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Does the Absence of Human Sellers Bias Bidding Behavior in Auction Experiments?

Björn Bartling, Tobias Gesche and Nick Netzer

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Björn Bartling
University of Zurich

Tobias Gesche
University of Zurich

Nick Netzer
University of Zurich

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Abstract

This paper studies the impact of the presence of human subjects in the role of a seller on bidding in experimental second-price auctions. Overbidding is a robust finding in second-price auctions, and spite among bidders has been advanced as an explanation. If spite extends to the seller, then the absence of human sellers who receive the auction revenue may bias upwards the bidding behavior in existing experimental auctions. We derive the equilibrium bidding function in a model where bidders have preferences regarding both, the payoffs of other bidders and the seller's revenue. Overbidding is optimal when buyers are spiteful only towards other buyers. However, optimal bids are lower and potentially even truthful when spite extends to the seller. We experimentally test the model predictions by exogenously varying the presence of human subjects in the roles of the seller and competing bidders. We do not detect a systematic effect of the presence of a human seller on overbidding. We conclude that overbidding is not an artefact of the standard experimental implementation of second-price auctions in which human sellers are absent.

Keywords: second-price auction, spite, overbidding, laboratory experiments

JEL Classification: C91, D03, D44, D82

*Email: bjoern.bartling@econ.uzh.ch, tobias.gesche@econ.uzh.ch, and nick.netzer@econ.uzh.ch. Department of Economics, University of Zurich, Blümlisalpstrasse 10, 8006 Zurich, Switzerland.

1 Introduction

Real-world sales auctions are mechanisms used to allocate goods among potential buyers and generate revenue for the seller. Experimental implementations of auctions in the laboratory do typically not have subjects in the role of the seller who receives the auction's revenue. However, there is empirical evidence that subjects care about the payoff of other subjects in auction experiments. In particular, the literature has documented spiteful preferences among the bidders. The question then arises whether these interdependent preferences also extend to the seller, in which case the absence of human sellers in the laboratory would systematically bias observed bidding behavior in auction experiments. We analyse this question in a second-price sealed-bid auction (SPA), both theoretically and experimentally.

Spite among bidders in the SPA has been proposed as an explanation for the common observation that subjects overbid in experimental SPAs (e.g. Morgan et al., 2003; Brandt et al., 2007; Andreoni et al., 2007; Cooper and Fang, 2008; Nishimura et al., 2011; Kimbrough and Reiss, 2012; Bartling and Netzer, 2016). Spiteful bidders may find it attractive to overbid in order to increase the buying price for the winning bidder. However, overbidding not only reduces the winning bidder's payoff but it also increases the seller's payoff. If a subject in the role of the seller is present, and if spite also extends to the seller, then the incentive to overbid will be reduced or even reversed. The often observed overbidding may thus be an artefact of the particular – and arguably unrealistic – way in which auctions are typically implemented in the laboratory: absent a human subject who receives the auction's revenue.

A seminal paper by Kahneman et al. (1986) provides survey evidence that people indeed care about the fairness of prices in buyer-seller relations (see also, e.g., Campbell, 1999; Rotemberg, 2011; Herz and Taubinsky, 2015; Bartling et al., 2016). Direct evidence that bidders care about the revenue in an auction setting is found for charity auctions in the lab (e.g. Goeree et al., 2005; Schram and Onderstal, 2009) and in the field (e.g. Carpenter et al., 2007; Leszczyc and Rothkopf, 2010). In charity auctions, bidders have a preference for high revenues, because the revenue is donated for a good cause. In standard auctions, in contrast, the revenue is kept by the seller, and spiteful bidders may have a preference for low revenues. After all, the revenue is generated by extracting rents from the buyers.

To examine this motivation more rigorously, we first derive the equilibrium bidding function in the SPA for bidders who care about the competing bidders' payoffs and the seller's revenue. We allow for spiteful as well as altruistic preferences. To the best of our knowledge, our model is the first to capture all these motives simultaneously. It unifies previous approaches such as the one by Morgan et al. (2003), who consider interdependent preferences only among the bidders, and the one by Engelbrecht-Wiggans (1994), who considers interdependent preferences only with respect to the seller. Our theoretical results confirm the intuition that preferences towards the seller counteract the effect of preferences towards the other bidders. In particular, spiteful preferences towards both parties may even restore truthful bidding.

In the second part of the paper, we implement SPAs experimentally. We conduct a fully factorial design, including a standard SPA as our benchmark condition, where we exogenously vary the presence of human subjects in the roles of the seller and competing bidders. When competing human bidders are absent, we hold strategic incentives constant through the use of computerized bidders. We observe overbidding in the presence of competing human bidders, which is reduced when human bidders are replaced by computerized bidders. This observation is consistent with the possibility that spite causes overbidding. We however do not detect a systematic effect of the presence of human sellers on overbidding. The latter observation thus suggests that the standard experimental implementation of auctions without subjects in the role of the seller does not systematically bias bidding behavior.

The remainder of the paper is organized as follows. Section 2 presents our theoretical model. Section 3 explains our experimental design and procedures. Section 4 summarizes our hypotheses and Section 5 presents the experimental results. Section 6 concludes with a discussion of possible reasons for our findings.

2 Theoretical Analysis

A seller wants to auction one indivisible item, for which she has a reservation value of zero. The set of bidders is given by $I = \{1, \ldots, n\}$ with $n \geq 2$. Bidders are risk-neutral. Bidder i values the item at v_i, which is private information. The valuations are drawn independently and identically from $[0, 1]$ according to a continuous distribution with cdf F and pdf f. We assume $f(v) > 0$ for all $v \in [0, 1]$. The item is allocated through a conventional SPA. Denote by $b_i \in [0, 1]$ bidder i's bid. The highest bidder wins the item and pays the second-highest bid (ties are broken randomly).

We assume that bidders experience a disutility if another bidder wins. This disutility is proportional to the winning bidder's surplus and weighted by the spite parameter α_B. In addition, we also allow bidders to have preferences with respect to the seller's surplus. They experience a disutility that is proportional to the auction's revenue and weighted by the spite parameter α_S. We assume that $\alpha_B, \alpha_S \in (-1, +1)$, where positive values correspond to spite and negative values correspond to altruism.[1] Thus, bidder i's ex-post utility in case of winning is given by

$$u_i(v_i|won) = (v_i - \max_{j\neq i}\{b_j\}) - \alpha_S \max_{j\neq i}\{b_j\}.$$

If bidder i looses and bidder $j \neq i$ wins, then i's ex-post utility is given by

$$u_i(v_i|lost) = -\alpha_B(v_j - \max_{k\neq j}\{b_k\}) - \alpha_S \max_{k\neq j}\{b_k\}.$$

The described environment defines a Bayesian game in which bidder i's strategy is a bidding function $\beta_i : [0, 1] \to [0, 1]$. We will derive a symmetric Bayes-Nash equilibrium in which all bidders adopt the same bidding function $\beta_i = \beta^*$.

Proposition 1. *The following bidding function constitutes a symmetric Bayes-Nash equilibrium:*

$$\beta^*(v) = \begin{cases} v + \frac{\int_v^1 [1-F(x)]^k dx}{[1-F(v)]^k} & \text{if } \alpha_S < \alpha_B, \\ v & \text{if } \alpha_S = \alpha_B, \\ v - \frac{\int_0^v [1-F(x)]^k dx}{[1-F(v)]^k} & \text{if } \alpha_S > \alpha_B, \end{cases}$$

where $k = (1 + \alpha_B)/(\alpha_B - \alpha_S)$.

Proof. See Appendix. □

Consider first the case where spite towards the seller is smaller than towards the winning bidder ($0 \leq \alpha_S < \alpha_B$). Then, the motive to increase the winning bidder's price outweighs the risk of winning the auction at a too high price and the additional disutility created by the seller's increased revenue. We therefore obtain bidding above value. Conversely, when spite towards the seller is larger than towards the winning bidder ($\alpha_S > \alpha_B \geq 0$), there will be underbidding. The risk of foregoing to win the auction at a profitable price and the chance of harming the winner are more than compensated by the seller's lower expected revenue. When both spite parameters are equal ($\alpha_S = \alpha_B$), the effects offset each other, thereby restoring truthful bidding. Analogous arguments extend to altruistic preferences, i.e., negative spite parameters.

Note that β^* is independent of the number of bidders n. This is due to the nature of auctions where it is only one buyer's bid which eventually determines the payoffs of the seller and the winning bidder. This implies that competition among bidders in the SPA does not eliminate over- or underbidding induced by interdependent preferences.[2]

[1] Restricting the parameters to a magnitude of less than one ensures that no player would pay one unit or more to increase or decrease another player's payoff by one unit.

[2] In large competitive markets, by contrast, players who have interdependent preferences may act as if they

In their analysis of spiteful bidding, Morgan et al. (2003) allow for spite among the bidders but do not consider the seller. Their analysis thus corresponds to the case where $\alpha_S = 0$ and $\alpha_B \geq 0$.[3] On the other hand, Engelbrecht-Wiggans (1994) considers preferences in favour of the auction's revenue but not with respect to the other bidders. This corresponds to the case where $\alpha_S \leq 0$ and $\alpha_B = 0$.[4] Our model covers both cases and any additional combination of spite and altruism.[5]

We now turn to our initial question: How does the presence of a human seller affect bidding behavior through interdependent preferences? The absence of a human seller can be captured by setting $\alpha_S = 0$, as there is no subject who obtains the revenue and to whom interdependent preferences could apply. We then obtain the following comparative statics:

Proposition 2. *For any $v \in (0, 1)$, $\beta^*(v)$ is strictly decreasing in α_S.*

Proof. See Appendix. □

Under the plausible conjecture that spite between bidders also extends to the seller, this result predicts a drop in bids upon the introduction of a human seller in experiments. With this model prediction in mind, we set up our experimental design.

3 Experimental Design

We implemented four treatments, summarized in Table 1. We conducted a second-price auction with two human bidders but without a human seller (SPA), a second-price auction with two human bidders and a human seller (SPA-S), and the two corresponding treatments in which there is only one human bidder who competes against a computerized second bidder (SPA-C and SPA-S-C). The data from treatments SPA and SPA-C are taken from Bartling and Netzer (2016) and will serve as the benchmark for comparison to our novel data from treatments SPA-S

had classical, self-centered preferences because they are not pivotal in determining the payoff of a seller (see e.g. Dufwenberg et al., 2011).

[3] See Brandt et al. (2007) for a model in which the bidders may be exclusively spiteful and may not care about their own payoff at all. Interdependent preferences among the bidders also arise when bidders are firms who own shares of each other. The literature has investigated the effect of such cross-shareholdings on equilibrium bidding in the SPA and other auction formats (e.g. Ettinger, 2003; Dasgupta and Tsui, 2004; Chillemi, 2005). In our model, symmetric cross-shareholdings correspond to the case where $\alpha_S = 0$ and $\alpha_B < 0$.

[4] We note that Engelbrecht-Wiggans (1994) analyzes a more general model with affiliated values. In his setting, the bidders' concern for the revenue arises because a share of the revenue is paid out to them. Preferences in favor of a high revenue can also arise with toeholds in takeover contests (e.g. Burkart, 1995; Singh, 1998), in charity auctions (e.g. Engers and McManus, 2007; Isaac et al., 2010), or with other financial externalities (e.g. Salmon and Isaac, 2006; Maasland and Onderstal, 2007).

[5] Ettinger (2008) and Lu (2012) also allow for both types of interdependent preferences. However, Ettinger (2008) analyzes equilibrium bidding in the SPA (and other auction formats) only separately for the two types, while Lu (2012) derives optimal auctions and does not consider equilibrium bidding in standard auctions.

and SPA-S-C.[6] This design provides us with two ceteris-paribus comparisons of the effect of the presence of a human seller in the laboratory.

	no human subject in role of seller	human subject in role of seller
human subject in role of competing bidder	SPA	SPA-S
no human subject in role of competing bidder	SPA-C	SPA-S-C

Table 1: Overview of Treatments.

Treatment SPA. This treatment is a standard second-price auction as it is commonly implemented in laboratory studies. There are two subjects who compete as bidders. First, each bidder is assigned a privately observed value, which is drawn independently from $\{1, \ldots, 100\}$ according to a uniform distribution. The two bidders then simultaneously place their bids, which can be any natural number between 1 and 100. The payoffs are determined according to the rules of the second-price auction: The bidder with the higher bid obtains her private value and pays the loser's bid, while the loser has a payoff of zero (ties are broken randomly). Each bidder is then informed about the competing bid and the own payoff. This procedure is repeated for 24 periods, with anonymous random rematching and newly determined valuations each period.

Treatment SPA-S. Treatment SPA-S is identical to treatment SPA, except for the fact that there is also a human subject in the role of the seller. A seller is a passive player whose payoff is the price paid by the winning bidder. At the end of each period, each bidder is informed about the competing bid, the own payoff, and the price obtained by the seller. Each subject remains in the role of either bidder or seller throughout the experiment, but subjects are anonymously and randomly rematched in groups of three (two bidders and one seller) each period.[7]

Treatment SPA-C. Treatment SPA-C is identical to treatment SPA, except for the fact that there is no competing human bidder. Instead, subjects compete against a computerized second bidder. They are informed that the bids of the computer are bids that human participants made in an earlier identical experiment but with two human bidders. In fact, each participant

[6] Bartling and Netzer (2016) rely on the mechanism design approach by Bierbrauer and Netzer (2016) to derive an externality-robust version of the SPA and compare its performance to the standard SPA in a laboratory experiment. They conclude that externality-robustness is of equal importance as dominant-strategy robustness.

[7] To avoid doubt among the subjects in the role of bidders that subjects in the role of the seller are really present in the experimental sessions, all subjects had to collect their written instructions from one of two piles upon entry into the laboratory. One pile was clearly labeled "bidder," the other pile was clearly labeled "seller." The bidders thus saw that there were instructions for subjects in the role of the seller and that some participants where instructed to take a copy from this pile when they entered the laboratory.

in SPA-C is assigned a sequence of private values and competing bids that a uniquely matched participant in SPA had been confronted with.

Treatment SPA-S-C. Treatment SPA-S-C implements the auction with a human seller but no competing human bidder. The relation between SPA-S-C and SPA-S is thus the same as the relation between SPA-C and SPA, and the relation between SPA-S-C and SPA-C is the same as the relation between SPA-S and SPA.

General Procedures. There were two sessions each for treatments SPA and SPA-C, with 70 participants in SPA and 64 participants in SPA-C. We conducted three sessions for treatment SPA-S, with 68 participants as bidders and 34 participants as sellers, and six sessions for treatment SPA-S-C, with 68 participants as bidders and 68 participants as sellers. We thus have roughly the same number of observations by subjects acting as bidders across all treatments.[8] For each treatment, six matching groups of 10 to 12 bidders were implemented. However, we can treat each bidder as an independent observation in the treatments with a computerized opponent bidder, where no spillovers between competitors can occur, which leaves us with 144 independent observations across all treatments.

The experiment took place in 2013 at the Laboratory for Behavioral and Experimental Economics at the University of Zurich. The software hroot (Bock et al., 2014) and z-Tree (Fischbacher, 2007) was used. Subjects were mainly students from the University of Zurich and the Swiss Federal Institute of Technology in Zurich. Each subject participated in only one treatment (between-subjects design). Students with a major in economics or psychology were excluded from the recruitment. The experimental instructions included comprehension questions that each subject had to answer correctly before the start of a session. A summary of the instructions was read out aloud. An English translation of the instructions for all treatments can be found in the Online Appendix.

During the experiment, payoffs were measured in points. Four randomly selected periods were paid out at the end of the experiment, where 4 points were converted into CHF 1.00 ($\approx$ USD 1.05 at the time of the study). A session lasted about 90 minutes. On average, subjects in the role of bidders earned CHF 13.50 and subjects in the role of sellers earned CHF 35.68 in the auctions. In addition, every subject received a show-up fee of CHF 10.00.[9]

[8] We had to conduct more sessions for SPA-S than for SPA and SPA-C, as for each pair of bidders a third subject in the role of the seller had to be present, such that fewer bidders could be placed in our laboratory. We had to conduct even more sessions for SPA-S-C, as each bidder had to be paired with a distinct seller.

[9] We also measured subjects' "joy of winning", using a symbolic contest (Sheremeta, 2010), and their "cognitive skills", using a 12-item Raven Advanced Progressive Matrices test (Raven et al., 2007), but do not use these data in this paper. Details of the two measures and how they affect individual bidding behavior in SPA and SPA-C is provided in Bartling and Netzer (2016).

4 Hypotheses

As discussed in the introduction, spiteful motives have been advanced as a possible explanation for overbidding in the SPA (e.g. Andreoni et al., 2007; Cooper and Fang, 2008; Nishimura et al., 2011; Bartling and Netzer, 2016). If bidders' spiteful preferences extend to the seller, our model in Section 2 predicts lower bids in the treatments with human subjects in the role of the seller, which gives rise to the following hypotheses:

Hypothesis 1. *Bids are lower in SPA-S than in SPA.*

Hypothesis 2. *Bids are lower in SPA-S-C than in SPA-C.*

5 Experimental Results

Figure 1 shows that there is on average overbidding ($bid - value$) in all our four treatments. The average overbidding in SPA is 5.1 points, which amounts to about 10 percent of the average value. This magnitude is in line with the earlier literature on experimental SPAs (e.g. Kagel, 1995). The figure further shows that average overbidding is reduced to 1.9 points in SPA-C, a difference that is statistically significant (Wilcoxon rank-sum test, $p = 0.0088$).[10] The presence of human subjects in the role of competing bidders thus causally leads to higher bids, suggesting that spite is indeed a major reason for overbidding in SPA. These two benchmark treatments, previously reported in Bartling and Netzer (2016), set the stage for the introduction of human sellers to the experimental auctions in treatments SPA-S and SPA-S-C.

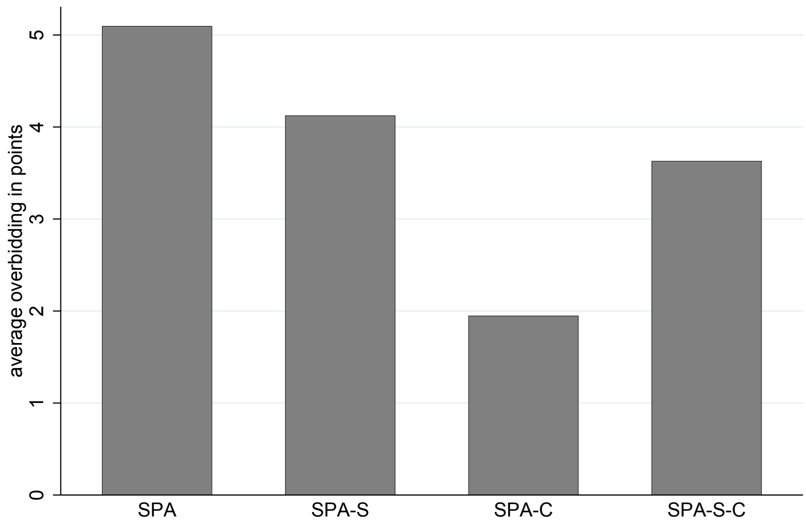

Figure 1: Average Overbidding Across Treatments

[10]All Wilcoxon ranks-sum tests reported here are two-sided and compare averages of the 144 independent observations described in the design section, unless stated otherwise.

Comparison of the two leftmost bars in Figure 1 indicates that the presence of a seller, who receives the auction revenue, reduces average overbidding from 5.1 to 4.1 points. While this difference between SPA and SPA-S is qualitatively consistent with Hypothesis 1, it is not statistically significant (Wilcoxon rank-sum test, $p = 0.6310$).

We also compare average overbidding in treatments SPA-C and SPA-S-C, to test for the effect of human sellers when competing human bidders are absent. The two rightmost bars in Figure 1 show that the introduction of a seller increases average overbidding from 1.9 to 3.6 points in this case. This difference is qualitatively opposed to Hypothesis 2, but again not statistically significant (Wilcoxon rank-sum test, $p = 0.6527$).[11]

We summarize our main finding as follows:

Result. *The presence of a human subject in the role of the seller does not affect average overbidding in a systematic way.*

6 Conclusions

The literature has documented interdependent preferences, and in particular spiteful motives, among the bidders in experimental auctions. Once we acknowledge the presence of such motives, an ubiquitous feature of typical experimental laboratory auctions may turn out to be of relevance for bidding behavior: the absence of human subjects in the role of the seller.[12] If the bidders' interdependent preferences extend to human sellers, their absence may systematically bias the observed bidding behavior. We show theoretically that spite towards the seller tends to offset the effects of spite towards the other bidders. We experimentally test this prediction by varying the presence of human subjects in the role of the seller, who earns the auction revenue. The main insight provided by this paper is that the standard experimental implementation of auctions without human subjects in the role of sellers does not systematically bias bidding behavior. In particular, our data suggest that the common finding that subjects overbid in the SPA is not an artefact of this implementation. Our results thus provide support for the external validity of the existing literature.

[11] Note also that average overbidding is smaller in SPA-S-C than in SPA-S (3.6 vs. 4.1), in line with the hypothesis of spite among bidders (Wilcoxon rank-sum test, $p = 0.0565$). This difference is, however, no longer significant if we consider "artificial matching groups," where we match subjects in SPA-S-C into the six matching groups that correspond to the matching groups that we implemented in SPA-S ($p = 0.9372$). The failure to find clearer evidence for lower bids in SPA-S-C than in SPA-S is presumably due to the unsystematic effect of the presence of a human seller on bidding behavior, which gives rise to relatively low bids in SPA-S but relatively high bids in SPA-S-C.

[12] One exception is Ivanova-Stenzel and Kröger (2008), who combine an SPA with a buy-it-now offer that is made by a subject in the role of the seller to a buyer prior to the SPA. They do not systematically vary the presence of the seller, however, as their interest is in studying the theoretical prediction that the price offer is always rejected and sales are made in the auction only. Grebe, Ivanova-Stenzel and Kröger (2016) study the effect of bargaining power and additionally consider sell-it-now offers, made by a buyer to the seller.

The natural question arising is why spite among bidders does not seem to extend to the seller. One reason may be that a bidder perceives the seller and the other bidders very differently. While the bidders are direct competitors for the good on sale, the seller is the one who, in some sense, enables the gains from trade in the first place. Another reason may be that the sellers in our experiment are passive players who do not make any choices and hence do not affect the outcome of the auction. While models of interdependent preferences that are solely outcome-based (e.g. Fehr and Schmidt, 1999; Bolton and Ockenfels, 2000) cannot capture such differences, the spirit of models of intention-based reciprocity preferences (e.g. Rabin, 1993; Dufwenberg and Kirchsteiger, 2004) is more in line with the observed bidding pattern. In these models, a player who cannot make any choices exhibits a (un)kindness of zero, and all other players become indifferent with respect to his payoff. It is an interesting avenue for future research to explore this possibility further, both theoretically and experimentally. We conjecture that the presence of a seller will have a more systematic effect on bidding behavior when she actively chooses the selling mechanism, for instance by setting a reserve price for the auction.

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A Appendix

Proof of Proposition 1

We proceed in two steps. First, we derive a necessary optimality condition from which function β^* is obtained. Second, we verify that β^* is in fact a Bayes-Nash equilibrium.

Step 1. Consider a candidate equilibrium in which all bidders adopt the strictly increasing and differentiable bidding function β. Without loss of generality, take the perspective of bidder 1. By definition of equilibrium, he cannot strictly increase his expected utility by bidding $\beta(\hat{v})$ for any "reported value" $\hat{v} \neq v_1$ instead of $\beta(v_1)$, for all $v_1 \in [0, 1]$. Expected utility as a function of v_1 and $\hat{v}$ can be written as

$$
\begin{aligned}
EU(v_1,\hat{v}) = \quad & (n-1)\int_0^{\hat{v}} \big[v_1-(1+\alpha_S)\beta(v_2)\big]F(v_2)^{n-2}f(v_2)\,dv_2 \\
& -(n-1)\int_{\hat{v}}^1 \big[\alpha_B v_2-(\alpha_B-\alpha_S)\beta(\hat{v})\big]F(\hat{v})^{n-2}f(v_2)\,dv_2 \\
& -(n-1)(n-2)\int_{\hat{v}}^1\int_{\hat{v}}^{v_2} \big[\alpha_B v_2-(\alpha_B-\alpha_S)\beta(v_3)\big]F(v_3)^{n-3}f(v_3)\,dv_3\,f(v_2)\,dv_2.
\end{aligned}
$$

The term in the first line, abbreviated $A(v_1,\hat{v})$ in the following, captures the cases in which bidder 1 wins, where multiplication by $n-1$ ensures that the assumption of bidder 2 submitting the second-highest bid is without loss of generality. The second term, abbreviated $B(v_1,\hat{v})$, captures the cases in which one of the $n-1$ other bidders wins but the bid of 1 determines the price. The last term, abbreviated $C(v_1,\hat{v})$, captures the cases in which one of the $n-1$ other bidders wins and the price is determined by one of the remaining $n-2$ bidders.[13]

We obtain the following derivatives:

$$
\begin{aligned}
\frac{\partial A(v_1,\hat{v})}{\partial \hat{v}} &= (n-1)\big[v_1-(1+\alpha_S)\beta(\hat{v})\big]F(\hat{v})^{n-2}f(\hat{v}), \\
\frac{\partial B(v_1,\hat{v})}{\partial \hat{v}} &= (n-1)\left[\alpha_B\hat{v}-(\alpha_B-\alpha_S)\beta(\hat{v})\right]F(\hat{v})^{n-2}f(\hat{v}) \\
& \quad -(n-1)\int_{\hat{v}}^1 \Big\{\big[\alpha_B v_2-(\alpha_B-\alpha_S)\beta(\hat{v})\big](n-2)F(\hat{v})^{n-3}f(\hat{v})f(v_2) \\
& \qquad -(\alpha_B-\alpha_S)\beta'(\hat{v})F(\hat{v})^{n-2}f(v_2)\Big\}\,dv_2, \\
\frac{\partial C(v_1,\hat{v})}{\partial \hat{v}} &= (n-1)(n-2)\int_{\hat{v}}^1 \big[\alpha_B v_2-(\alpha_B-\alpha_S)\beta(\hat{v})\big]F(\hat{v})^{n-3}f(\hat{v})f(v_2)\,dv_2.
\end{aligned}
$$

The term in the second line of $\partial B(v_1,\hat{v})/\partial\hat{v}$ cancels with $\partial C(v_1,\hat{v})/\partial\hat{v}$. Simplifying then yields

$$
\frac{\partial EU(v_1,\hat{v})}{\partial \hat{v}} = (n-1)F(\hat{v})^{n-2}\Big[f(\hat{v})\big[v_1+\alpha_B\hat{v}-(1+\alpha_B)\beta(\hat{v})\big]+(\alpha_B-\alpha_S)\big[1-F(\hat{v})\big]\beta'(\hat{v})\Big]. \quad (1)
$$

Setting this expression zero at $v_1=\hat{v}=:v$ yields the necessary condition

$$
f(v)\,(1+\alpha_B)\,[v-\beta^*(v)] = (\alpha_S-\alpha_B)\,[1-F(v)]\,\beta^{*\prime}(v) \quad (2)
$$

[13] With the convention $0^0=1$, the expression of $EU(v_1,\hat{v})$ is applicable to any $n\geq 2$.

for all $v \in (0,1)$. If $\alpha_S = \alpha_B$, this immediately implies $\beta^*(v) = v$, which can be extended to all $v \in [0,1]$ by continuity of β^*. Otherwise, if $\alpha_S \neq \alpha_B$, rearranging (2) yields

$$\beta^{*\prime}(v) + \left(\frac{-kf(v)}{1-F(v)}\right)\beta^*(v) = \left(\frac{-kf(v)}{1-F(v)}\right)v,$$

where $k = (1+\alpha_B)/(\alpha_B - \alpha_S)$. Using the integrating factor $[1-F(v)]^k$, this differential equation can be solved to

$$\beta^*(v) = v + \frac{K - \int_0^v [1-F(x)]^k\,dx}{[1-F(v)]^k} \tag{3}$$

for all $v \in (0,1)$, where K is a constant of integration.

Suppose first that $\alpha_S < \alpha_B$, which implies $k > 0$. It follows that $\beta^*(v)$ is unbounded as $v \to 1$ except if $K = \int_0^1 [1-F(x)]^k\,dx$, in which case $\lim_{v\to 1}\beta^*(v) = 1$. This determines the constant and yields

$$\beta^*(v) = v + \frac{\int_v^1 [1-F(x)]^k\,dx}{[1-F(v)]^k},$$

which can be extended to all $v \in [0,1]$ by continuity.

Suppose now that $\alpha_S > \alpha_B$, which implies $k < 0$. Since (2) then requires $\beta^*(v) < v$ for all $v \in (0,1)$, we must have $\lim_{v\to 0}\beta^*(v) = K = 0$. This yields

$$\beta^*(v) = v - \frac{\int_0^v [1-F(x)]^k\,dx}{[1-F(v)]^k},$$

which can be extended to all $v \in [0,1]$ by continuity.

Step 2. It remains to be shown that β^* as derived in Step 1 is in fact an equilibrium. We can first calculate the derivative

$$\beta^{*\prime}(v) = \begin{cases} \left(\frac{kf(v)}{1-F(v)}\right)\cdot\frac{\int_v^1[1-F(x)]^k dx}{[1-F(v)]^k} & \text{if } \alpha_S < \alpha_B, \\ 1 & \text{if } \alpha_S = \alpha_B, \\ \left(\frac{-kf(v)}{1-F(v)}\right)\cdot\frac{\int_0^v[1-F(x)]^k dx}{[1-F(v)]^k} & \text{if } \alpha_S > \alpha_B, \end{cases}$$

which verifies that β^* is strictly increasing. If $\alpha_S < \alpha_B$, substituting β^* as well as its derivative into (1) yields after some simplifications

$$\frac{\partial EU(v_1,\hat{v})}{\partial \hat{v}} = (n-1)F(\hat{v})^{n-2}f(\hat{v})\big[v_1 - \hat{v}\big].$$

Hence expected utility is strictly increasing in $\hat{v}$ when $\hat{v} < v_1$ and strictly decreasing in $\hat{v}$ when $\hat{v} > v_1$, so that $\hat{v} = v_1$ is in fact optimal. Proceeding analogously, exactly the same result is obtained for $\alpha_S = \alpha_B$ and for $\alpha_S > \alpha_B$. This completes the proof for the latter two cases, in which surjectiveness $\beta^*([0,1]) = [0,1]$ implies that every possible bid can be made by some announcement $\hat{v} \in [0,1]$. If $\alpha_S < \alpha_B$, we have $\beta^*([0,1]) = [K,1]$ for $K = \int_0^1 [1-F(x)]^k dx$. It is easily verified, however, that the expected utility of any bidder with any valuation is non-decreasing in the bid for $b \in [0,K]$, provided all other bidders follow strategy β^*. This completes the proof also for $\alpha_S < \alpha_B$. □

Proof of Proposition 2

Fix any $v \in (0,1)$. We are interested in the effect of α_S on $\beta^*(v)$, keeping $\alpha_B \in (-1,+1)$ fixed. Within each segment of the piecewise defined function β^*, α_S affects $\beta^*(v)$ only through $k = (1+\alpha_B)/(\alpha_B - \alpha_S)$. Note that $\partial k/\partial \alpha_S = (1+\alpha_B)/(\alpha_B-\alpha_S)^2 > 0$ whenever $\alpha_S \neq \alpha_B$. Now consider the effect of k on $\beta^*(v)$. We obtain

$$\frac{\partial \beta^*(v)}{\partial k} = \begin{cases} \frac{\int_v^1 [1-F(x)]^k \log[1-F(x)]dx - \int_v^1 [1-F(x)]^k dx \cdot \log[1-F(v)]}{[1-F(v)]^k} & \text{if } \alpha_S < \alpha_B, \\ -\frac{\int_0^v [1-F(x)]^k \log[1-F(x)]dx - \int_0^v [1-F(x)]^k dx \cdot \log[1-F(v)]}{[1-F(v)]^k} & \text{if } \alpha_S > \alpha_B. \end{cases} \tag{4}$$

We claim that the expression for $\alpha_S < \alpha_B$ is strictly negative. Indeed, this follows since

$$\int_v^1 [1-F(x)]^k \log[1-F(x)]dx < \int_v^1 [1-F(x)]^k \log[1-F(v)]dx$$

by the fact that $\log[1-F(x)]$ is strictly decreasing in x. The analogous argument reveals that the expression for $\alpha_S > \alpha_B$ is also strictly negative. We can thus conclude that $\beta^*(v)$ is strictly decreasing in α_S whenever $\alpha_S \neq \alpha_B$. We finally claim that $\lim_{\alpha_S \nearrow \alpha_B} \beta^*(v) = \lim_{\alpha_S \searrow \alpha_B} \beta^*(v) = v$, so that $\beta^*(v)$ is continuous in α_S. Note that $\lim_{\alpha_S \nearrow \alpha_B} k = +\infty$ and $\lim_{\alpha_S \searrow \alpha_B} k = -\infty$. Note further that

$$\lim_{k\to+\infty} \frac{\int_v^1 [1-F(x)]^k dx}{[1-F(v)]^k} = \lim_{k\to+\infty} \int_v^1 \left[\frac{1-F(x)}{1-F(v)}\right]^k dx = 0$$

and

$$\lim_{k\to-\infty} \frac{\int_0^v [1-F(x)]^k dx}{[1-F(v)]^k} = \lim_{k\to-\infty} \int_0^v \left[\frac{1-F(x)}{1-F(v)}\right]^k dx = 0.$$

This completes the proof.