding behavior between ERA-C and ERA.*

Overbidding can also be explained by a joy of winning motive (Cooper and Fang, 2008; Sheremeta, 2010). If subjects derive utility from the mere event of winning, then their optimal bids should be increased irrespective of the specific treatment:

[17]One participant made an overall loss of CHF 2.50 and paid her dues at the end of the experiment.

Hypothesis 4. *Higher joy of winning is associated with larger bids in all treatments.*

Better cognitive skills might be expected to lead to bidding behavior that is closer to optimal (Cooper and Fang, 2008), but optimality is determined by the subjects' preferences and the direction of deviation from optimality due to lack of cognitive skills in the different auction formats is not obvious. We thus have no ex-ante hypothesis about the effect of cognitive skills.

5 Experimental Results

5.1 Bidding Behavior

Figure 2 shows the average overbidding ($bid - value$ in points) in our four treatments. The leftmost bar indicates that we replicate the well-documented finding that subjects overbid in second-price auctions (Kagel, 1995). On average, our subjects' bids exceed their valuations by 5.1 points in SPA, which corresponds to about 10 percent given that the expected valuation is 50.5. In line with Hypothesis 1, Figure 2 also shows that there is no overbidding on average in ERA. Indeed, on average subjects bid 0.4 points less than their valuation. A Wilcoxon rank-sum test on matching group averages rejects the null hypothesis that overbidding is the same in SPA and in ERA ($p = 0.0043$, one-sided).

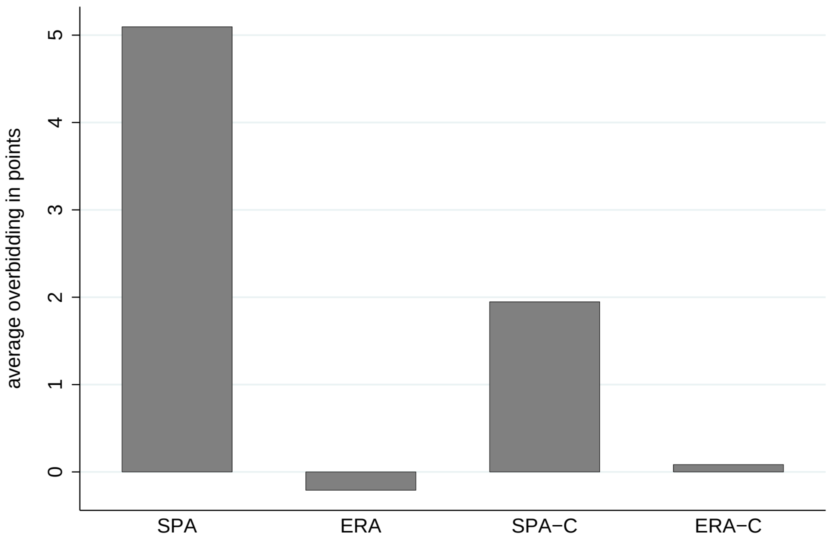
Result 1. *Average overbidding is significantly lower in ERA than in SPA. On average, there is no overbidding in ERA, while bids are about 10 percent above valuations in SPA.*

Result 1 confirms Hypothesis 1 and is consistent with the idea that spiteful preferences are a reason for overbidding in the SPA. To test more directly for the contribution of spiteful preferences to overbidding, we conducted the control treatment SPA-C. Figure 2 reveals that overbidding amounts to only 1.9 points on average in SPA-C. A Wilcoxon rank-sum test comparing matching group averages in SPA and individual averages in SPA-C rejects the null hypothesis that overbidding is the same in SPA and in SPA-C ($p = 0.0044$, one-sided).[18]

Result 2. *Average overbidding is significantly lower in SPA-C than in SPA. On average, bids are only about 4 percent above valuations in SPA-C.*

[18]Recall that for each bidder in SPA-C we have a bidder in SPA with an identical sequence of values and opponent bids. We are thus able to group participants in SPA-C into the corresponding matching groups. Assigning matching groups in SPA-C is artificial as there is no interaction between subjects, but it provides for a conservative test. A Wilcoxon rank-sum test comparing matching group averages in SPA and SPA-C yields $p = 0.0076$, one-sided.

Figure 2: Average Overbidding



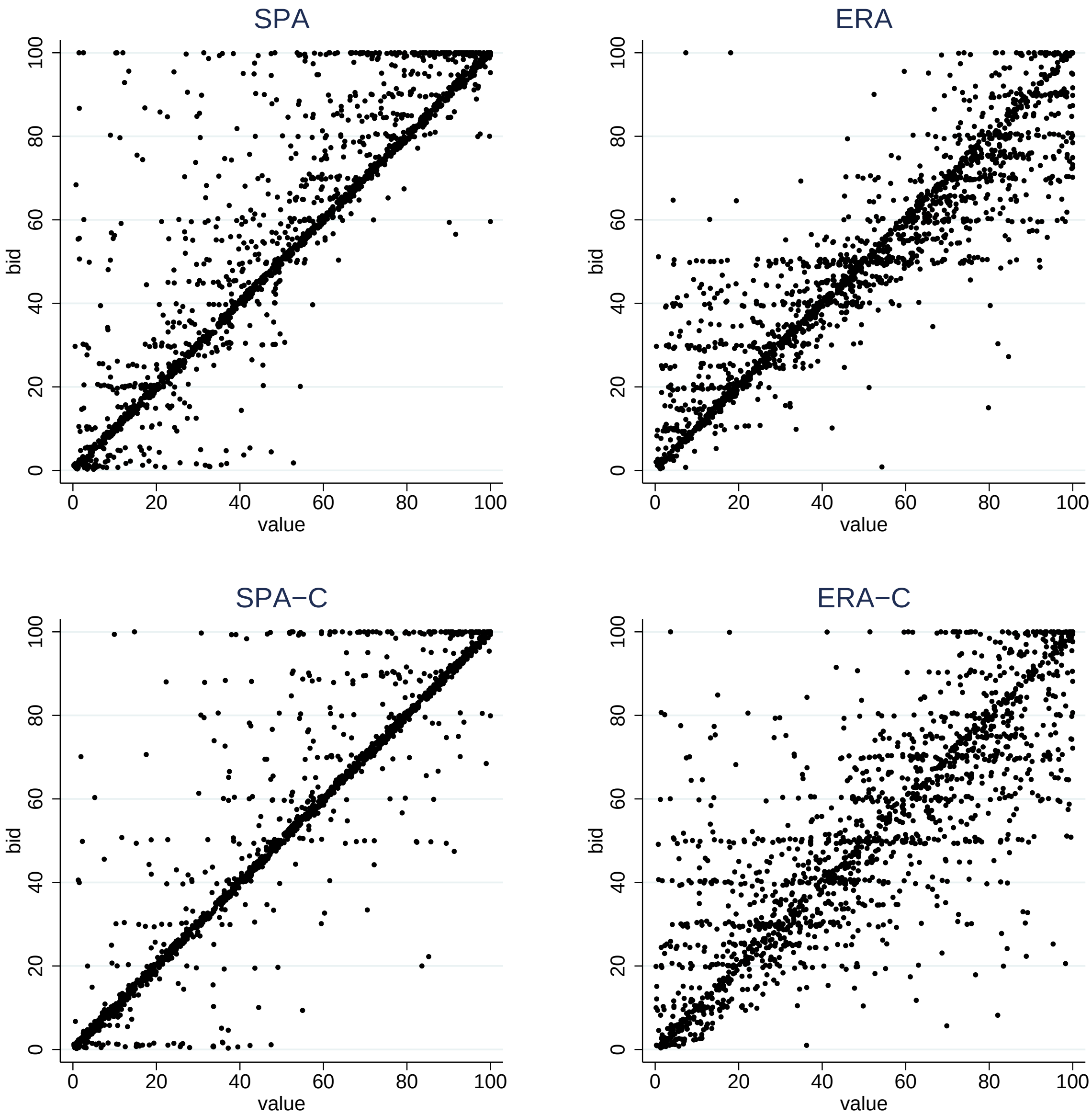
Result 2 confirms Hypothesis 2 and corroborates the idea that spiteful preferences are a reason for overbidding in the SPA. It also shows that some overbidding persists in SPA-C, even though bidders do not interact with other bidders in this treatment. This reveals that spite cannot be the only reason for overbidding. We also conducted the control treatment ERA-C. In line with Hypothesis 3, Figure 2 shows that average bids in ERA-C are very similar to average bids in ERA. Average overbidding amounts to 0.08 points in ERA-C. A Wilcoxon rank-sum test comparing matching group averages in ERA and individual averages in ERA-C does not reject the null hypothesis that overbidding is the same in ERA and in ERA-C ($p = 0.9526$, two-sided).[19]

Result 3. *Average overbidding does not differ between ERA-C and ERA.*

While Figure 2 illustrates our main results in a clear way, it hides a considerable variance in the subjects' behavior. Figure 3 provides scatter plots showing all individual bids that were submitted for given values in our four treatments. Dots on the 45-degree line indicate cases where a bidder submitted a bid that equals her valuation. Dots above (below) the 45-degree line indicate instances of overbidding (underbidding). In addition to the previously discussed differences in average overbidding, the scatter plots also show that the variance in bidding behavior differs between the four treatments. Bids are more dispersed in the externality-robust

[19] The same result prevails if we consider averages in the artificial matching groups in ERA-C and compare them to the matching group averages in ERA (Wilcoxon rank-sum test, $p = 0.9372$, two-sided).

Figure 3: Scatter Plots



auctions than in the second-price auctions. This finding might be due to the trade-off between the two different concepts of robustness – dominant strategies versus externality-robustness – mentioned earlier. In a very general FPA setting, Battigalli and Siniscalchi (2003) apply the concept of interim rationalizability, which rests on the assumption of common knowledge of rationality but not of correct equilibrium beliefs. They show that, while only truthful bidding is rationalizable in the SPA with independent private values and selfish bidders, bids both above and below the Bayes-Nash equilibrium are rationalizable in the corresponding FPA. Hence dispersion in bidding behavior should be expected in the FPA but not in the SPA when bidders are rational but do not hold correct equilibrium beliefs. In conjunction with the spite motive, a similar reasoning might explain why average overbidding is smaller but the variance is larger in the ERA than in the SPA.[20]

5.2 Efficiency and Revenue

We can also compare efficiency and revenue of the SPA and the ERA. The data reveal that the allocation is ex-post efficient (i.e., the bidder with the highest valuation receives the good) in 89.3 percent of the cases (750 out of 840) in SPA and in 90.1 percent of the cases (757 out of 840) in ERA. A Wilcoxon rank-sum test on matching group averages reveals that the null hypothesis that the efficiency is the same in SPA and ERA cannot be rejected ($p = 0.5745$, two-sided).

With regard to the seller's revenue, we find that a seller receives 38.04 on average in SPA (average price paid by the winning bidder), while a seller receives only 34.04 in ERA (average price paid by the winning bidder minus bonus payments to both bidders). A Wilcoxon rank-sum test on matching group averages rejects the null hypothesis that the revenue is the same in SPA and in ERA with marginal significance ($p = 0.0547$, two-sided). The higher revenue in SPA than in ERA reflects the fact that subjects overbid on average in SPA but not in ERA.[21]

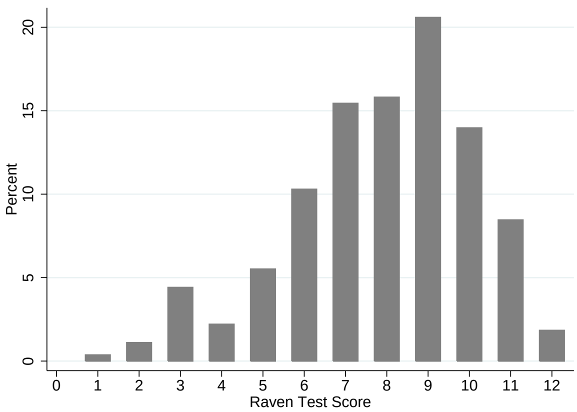
5.3 Individual Determinants of Bidding Behavior

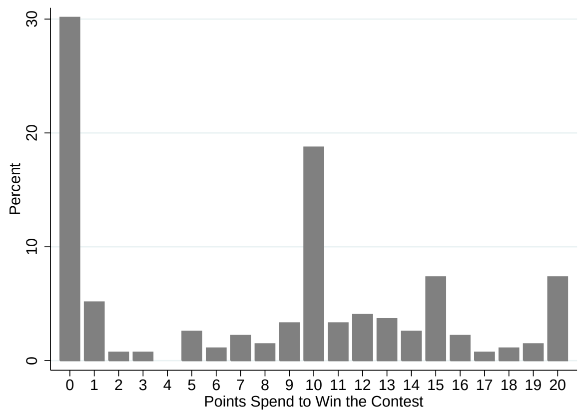
In order to better understand the individual heterogeneity in bidding behavior, we rely on our measures of joy of winning and cognitive skills. Figure 4 shows the distribution of these two measures over all four treatments. The left panel shows the distribution of the Raven test scores. On average subjects solved 7.9 puzzles, the modal value is 9. Very few subjects could solve all twelve puzzles (5 out of 272 subjects). The right panel reveals that, while subjects spent about 8 points on average to win the contest against the computer, about 30 percent of the subjects spent nothing. Almost 20 percent of the subjects spent 10 points and about 7 percent spent all 20 points. We cannot exclude that some of these decisions are due to a lack of understanding of the contest. The two measures are in fact negatively correlated: subjects who score higher in the cognitive skill task spend less money to win the contest against the computer. The correlation is not very strong ($\rho = -0.17$) but highly significant ($p = 0.005$).

[20] The scatter plots also reveal a tendency of more overbidding for small values and more underbidding for large values in treatment ERA and, to a lesser extent, also in ERA-C. We have no simple explanation for this observation, but it would be interesting to see if it is consistent with or even predicted by rationalizability. Deriving the rationalizable bidding strategies for the ERA is, however, beyond the scope of this paper.

[21] With externalities from cross-shareholdings rather than from spitefulness, revenues should instead be lower in the SPA than in the ERA. An experimental test of this hypothesis could provide further evidence for the impact of externalities on bidding behavior.

Figure 4: Individual Characteristics





We elicited a measure of joy of winning because it is one explanation for overbidding discussed in the literature (e.g. Cooper and Fang, 2008). Regression (1) in Table 2 includes all observations from SPA and SPA-C and reports a fully interacted random effects regression of overbidding on period, joy of winning, and cognitive skills. We also control for value, value squared, value cubed, and the respective interactions, because the deviation of a bid from value can depend on the underlying value. The regression shows that our measure of joy of winning is indeed positively associated with overbidding in SPA. While the size of the coefficient is large (a subject who spends all 20 points in the joy of winning contest is predicted to overbid 4.72 points more than a subject who spends no points), it is not significant. An F-test however rejects the hypothesis that the sum of the coefficients "Joy" and "Joy x C" is zero, i.e., joy of winning has a significant impact on overbidding in SPA-C ($p = 0.0323$). Model (4) provides the equivalent regression for ERA and ERA-C. Again, both coefficients of the joy of winning measure are positive, but small in ERA and large and significant only in ERA-C (F-test on the hypothesis that "Joy" plus "Joy x C" equal zero, $p = 0.0025$). In sum, our data provide weak support for Hypothesis 4 according to which joy of winning should be associated with higher bids.

Result 4. *Joy of winning is positively correlated with overbidding in all four treatments, but the effect is significant only in SPA-C and ERA-C.*

In a common value auction experiment, van den Bos et al. (2008) find that overbidding and the winner's curse disappear when subjects play against the computer instead of human bidders. They explain this finding with the hypothesis that subjects experience joy of winning only when winning against human bidders. The results of our private value auction experiment are not consistent with this hypothesis. With joy of winning against humans but not against the computer, we should expect to find a difference in overbidding between ERA and ERA-C, similar to the difference that we find between SPA and SPA-C. Since this is not the case, the difference in average overbidding between SPA and SPA-C cannot be explained by the hypothesis that joy of winning depends on the existence of a human opponent, but is consistent with the hypothesis of spiteful preferences.

Table 2: Regression Analysis

	SP			ER		
Dep. Variable	(1) Over-bidding	(2) Positive deviation	(3) Negative deviation	(4) Over-bidding	(5) Positive deviation	(6) Negative deviation
Joy	0.236	0.207	-0.029	0.012	0.020	0.008
	(0.182)	(0.177)	(0.046)	(0.123)	(0.058)	(0.079)
Joy x C	0.018	0.087	0.070	0.363**	0.355***	-0.008
	(0.217)	(0.213)	(0.070)	(0.175)	(0.098)	(0.111)
Cog. Skills	-1.683**	-1.821**	-0.138	0.083	0.023	-0.060
	(0.748)	(0.773)	(0.137)	(0.392)	(0.221)	(0.266)
Cog. Skills x C	1.405*	1.350*	-0.055	0.066	-0.137	-0.203
	(0.786)	(0.817)	(0.193)	(0.559)	(0.312)	(0.379)
Period	0.021	-0.012	-0.034***	-0.037	-0.070***	-0.033
	(0.025)	(0.024)	(0.008)	(0.033)	(0.027)	(0.027)
Period x C	0.045	-0.019	-0.064*	0.090	0.067	-0.023
	(0.053)	(0.038)	(0.035)	(0.079)	(0.056)	(0.054)
Constant	19.347***	20.537***	1.216	12.151***	13.257***	1.099
	(6.710)	(7.064)	(1.440)	(4.497)	(2.873)	(2.702)
Constant x C	-17.972**	-16.464**	1.483	-3.106	-0.624	2.490
	(7.512)	(7.815)	(2.091)	(5.884)	(3.935)	(3.515)
Contr. for value	yes	yes	yes	yes	yes	yes
R-squared	0.21	0.23	0.04	0.17	0.26	0.10
No. Obs.	3216	3216	3216	3312	3312	3312
No. Clusters	70	70	70	74	74	74

Notes: The table reports random effects regressions, with subject random effect. Standard errors in parentheses control for clustering at the matching group level in SPA and ERA (6 clusters each) and at the subject level in SPA-C (64 clusters) and ERA-C (68 clusters). Recall that no interaction between subjects occurs in the computer treatments. The omitted category is SPA in regressions (1)-(3) and ERA in (4)-(6), and the interaction is with the respective computer treatment. *, ** and *** denote significance at 10%, 5% and 1%.

Regressions (1) and (4) also control for a subject's cognitive skills, because overbidding in second-price auctions (and other auction formats) is often attributed to bounded rationality (Kagel and Levin, 1993; Goeree et al., 2002; Cooper and Fang, 2008). Regression (1) confirms that cognitive skills are a significant predictor of bidding behavior in SPA: subjects who score higher in the Raven test show less overbidding. The size of the effect is large. Each additionally solved puzzle is associated with a reduction in overbidding by about 1.7 points. For SPA-C we find that cognitive skills are much less associated with overbidding, which can be seen by the positive and significant interaction term of cognitive skills and the computer treatment. An F-test cannot reject the hypothesis that the sum of the coefficients "Cog. Skills" and "Cog. Skills x C" is zero ($p = 0.2500$). The much smaller association of cognitive skills with overbidding is, at first sight, a surprising finding, because there is no apparent reason why SPA-C should be cognitively less demanding than SPA. Moreover, regression (4) shows that cognitive skills are not significantly associated with overbidding in ERA and ERA-C either (an F-test cannot reject that the sum of "Cog. Skills" and "Cog. Skills x C" equals zero, $p = 0.7094$). Again, there is no apparent reason why these auction formats should be cognitively less demanding than SPA. Interestingly, prior research documented a relation between cognitive skills measured by the Raven test and different forms of pro-social behavior. Burks et al. (2009) find a positive relationship between Raven test scores and cooperative behavior in a sequential prisoners' dilemma game. Similarly, Millet and Dewitte (2007) find that cognitive skills measured by the Raven test are positively correlated with altruistic behavior in public goods and dictator games.[22] Our finding that cognitive skills are significantly and negatively associated with overbidding in SPA (where spiteful preferences predict overbidding) but not in SPA-C, ERA, and ERA-C (where spiteful preferences do not predict overbidding), together with the existing empirical results linking low cognitive skills to less pro-social behavior, suggests that low cognitive skills are not necessarily the ultimate reason for overbidding in SPA. Rather, they might instead serve as a proxy for spiteful preferences (which can be classified as non-cooperative and non-altruistic) in our analysis.

Further support for this possibility is provided by regressions (2) and (3), were the dependent variables are "positive deviation" and "negative deviation," respectively. Positive deviation equals overbidding if overbidding is positive, and is zero otherwise. Negative deviation equals the absolute value of overbidding if overbidding is negative, and is zero otherwise. These regres-

[22]Using different measures of cognitive skills, James (2011) reports a positive relationship between cognitive skills and charitable giving. Segal and Hershberger (1999) find that IQ is positively correlated with cooperation among twins in the repeated prisoners' dilemma. The meta study by Jones (2008) reveals that cooperation rates in the repeated prisoners' dilemma are higher at universities whose students score higher in standardized cognitive tests. It should be noted that there is also evidence linking higher cognitive skills to less pro-social behavior. For example, Ben-Ner et al. (2004) find a negative relationship between their measure of cognitive skills and dictator game giving (but only for women). Brandstätter and Güth (2002), however, find no effect of cognitive skills on behavior in dictator and ultimatum games.

sions provide two interesting observations. First, cognitive skills are negatively and significantly associated with positive deviations of bids from value but not with negative deviations in SPA. This is consistent with the idea that cognitive skills are a proxy for spiteful preferences, while a bounded rationality argument might predict that low cognitive skills are associated with both positive and negative deviations of bids from value. Second, the significant negative coefficient of "Period" reveals that negative deviations decline over time in SPA. This suggests that subjects learn to some extent not to underbid. Positive deviations, in contrast, do not decline over time. This is again consistent with a preference explanation for overbidding.[23]

6 Conclusions

The behavioral economics literature established a range of interesting behavioral phenomena over the last decades. The implications of these phenomena for the design of economic institutions have become the focus of the emerging field of behavioral mechanism design theory (e.g. Glazer and Rubinstein, 1998; Eliaz, 2002; Cabrales and Serrano, 2011; Bierbrauer and Netzer, 2014; de Clippel, 2012). We contribute to this literature by proposing and testing a selling mechanism, the externality-robust auction, which removes payoff externalities arising from spitefulness, inequality aversion, or other types of interdependent preferences. Our concept of robustness also covers non-behavioral interdependencies such as cross-shareholdings between competing firms.

The externality-robust auction can also be seen as an experimental tool. Since it eliminates the channel through which spiteful preferences manifest themselves in equilibrium behavior, a comparison of the second-price auction and its externality-robust counterpart helps disentangling different behavioral motivations that might jointly determine bidding in experimental auctions, such as spitefulness, joy of winning, and bounded rationality. In particular, our experimental evidence corroborates the idea that spiteful preferences are an important determinant of overbidding in the second-price auction.

[23] In SPA-C, the effect of period is qualitatively the same as in SPA, with a significant decrease of negative deviations over time (F-test, $p = 0.0049$) but no significant effect on positive deviations (F-test, $p = 0.3010$). Regressions (5) and (6) are the equivalent regressions for the externality-robust auction. Positive deviations of bids from value decline significantly over time in ERA. The effect is not significant in ERA-C (F-test, $p = 0.9502$). There is no significant effect of period on negative deviations in both treatments (F-test for ERA-C, $p = 0.2347$).

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A Appendix

A.1 Proof of Proposition 1

We prove the proposition in three steps, fixing a bidder $i \in I$ with valuation $\theta_i = \theta^k$ for some $k \in \{1, \ldots, m\}$ throughout. First, we derive an expression for $V_i^*(\theta_i) := \mathbb{E}_{\theta_{-i}}\left[q_i^*(\theta_i, \theta_{-i})\, \theta_i\right]$, followed by an analogous expression for $T_i^{SPA}(\theta_i) := \mathbb{E}_{\theta_{-i}}\left[t_i^{SPA}(\theta_i, \theta_{-i})\right]$. Finally, these results will be combined to derive $t_i^{ERA}(\theta) = V_i^*(\theta_i) + T_i^{SPA}(\theta_i) - q_i^*(\theta)\, \theta_i$ according to (3).

Step 1. Given $\theta_i = \theta^k$, the probability that exactly x other bidders also have valuation θ^k, while all remaining bidders have a strictly smaller valuation, so that $i \in W(\theta)$ and $|W(\theta)| = x + 1$, is

$$\binom{n-1}{x} \left(p^k\right)^x \left(P^{k-1}\right)^{n-1-x}$$

for any $0 \leq x \leq n-1$.[24] According to (1), $q_i^*(\theta)$ is non-zero only when $i \in W(\theta)$, so that

$$V_i^*(\theta_i) = \sum_{x=0}^{n-1} \binom{n-1}{x} \left(p^k\right)^x \left(P^{k-1}\right)^{n-1-x} \left(\frac{\theta^k}{x+1}\right). \tag{8}$$

Step 2. Similarly, the transfers (2) for bidder i are non-zero only when $i \in W(\theta)$. In that case, observe that $s(\theta) = \theta^k$ when $|W(\theta)| > 1$ and $s(\theta) < \theta^k$ when $|W(\theta)| = 1$. Thus

$$T_i^{SPA}(\theta_i) = -\left(P^{k-1}\right)^{n-1} S^k - \sum_{x=1}^{n-1} \binom{n-1}{x} \left(p^k\right)^x \left(P^{k-1}\right)^{n-1-x} \left(\frac{\theta^k}{x+1}\right),$$

where S^k denotes the expected largest valuation among all $n-1$ other bidders, conditional on all of them remaining strictly below θ^k. The first term captures the case where i is the unique bidder with largest valuation, while the second term captures the possibility that $x \in \{1, \ldots, n-1\}$ other bidders might have the same largest valuation. An expression for S^k will be derived next. Denote by $\hat{P}^j = P^j / P^{k-1}$ the cumulated probabilities of the distribution truncated at θ^{k-1}, for $j \in \{0, 1, \ldots, k-1\}$.[25] Using standard results about order statistics, the probability that the largest valuation among the $n-1$ other bidders is equal to θ^j, conditional on all their valuations being strictly below θ^k, is given by

$$\left(\hat{P}^j\right)^{n-1} - \left(\hat{P}^{j-1}\right)^{n-1} = \frac{\left(P^j\right)^{n-1} - \left(P^{j-1}\right)^{n-1}}{\left(P^{k-1}\right)^{n-1}}.$$

[24] With the convention $0^0 = 1$ this expression is also applicable to the case of $x = n-1$ and $k = 1$.

[25] With the convention $0/0 = 0$ this expression is also applicable to the case of $k = 1$.

Hence it is possible to write

$$S^k = \sum_{j=1}^{k-1} \left[\frac{\left(P^j\right)^{n-1} - \left(P^{j-1}\right)^{n-1}}{\left(P^{k-1}\right)^{n-1}} \right] \theta^j.$$

Collecting results, we obtain

$$T_i^{SPA}(\theta_i) = \\ -\sum_{j=1}^{k-1} \left[\left(P^j\right)^{n-1} - \left(P^{j-1}\right)^{n-1} \right] \theta^j - \sum_{x=1}^{n-1} \binom{n-1}{x} \left(p^k\right)^x \left(P^{k-1}\right)^{n-1-x} \left(\frac{\theta^k}{x+1} \right). \tag{9}$$

Step 3. Adding (8) and (9) yields

$$B(\theta_i) := V_i^*(\theta_i) + T_i^{SPA}(\theta_i) = \left(P^{k-1}\right)^{n-1} \theta^k - \sum_{j=1}^{k-1} \left[\left(P^j\right)^{n-1} - \left(P^{j-1}\right)^{n-1} \right] \theta^j.$$

The function $B(\theta_i)$ can be simplified using a recursive formulation. When $\theta_i = \theta^1$, so that $k = 1$, it follows immediately that $B(\theta^1) = 0$. Furthermore, for any $l \in \{1, \ldots, m-1\}$ it follows after some simplifications that

$$B(\theta^{l+1}) - B(\theta^l) = \left(P^l\right)^{n-1} \left(\theta^{l+1} - \theta^l\right).$$

Thus, for $\theta_i = \theta^k$ it is possible to write

$$B(\theta_i) = \sum_{j=1}^{k-1} \left(P^j\right)^{n-1} \left(\theta^{j+1} - \theta^j\right),$$

which is expression (5) in Proposition 1. It now follows that

$$t_i^{ERA}(\theta) = V_i^*(\theta_i) + T_i^{SPA}(\theta_i) - q_i^*(\theta)\,\theta_i = B(\theta_i) - q_i^*(\theta)\,\theta_i.$$

Using (1), this becomes expression (4) in the proposition.

A.2 Ex-Post Revenues in the ERA

Condition (6) is most stringent for θ^m. Consider revenue $\theta^k - nB(\theta^k)$. Straightforward calculations reveal that an increase from k to $k+1$ changes this expression by $[1-n(P^k)^{n-1}](\theta^{k+1}-\theta^k)$, the sign of which is equal to the sign of $[1-n(P^k)^{n-1}]$. This latter expression is strictly decreasing in k, so whenever revenue has become smaller in response to an increased k, further increases in k will continue to reduce the revenue. Now observe that (6) is satisfied for $k = 1$, because $B(\theta^1) = 0$. Therefore, whenever a deficit occurs for some larger k – which requires that revenue has eventually decreased – then a deficit also occurs for all $k' > k$. To rule out deficits, it is therefore enough to check condition (6) for the largest value θ^m.

Condition (7) holds in the framework of Section 2.4. In this case, (7) can be rearranged to

$$n \sum_{j=1}^{m-1} (j)^{n-1} \leq m^n. \tag{10}$$

Fix arbitrary values of $n \geq 2$ and $m \geq 2$ and assume that (10) is satisfied. Then it must also be satisfied for all values $m' > m$, holding n fixed. Indeed, increasing m by one increases the LHS of the inequality by $n\,(m)^{n-1}$ and the RHS by $(m+1)^n - m^n$. An immediate application of the binomial theorem reveals that $(m+1)^n - m^n = n\,(m)^{n-1} + \gamma$, where γ summarizes all remaining terms and is positive. Hence increasing m slackens (10). For the smallest possible value $m = 2$, (10) simplifies to $n \leq 2^n$, which is satisfied for all $n \geq 2$.

A.3 Experimental Instructions

A.3.1 Instructions for SPA

General Instructions for Bidders: We are pleased to welcome you to this economic study. If you read the following instructions carefully, you can earn money in addition to the 10 Swiss francs that you receive as an initial endowment for participating. The exact amount depends on your decisions and those of the other participants. It is thus very important that you read these instructions carefully. If you have any questions, please contact us. During the study, we will not speak of francs, but of points. Your entire income will thus first be calculated in points. The points you earn during the study will be converted to Swiss francs at the end of the study. The following conversion rate applies: 4 points = 1 Swiss franc. At the end of today's study, you will receive the number of points earned during the study plus the initial endowment of 10 Swiss francs in cash. We will explain the exact procedure of the study on the next pages. For the sake of simplicity, we will always use male forms for participants; we obviously include female participants in any case.

The Study: This study lasts for 24 periods. All participants are in the roll of bidders. In each period, two bidders are randomly assigned to a group of two. An auction takes place in each of these groups of two; in the auction, one of the two bidders can purchase a commodity by paying a price. No real commodities are purchased in this study. The "purchase of a commodity" means that the winner of the auction receives a number of points corresponding to the value of the commodity to him which is credited to his account. The price of the commodity will also be determined in points and deducted from the winner's account. The value of a commodity for a bidder will be randomly determined in each period. The value can be any integer between 1 and 100, where every value is equally probable. The value of the commodity for the two bidders in a group of two is thus typically variously large. Each bidder only knows the value that the commodity has for him but not the value that the commodity has for the other bidder. The procedure in a period:

1. First, each bidder learns the value that the commodity has for him in the current period (but not the value of the commodity for the other bidder).

2. Each bidder then places his bid for the commodity. The placement of the bids takes place simultaneously. A bidder thus does not know the other bidder's bid for the time being.

3. The bidder in the group of two who makes the higher bid wins the auction and receives the commodity. If both bidders make the same bid, random chance (with the same probability for each bidder) determines who wins the auction.

4. The price that the winner of the auction must pay for the commodity corresponds to the losing bidder's bid.

5. At the end of a period, the payment of the bidder who won the auction is: Payment = own value of commodity – the losing bidder's bid. The payment of the bidder who did not win the auction is: Payment = 0.

Examples: Bidders A and B form a group of two. The value of the commodity for bidder A in a given period is 20 points. The value of the commodity for bidder B is 60 points in this period.

1. Assume that bidder A makes a bid of 20 points and bidder B makes a bid of 60 points. Bidder B thus wins the auction, as his bid (60) is higher than that of bidder A (20). The price that bidder B must pay is bidder A's bid. The following payments in points thus

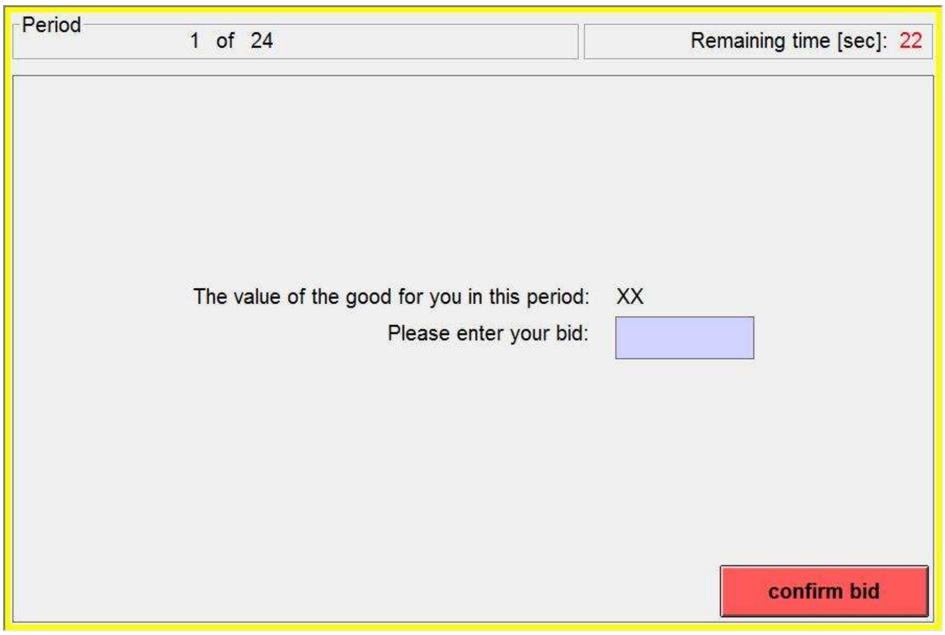
result: Payment for bidder A = 0. Payment for bidder B = own value – price (bidder A's bid) = 60 – 20 = 40.

2. Now assume that bidder A makes a bid of 18 points and bidder B a bid of 12 points. Bidder A thus wins the auction, as his bid (18) is higher than that of bidder B (12). The price that bidder A must pay is bidder B's bid. The following payments in points thus result: Payment for bidder A = own value – price (bidder B's bid) = 20 – 12 = 8. Payment for bidder B = 0.

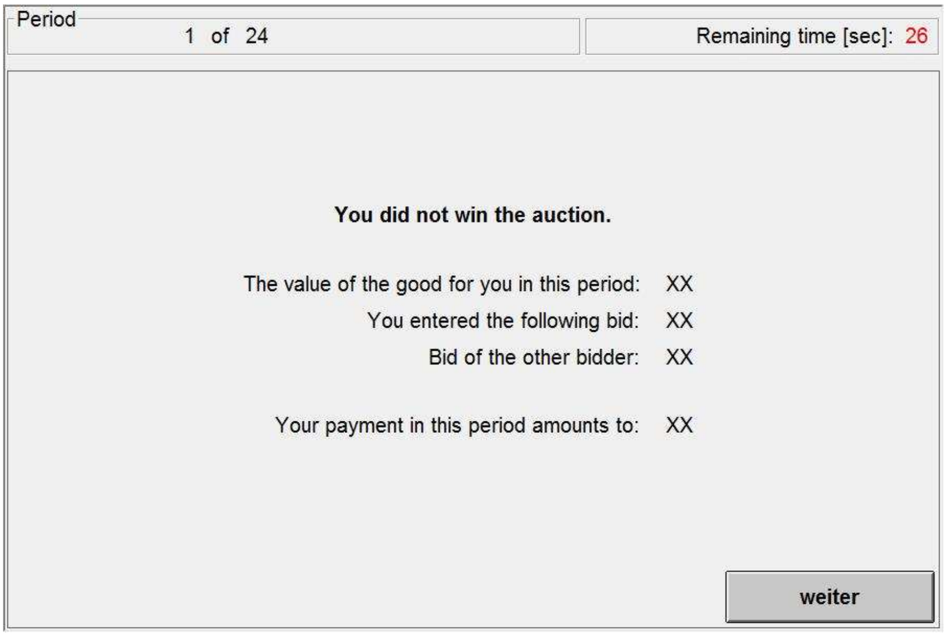
3. Now assume that bidder A makes a bid of 68 points and bidder B a bid of 45 points. Bidder A thus wins the auction, as his bid (68) is higher than that of bidder B (45). The price bidder A must pay is bidder B's bid. The following payments in points thus result: Payment for bidder A = own value – price (bidder B's bid) = 20 – 45 = –25. Payment for bidder B = 0.

Please note, as in example 3, that the payment of the bidder who wins the auction can also be negative. Losses will be compensated with profits from other periods and with the initial endowment.

Procedure on the Computer: A bidder is informed in each period about the value of the commodity for him on the screen below. A bidder also places his bid on this screen:



The upper part of the screen shows the period you are in on the left; in this example, it is period 1 of 24. On the right you see the maximum amount of time you should take for entering your bid. This time limitation is not binding, however; a bid can also be placed after the time has expired. The middle part of the screen shows the value that the commodity has for you in the current period. Here on the example screen, "XX" is shown instead of a value. You enter your bid in the field directly under the value of the commodity. Any integer between 1 and 100 can be entered as a bid. In order to confirm a bid, you must click on the "confirm bid" button. You can change your bid until you click on this button. After both bidders have entered their bids, it will be determined who won the auction. Both bidders will be informed of the results of the auction on a screen. Each bidder sees whether he or the other bidder won the auction on the information screen. A bidder will again see the value of the commodity for him in the period in question and his bid. He will also learn of the other bidder's bid (but not of the value of the commodity to the other bidder). Here is an example of the screen for the bidder who did not win the auction:



The screen for the bidder who won the auctions is equivalent. The next period begins after all participants have looked at their information screens. Again, two bidders will be randomly assigned to each other in this period. Your payment at the end of the study is the sum of all of your payments from four periods that the computer randomly selects. As you do not know which periods will be randomly selected, you should consider your decisions in each of the 24 periods very carefully. Do you have any further questions? If yes, please raise your hand. We will come to you at your workplace. Otherwise, we ask you to answer the control questions on the next pages.

Control Questions: The value of the commodity for bidder A amounts to 50 points in all questions.

1. Bidder A places a bid of 50, and bidder B places a bid of 30. How high is bidder A's payment in this period? How high is bidder B's payment in this period?
2. Bidder A places a bid of 83, and bidder B places a bid of 18. How high is bidder A's payment in this period? How high is bidder B's payment in this period?
3. Bidder A places a bid of 100, and bidder B places a bid of 65. How high is bidder A's payment in this period? How high is bidder B's payment in this period?
4. Bidder A places a bid of 1, and bidder B places a bid of 28. How high is bidder A's payment in this period? How high is bidder B's price in this period? (You can only determine the price but not the payment for bidder B, as you do not know the value of the commodity for bidder B.)
5. Bidder A places a bid of 50, and bidder B places a bid of 75. How high is bidder A's payment in this period? How high is bidder B's price in this period?
6. Bidder A places a bid of 43, and bidder B places a bid of 24. How high is bidder A's payment in this period? How high is bidder B's payment in this period?
7. Bidder A places a bid of 72, and bidder B places a bid of 90. How high is bidder A's payment in this period? How high is bidder B's price in this period?

Please raise your hand when you have completed the control questions. We will then come to you at your workplace.

A.3.2 Instructions for SPA-C

General Instructions for Bidders: [As in SPA]

The Study: This study lasts for 24 periods. All participants are in the roll of bidders. An auction takes place in each period; in this auction, you as bidder can purchase a commodity by paying a price. No real commodities are purchased in this study. The "purchase of a commodity" means that the winner of the auction receives a number of points corresponding to the value of the commodity to him which is credited to his account. The price of the commodity will also be determined in points and deducted from the winner's account. The value of a commodity for a bidder will be randomly determined in each period. The value can be any integer between 1 and 100, where every value is equally probable. The procedure in a period:

1. You will first learn the value that the commodity has for you in the current period.
2. You then place a bid for the commodity. At the same time, a number between 1 and 100 will be assigned to you. You do not know this number for the time being. (The exact distribution of the randomly assigned numbers corresponds to the bids that were made in the past in an identical auction with two bidders.)
3. If your bid is higher than the randomly assigned number, you win the auction and receive the commodity. If your bid exactly equals the assigned number, random choice (with a probability of 50%) determines whether you win the auction.
4. The price that you must pay for the commodity if you win the auction corresponds to the randomly assigned number.
5. If you win the auction, your payment at the end of the period is: Payment = value of commodity to you – the randomly assigned number. If you do not win the auction, your payment is: Payment = 0.

Examples: The value of a commodity for a bidder in a given period is 20 points.

1. Assume that the bidder makes a bid of 20 points and the randomly assigned number is 60. The bidder thus does not win the auction, as his bid (20) is less than the randomly assigned number (60). The following payments in points thus results: Payment for the bidder = 0.
2. Now assume that the bidder makes a bid of 18 points and the randomly assigned number is 12. The bidder thus wins the auction, as his bid (18) is higher than the randomly assigned number (12). The price the bidder must pay is randomly assigned number. The following payment in points thus results: Payment for the bidder = own value – price (randomly assigned number) = 20 – 12 = 8.
3. Now assume that the bidder makes a bid of 68 points and the randomly assigned number is 45. The bidder thus wins the auction, as his bid (68) is higher than the randomly assigned number (45). The price the bidder must pay is the randomly assigned number.

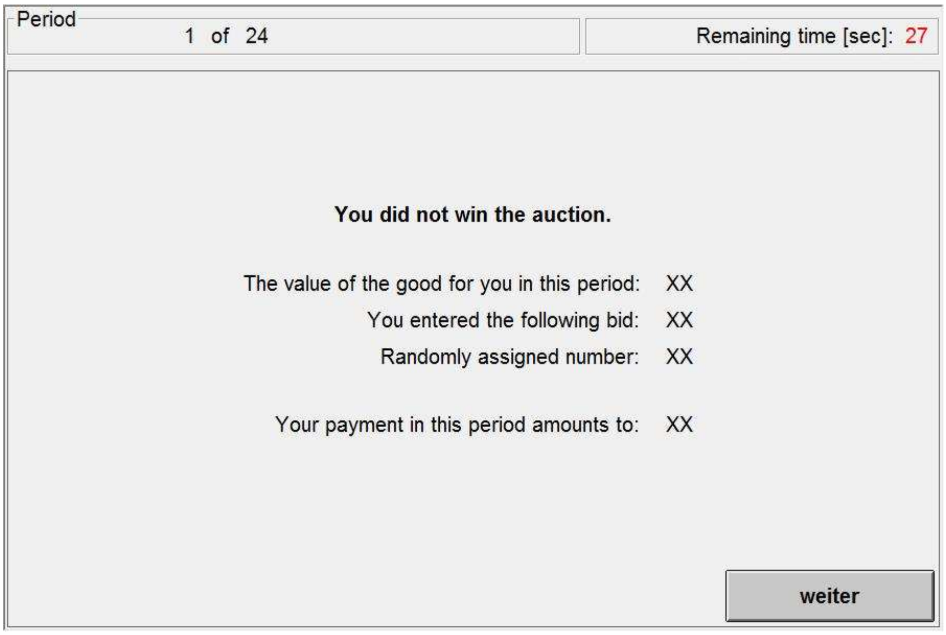
The following payment in points thus results: Payment for the bidder = own value − price (randomly assigned number) = 20 − 45 = −25.

Please note, as in example 3, that the payment of the bidder who wins the auction can also be negative. Losses will be compensated with profits from other periods and with the initial endowment.

Procedure on the Computer: A bidder is informed in each period about the value of the commodity for him on the screen below. A bidder also places his bid on this screen:

[Same screen as in SPA]

The upper part of the screen shows the period you are in on the left; in this example, it is period 1 of 24. On the right you see the maximum amount of time you should take for entering your bid. This time limitation is not binding, however; a bid can also be placed after the time has expired. The middle part of the screen shows the value that the commodity has for you in the current period. Here on the example screen, "XX" is shown instead of a value. You enter your bid in the field directly under the value of the commodity. Any integer between 1 and 100 can be entered as a bid. In order to confirm a bid, you must click on the "confirm bid" button. You can change your bid until you click on this button. After a bidder has entered his bid, it will be determined whether he won the auction. The bidder will be informed of the results of the auction on a screen. You will see whether you won the auction on the information screen. You will again see the value of the commodity for you in the period in question and your bid. He will also learn of the randomly assigned number. Here is an example of the screen for the bidder who did not win the auction:



The screen for a bidder who won the auctions is equivalent. The next period begins after all participants have looked at their information screens. Your payment at the end of the study is the sum of all of your payments from four periods that the computer randomly selects. As you do not know which periods will be randomly selected, you should consider your decisions in each of the 24 periods very carefully. Do you have any further questions? If yes, please raise your hand. We will come to you at your workplace. Otherwise, we ask you to answer the control questions on the next pages.

Control questions: The value of the commodity for a bidder amounts to 50 points in all questions.

1. The bidder places a bid of 50, and the randomly assigned number is 30. How high is the bidder's payment in this period?
2. The bidder places a bid of 83, and the randomly assigned number is 18. How high is the bidder's payment in this period?
3. The bidder places a bid of 100, and the randomly assigned number is 65. How high is the bidder's payment in this period?
4. The bidder places a bid of 1, and the randomly assigned number is 28. How high is the bidder's payment in this period?
5. The bidder places a bid of 50, and the randomly assigned number is 75. How high is the bidder's payment in this period?

6. The bidder places a bid of 43, and the randomly assigned number is 24. How high is the bidder's payment in this period?

7. The bidder places a bid of 72, and the randomly assigned number is 90. How high is the bidder's payment in this period?

Please raise your hand when you have completed the control questions. We will then come to you at your workplace.

A.3.3 Instructions for ERA

General Instructions for Bidders: [As in SPA]

The Study: This study lasts for 24 periods. All participants are in the roll of bidders. In each period, two bidders are randomly assigned to a group of two. An auction takes place in each of these groups of two; in the auction, one of the two bidders can purchase a commodity by paying a price. No real commodities are purchased in this study. The "purchase of a commodity" means that the winner of the auction receives a number of points corresponding to the value of the commodity to him which is credited to his account. The price of the commodity will also be determined in points and deducted from the winner's account. The value of a commodity for a bidder will be randomly determined in each period. The value can be any integer between 1 and 100, where every value is equally probable. The value of the commodity for the two bidders in a group of two is thus typically variously large. Each bidder only knows the value that the commodity has for him but not the value that the commodity has for the other bidder. The procedure in a period:

1. First, each bidder learns the value that the commodity has for him in the current period (but not the value of the commodity for the other bidder).

2. Each bidder then places his bid for the commodity. The placement of the bids takes place simultaneously. A bidder thus does not know the other bidder's bid for the time being.

3. The bidder in the group of two who makes the higher bid wins the auction and receives the commodity. If both bidders make the same bid, random chance (with the same probability for each bidder) determines who wins the auction.

4. The price that the winner of the auction must pay for the commodity corresponds to his own bid. Furthermore, each bidder receives a bonus payment that only depends on the

own bid. Your bonus payment is higher, the higher your bid is. You can see the exact amount of the bonus for each bid on the supplementary information sheet.

5. At the end of a period, the payment of the bidder who won the auction is: Payment = own value of commodity – own bid + bonus payment. The payment of the bidder who did not win the auction is: Payment = bonus payment.

Examples: Bidders A and B form a group of two. The value of the commodity for bidder A in a given period is 20 points. The value of the commodity for bidder B is 60 points in this period.

1. Assume that bidder A makes a bid of 20 points and bidder B makes a bid of 60 points. Bidder B thus wins the auction, as his bid (60) is higher than that of bidder A (20). The price that bidder B must pay is his own bid. Both bidders also receive a bonus payment determined by their own bids (see supplementary information sheet). The following payments in points thus result: Payment for bidder A = bonus payment = 1.9. Payment for bidder B = own value – price (own bid) + bonus payment = 60 – 60 + 17.7 = 17.7.

2. Now assume that bidder A makes a bid of 18 points and bidder B a bid of 12 points. Bidder A thus wins the auction, as his bid (18) is higher than that of bidder B (12). The price bidder A must pay is his own bid. Both bidders also receive their own bonus payments. The following payments in points thus result: Payment for bidder A = own value – price (own bid) + bonus payment = 20 – 18 + 1.53 = 3.53. Payment for bidder B = bonus payment = 0.66.

3. Now assume that bidder A makes a bid of 68 points and bidder B a bid of 45 points. Bidder A thus wins the auction, as his bid (68) is higher than that of bidder B (45). The price bidder A must pay is his own bid. Both bidders also receive their own bonus payments. The following payments in points thus result: Payment for bidder A = own value – price (own bid) + bonus payment = 20–68+22.78 = –25.22. Payment for bidder B = bonus payment = 9.9.

Please note, as in example 3, that the payment of the bidder who wins the auction can also be negative. Losses will be compensated with profits from other periods and with the initial endowment.

Procedure on the Computer: A bidder is informed in each period about the value of the commodity for him on the screen below. A bidder also places his bid on this screen:

[Same screen as in SPA]

The upper part of the screen shows the period you are in on the left; in this example, it is period 1 of 24. On the right you see the maximum amount of time you should take for entering your bid. This time limitation is not binding, however; a bid can also be placed after the time has expired. The middle part of the screen shows the value that the commodity has for you in the current period. Here on the example screen, "XX" is shown instead of a value. You enter your bid in the field directly under the value of the commodity. Any integer between 1 and 100 can be entered as a bid. In order to confirm a bid, you must click on the "confirm bid" button. You can change your bid until you click on this button. After both bidders have entered their bids, it will be determined who won the auction. Both bidders will be informed of the results of the auction on a screen. Each bidder sees whether he or the other bidder won the auction on the information screen. A bidder will again see the value of the commodity for him in the period in question and his bid. He will also learn of the other bidder's bid (but not of the value of the commodity to the other bidder). Here is an example of the screen for the bidder who did not win the auction:

[Same screen as in SPA]

The screen for the bidder who won the auctions is equivalent. The next period begins after all participants have looked at their information screens. Again, two bidders will be randomly assigned to each other in this period. Your payment at the end of the study is the sum of all of your payments from four periods that the computer randomly selects. As you do not know which periods will be randomly selected, you should consider your decisions in each of the 24 periods very carefully. Do you have any further questions? If yes, please raise your hand. We will come to you at your workplace. Otherwise, we ask you to answer the control questions on the next pages.

Control Questions: The value of the commodity for bidder A amounts to 50 points in all questions.

1. Bidder A places a bid of 50, and bidder B places a bid of 30. How high is bidder A's payment in this period? How high is bidder B's payment in this period?

2. Bidder A places a bid of 83, and bidder B places a bid of 18. How high is bidder A's payment in this period? How high is bidder B's payment in this period?

3. Bidder A places a bid of 100, and bidder B places a bid of 65. How high is bidder A's payment in this period? How high is bidder B's payment in this period?

4. Bidder A places a bid of 1, and bidder B places a bid of 28. How high is bidder A's payment in this period? How high is bidder B's price in this period? (You can only determine the price but not the payment for bidder B, as you do not know the value of the commodity for bidder B.)

5. Bidder A places a bid of 50, and bidder B places a bid of 75. How high is bidder A's payment in this period? How high is bidder B's price in this period?

6. Bidder A places a bid of 43, and bidder B places a bid of 24. How high is bidder A's payment in this period? How high is bidder B's payment in this period?

7. Bidder A places a bid of 72, and bidder B places a bid of 90. How high is bidder A's payment in this period? How high is bidder B's price in this period?

Please raise your hand when you have completed the control questions. We will then come to you at your workplace.

A.3.4 Instructions for ERA-C

General Instructions for Bidders: [As in SPA]

The Study: This study lasts for 24 periods. All participants are in the roll of bidders. An auction takes place in each period; in this auction, you as bidder can purchase a commodity by paying a price. No real commodities are purchased in this study. The "purchase of a commodity" means that the winner of the auction receives a number of points corresponding to the value of the commodity to him which is credited to his account. The price of the commodity will also be determined in points and deducted from the winner's account. The value of a commodity for a bidder will be randomly determined in each period. The value can be any integer between 1 and 100, where every value is equally probable. The procedure in a period:

1. You will first learn the value that the commodity has for you in the current period.

2. You then place a bid for the commodity. At the same time, a number between 1 and 100 will be assigned to you. You do not know this number for the time being. (The exact distribution of the randomly assigned numbers corresponds to the bids that were made in the past in an identical auction with two bidders.)

3. If your bid is higher than the randomly assigned number, you win the auction and receive the commodity. If your bid exactly equals the assigned number, random choice (with a probability of 50%) determines whether you win the auction.

4. The price that you must pay for the commodity if you win the auction corresponds to your own bid. Furthermore, you receive a bonus payment that only depends on your own bid. Your bonus payment is higher, the higher your bid is. You can see the exact amount of the bonus for each bid on the supplementary information sheet.

5. If you win the auction, your payment at the end of the period is: Payment = value of commodity to you − your bid + bonus payment. If you do not win the auction, your payment is: Payment = bonus payment.

Examples: The value of a commodity for a bidder in a given period is 20 points.

1. Assume that the bidder makes a bid of 20 points and the randomly assigned number is 60. The bidder thus does not win the auction, as his bid (20) is less than the randomly assigned number (60). He receives a bonus payment, however, determined by his own bid (see supplementary information sheet). The following payments in points thus results: Payment for the bidder = bonus payment = 1.9.

2. Now assume that the bidder makes a bid of 18 points and the randomly assigned number is 12. The bidder thus wins the auction, as his bid (18) is higher than the randomly assigned number (12). The price the bidder must pay is his own bid. He also receives his bonus payments. The following payment in points thus results: Payment for the bidder = own value − price (own bid) + bonus payment = 20 − 18 + 1.53 = 3.53.

3. Now assume that the bidder makes a bid of 68 points and the randomly assigned number is 45. The bidder thus wins the auction, as his bid (68) is higher than the randomly assigned number (45). The price the bidder must pay is his own bid. He also receives his bonus payments. The following payment in points thus results: Payment for the bidder = own value − price (own bid) + bonus payment = 20–68+22.78 = –25.22.

Please note, as in example 3, that the payment of the bidder who wins the auction can also be negative. Losses will be compensated with profits from other periods and with the initial endowment.

Procedure on the Computer: A bidder is informed in each period about the value of the commodity for him on the screen below. A bidder also places his bid on this screen:

[Same screen as in SPA]

The upper part of the screen shows the period you are in on the left; in this example, it is period 1 of 24. On the right you see the maximum amount of time you should take for entering your bid. This time limitation is not binding, however; a bid can also be placed after the time has expired. The middle part of the screen shows the value that the commodity has for you in the current period. Here on the example screen, "XX" is shown instead of a value. You enter your bid in the field directly under the value of the commodity. Any integer between 1 and 100 can be entered as a bid. In order to confirm a bid, you must click on the "confirm bid" button. You can change your bid until you click on this button. After a bidder has entered his bid, it will be determined whether he won the auction. The bidder will be informed of the results of the auction on a screen. You will see whether you won the auction on the information screen. You will again see the value of the commodity for you in the period in question and your bid. He will also learn of the randomly assigned number. Here is an example of the screen for the bidder who did not win the auction:

[Same screen as in SPA-C]

The screen for a bidder who won the auctions is equivalent. The next period begins after all participants have looked at their information screens. Your payment at the end of the study is the sum of all of your payments from four periods that the computer randomly selects. As you do not know which periods will be randomly selected, you should consider your decisions in each of the 24 periods very carefully. Do you have any further questions? If yes, please raise your hand. We will come to you at your workplace. Otherwise, we ask you to answer the control questions on the next pages.

Control Questions: The value of the commodity for a bidder amounts to 50 points in all questions.

1. The bidder places a bid of 50, and the randomly assigned number is 30. How high is the bidder's payment in this period?

2. The bidder places a bid of 83, and the randomly assigned number is 18. How high is the bidder's payment in this period?

3. The bidder places a bid of 100, and the randomly assigned number is 65. How high is the bidder's payment in this period?

4. The bidder places a bid of 1, and the randomly assigned number is 28. How high is the bidder's payment in this period?

5. The bidder places a bid of 50, and the randomly assigned number is 75. How high is the bidder's payment in this period?

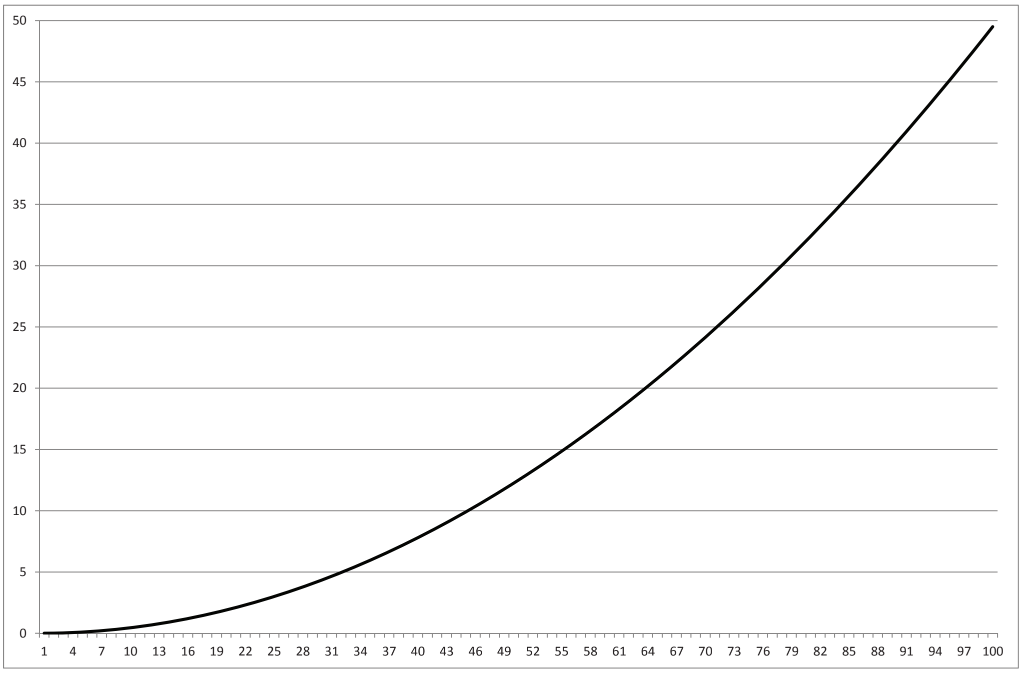
6. The bidder places a bid of 43, and the randomly assigned number is 24. How high is the bidder's payment in this period?

7. The bidder places a bid of 72, and the randomly assigned number is 90. How high is the bidder's payment in this period?

Please raise your hand when you have completed the control questions. We will then come to you at your workplace.

A.3.5 Supplementary Information Sheet

Bonus Payments



Bid	Bonus
1	0
2	0.01
3	0.03
4	0.06
5	0.1
6	0.15
7	0.21
8	0.28
9	0.36
10	0.45
11	0.55
12	0.66
13	0.78
14	0.91
15	1.05
16	1.2
17	1.36
18	1.53
19	1.71
20	1.9
21	2.1
22	2.31
23	2.53
24	2.76
25	3

Bid	Bonus
26	3.25
27	3.51
28	3.78
29	4.06
30	4.35
31	4.65
32	4.96
33	5.28
34	5.61
35	5.95
36	6.3
37	6.66
38	7.03
39	7.41
40	7.8
41	8.2
42	8.61
43	9.03
44	9.46
45	9.9
46	10.35
47	10.81
48	11.28
49	11.76
50	12.25

Bid	Bonus
51	12.75
52	13.26
53	13.78
54	14.31
55	14.85
56	15.4
57	15.96
58	16.53
59	17.11
60	17.7
61	18.3
62	18.91
63	19.53
64	20.16
65	20.8
66	21.45
67	22.11
68	22.78
69	23.46
70	24.15
71	24.85
72	25.56
73	26.28
74	27.01
75	27.75

Bid	Bonus
76	28.5
77	29.26
78	30.03
79	30.81
80	31.6
81	32.4
82	33.21
83	34.03
84	34.86
85	35.7
86	36.55
87	37.41
88	38.28
89	39.16
90	40.05
91	40.95
92	41.86
93	42.78
94	43.71
95	44.65
96	45.6
97	46.56
98	47.53
99	48.51
100	49.5