Sealed-Bid Auctions with Human Auctioneers: An Experimental Study*

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Abstract

This paper studies first-price (FPA) and second-price (SPA) sealed-bid auctions with independent private values in a laboratory experiment in the presence human auctioneers (HA) who set reserve prices. When comparing bidder behavior in these auctions with near-zero reserve prices to identical auctions without HA and zero reserve prices, we find that in the presence of HA bidders bid less for a range of intermediate-to-higher valuations, especially in the FPA. This suggests that the presence of HA *per se* may have an effect on bidder behavior. In sessions with HA, we find that bidding in the FPA is broadly consistent with equilibrium theory, whereas bidding in the SPA is not, due to overbidding. The average reserve price set by the auctioneers is the same in both auction formats, but many reserve prices are out of range predicted by equilibrium theory. The FPA dominates the SPA in terms of revenue for the bottom third of reserve prices. The probability of sale is higher in the SPA compared to the FPA for a range of lower-to-medium reserve prices. The probability of selling to the highest valuation bidder conditional on sale exceeds 80 percent in the FPA and 92 percent in the SPA, but it is statistically different from 100 percent for majority of reserve prices, but not different between the two auction formats.

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1 Introduction

There is a large body of existing theoretical literature on equilibrium bidding and optimal reserve price setting in independent private value (IPV) sealed-bid auctions.[1] There is also a lot of laboratory- and field-based experimental research on the behavior of bidders in such auctions (Kagel 1995). Yet, to our knowledge there are no laboratory studies that would examine simultaneous behavior of bidders and auctioneers despite this being the empirically most relevant case. Among the few existing studies that do subject bidders to non-zero reserve prices or investigate auctioneer behavior, Reiley (2006) conducts a field experiment of first-price auctions of *Magic cards*, exogenously varying the reserve price. He finds that the number of bidders and the probability of sale decline with the reserve price, which is easily explained by low-valuation bidders being priced out,[2] bids of bidders with (presumed) valuations in excess of the reserve price increase with the reserve price and the shape of the expected revenue as a function of the reserve price has a W pattern. Focusing on auctioneer behavior, Davis, Katok and Kwasnica (2009) analyze reserve price setting in second-price auctions with computerized bidders who always bid their valuation. They find that the observed reserve prices respond to shifts in the distribution of valuations as theory would predict, but these reserve prices tend to be lower that what would be optimal under risk-neutrality. However, controlling for risk-aversion explains only a part of the gap. In addition, the reserve prices tend to increase with the number of bidders, contrary to theoretical predictions. The authors conclude that anticipated regret appears to be the best explanation for the data.[3]

These studies have important limitations, though. Reiley (2006) cannot control for bidder valuations that are, by nature of field experiments, home-grown. This poses challenges to the interpretation of his results. Davis et al. (2009), by focusing only on second-price auctions and employing computerized bidders, eliminate any potential strategic impact that the auctioneers may believe they have on bidders (although, by employing the dominant strategy bidding argument, they should not have any). Moreover, none of these existing studies incorporate both human bidders and human auctioneers, which is the case in all real-world auctions. We aim to fill this important gap in the literature by investigating both first-price (FPA) and second-price (SPA) IPV sealed-bid auctions with human bidders *and* human auctioneers and with induced bidder and auctioneer valuations.

The presence of human auctioneers (HA) raises four empirical questions. First, does their presence *per se* change bidder behavior in any way? That is, controlling for valuations, do bidders behave the same way for the same reserve price set by the experimenter as opposed to a HA? Second, does bidder and auctioneer behavior accord to equilibrium predictions from game theory? Third, how does the average reserve price, revenue, the probability of sale (sale efficiency) and the probability of allocating the object to the higher valuation bidder conditional on sale (allocative efficiency) differ for the FPA and the SPA, given any particular reserve price? Fourth, how do these revenue and efficiency comparisons differ from analogous comparisons in auctions without HA and with zero reserve prices?

We examine the first question by comparing the behavior of bidders in treatments without

[1] See, for example, Krishna (2002) for an authoritative synthesis.

[2] Note, however, that this is a field experiment with home-grown values, and hence, unlike in the experiment presented in this paper, this explanation cannot be verified in the data.

[3] Greenleaf (2004) studies the impact of anticipated regret and rejoicing on reserve price setting in English auctions as well, but he employs secrete reserve prices, hence diverging from the auction design that is a focus of this paper.

HA and with zero reserve prices and treatments with HA when they set near-zero reserve prices. We find that the presence of HA *per se* has a negative effect on bids over intermediate-to-higher valuations, with the effect being more profound for the FPA. It is not clear what drives this difference, but the finding potentially carries an important message for all experimental work that examines sealed-bid independent private value auctions without HA and with zero reserve prices: the measured bidder behavior may be different depending on whether another human subject or the experimenter is the auctioneer, with implications for external validity of these experiments.

Regarding the second question, we find that bidder behavior in the FPA is fairly consistent with basic features of equilibrium behavior: bidders bid below the reserve price if their valuation falls short of it, bid below or at the reserve price if their valuation is equal to the reserve price, and bid between the reserve price and their valuation otherwise. Although such behavior is not universal, deviations are (statistically) rare. Moreover, bids are increasing in the reserve price among bidders whose valuation exceeds the reserve price, as predicted by the equilibrium theory. Results are different for the SPA, though. There, a significant fraction of bidders overbid their valuation, and sometimes even overbid the reserve price despite the latter being more than their valuation. This is consistent with many previous experimental studies without HA (Kagel, Harstad and Levin 1987, Kagel and Levin 1993, Harstad 2000), and we find it in our data also in the absence of HA (Chen, Katuščák and Ozdenoren 2007). On the other hand, in the SPA the bids of bidders whose valuation exceeds the reserve price are not sensitive to the reserve price, consistently with dominant strategy bidding.

As for the third question, the average reserve price set by the auctioneers is statistically indistinguishable between the two formats. We also find that the FPA dominates the SPA in terms of revenue for the bottom third of reserve prices, which can be explained by bidder risk aversion. Sale efficiency is higher in the SPA compared to the FPA for a range of lower-to-medium reserve prices. Allocative efficiency exceeds 80 percent in the FPA and 92 percent in the SPA over the range of relevant reserve prices, but it is statistically different from 100 percent for majority of reserve prices in the FPA and all reserve prices in the SPA. On the other hand, it is not different between the two auction formats.

Regarding the fourth question, in the absence of HA, the FPA generates a significantly higher average revenue than the SPA, as is the case for the bottom third of reserve prices in the presence of HA. Without HA, sale efficiency is 100 percent by construction since the object is always sold, and so there is no difference between the FPA and the SPA. This is in contrary to auctions with HA, in which there is a significant difference for a certain range of reserve prices. In the absence of HA, allocative efficiency is estimated to be around 89 percent in both auction formats, with the difference being statistically insignificant, like in the presence of HA. Therefore the comparisons of revenue and efficiency in auctions with and without HA are qualitatively very similar with the exception of sale efficiency. However, the latter measure is *not* based on subject behavior in auctions without HA, and hence the sale efficiency comparison is qualitatively different from the other two comparisons.

The rest of the paper proceeds as follows. Section 2 outlines a standard equilibrium game-theoretic framework underlying sealed-bid auctions in the presence of auctioneers and derives a set of testable hypotheses for bidder and auctioneer behavior. Section 3 presents the experimental design. Section 4 presents the results. Section 5 discusses the results and concludes.

2 Theoretical Model and Hypotheses

In the first subsection, we derive game-theoretic predictions based on a concept of a sequential equilibrium. In the following subsection, we in turn derive a set of testable hypotheses following from these predictions.

2.1 Theory

In light of the experimental design, we analyze first- and second-price auctions with independent private values, two competing bidders $i = 1, 2$, and an auctioneer with one indivisible object for sale with zero valuation. The support of possible bidder valuations for the object is $[0, 1]$, with V_i denoting bidder i's valuation. Bidder valuations are private information, but they are known to be independent draws from a distribution $F(\cdot)$ with a strictly positive and bounded density $f(\cdot)$ throughout the support. We also assume that $f(\cdot)$ is continuous except for a finite set of points. In our experimental application, $F(\cdot)$ and $f(\cdot)$ are given by

$$F(V) = \begin{cases} 1.2V & \text{if } 0 \leq V \leq \frac{1}{2} \\ 0.2 + 0.8V & \text{if } \frac{1}{2} < V \leq 1 \end{cases} \tag{1}$$

and

$$f(V) = \begin{cases} 1.2 & \text{if } 0 \leq V < \frac{1}{2} \\ 0.8 & \text{if } \frac{1}{2} < V \leq 1 \end{cases}, \tag{2}$$

respectively.

In the auction, the auctioneer first sets her reserve price r. Upon observing this price, the bidders simultaneously submit their bids b_1 and b_2. The object is then allocated to the highest bidder conditional on the bid at least matching the reserve price. Any ties are broken by a fair random device. If the object is not sold, everyone's payoff is zero. If the object is sold, the sale price p is equal to highest bid in the FPA and to the maximum of the second highest bid and the reserve price r in the SPA. In such case the winning bidder's payoff is $V_i - p$, the losing bidder's payoff is zero, and the auctioneer's payoff is p. Bidders' utility functions are given by $w_i(\cdot)$ with $w_i' > 0$ and $w_i'' \leq 0$, $i \in \{1, 2\}$, and the auctioneer's utility function is given by $u(\cdot)$ with $u' > 0$ and $u'' \leq 0$, with intercept and scale normalization $w_i(0) = u(0) = 0$ and $w_i(1) = u(1) = 1$, $i \in \{1, 2\}$.

In what follows, we discuss theoretical benchmarks for equilibrium bidding and reserve price setting behavior. Given that the auctioneer moves first and the bidders move only after observing the reserve price set by the auctioneer, without knowing each other's valuations, we use the concept of a sequential equilibrium. The bidders do not update their beliefs about each other's valuations, however, after observing the reserve price. We first analyze the symmetric Bayesian Nash equilibrium of the bidding subgame and then characterize the optimal reserve price as a best response to the equilibrium bidding strategies of the two bidders.

In the SPA, there is a unique weakly dominant bidding strategy regardless of bidder risk attitudes, giving the usual strong prediction:

Proposition 1. *In the SPA, if $V_i > r$, bidding one's valuation is the unique weakly dominant strategy irrespective of bidder risk attitude. If $V_i < r$, the set of optimal bids is given by $[0, r)$. If $V_i = r$, the set of optimal bids is given by $[0, r]$.*

In the FPA, these is no dominant bidding strategy in general. Relying purely on rationalizability of bidders' strategies has a weak predictive power (Battigalli and Siniscalchi 2003). Our characterization of bidding strategies therefore takes the usual approach of assuming that bidders are *ex ante* identical ($w_1(\cdot) = w_2(\cdot) \equiv w(\cdot)$) and, given any particular reserve price, they use a symmetric *Bayesian Nash equilibrium* bidding strategy. The following proposition characterizes this bidding strategy. The proof, which is provided in Appendix B, is based on Theorem 2 in Maskin and Riley (1984), which is a generalization of Proposition 4 in Riley and Samuelson (1981).

Proposition 2. *In the FPA, when the reserve price is set at r, there is a unique symmetric Bayesian Nash equilibrium bidding strategy $s(V, r)$ for $V > r$ that is continuous and strictly increasing in V, weakly increasing in (and hence almost everywhere differentiable with respect to) r, and satisfies*

$$r < s(V, r) < V \tag{3}$$

and

$$s(V, r) = r + \int_r^V \frac{f(x)}{F(x)} h[x - s(x, r)]dx, \tag{4}$$

where $h : \mathbb{R}^+ \to \mathbb{R}^+$ is defined by $h(y) \equiv w(y)/w'(y)$. If $V < r$, the set of optimal bids is given by $[0, r)$. If $V = r$, the set of optimal bids is given by $[0, r]$.

Proof: See Appendix B.

If bidders are risk-neutral, we obtain the usual bidding function (Riley and Samuelson 1981) of the following form:

Corollary 1. *In the FPA, if bidders are risk-neutral,*

$$s^{RN}(V, r) = V - \frac{\int_r^V F(x)dx}{F(V)} \tag{5}$$

for any $V > r$.

Proof: See Appendix B.

Solving for a closed-form of the bidding function is not possible in general if bidders are risk-averse. However, some important comparative statics can be obtained:

Proposition 3. *In the FPA, given (V, r) with $V > r$, $s(V, r)$ is strictly higher and $s_2(V, r)$ is, provided that $r > 0$, strictly lower if bidders are risk-averse compared to when bidders are risk-neutral. Also, $s_2(V, 0) = 0$ regardless of bidder risk aversion.*

Proof: See Appendix B.

Having characterized the equilibrium bidding behavior in the two auction formats, we are now ready to characterize the reserve price setting as an optimal response to these bidding strategies.

Proposition 4. *In the SPA, regardless of bidder risk attitudes, an optimal reserve price r^*_{SPA} satisfies $r^*_{SPA} \in (0, 1)$ and*

$$\lim_{r \downarrow r^*_{SPA}} \frac{1 - F(r)}{f(r)} \leq \frac{u(r^*_{SPA})}{u'(r^*_{SPA})} \leq \lim_{r \uparrow r^*_{SPA}} \frac{1 - F(r)}{f(r)}, \tag{6}$$

where either of the two inequalities can only be strict at a point of discontinuity of $f(\cdot)$. Furthermore, if $F(\cdot)$ displays a non-decreasing hazard rate, there is a unique optimal reserve price.

Proof: See Appendix B.

If the auctioneer is risk-neutral and $f(\cdot)$ is continuous, this reduces to the standard optimal reserve price characterization of Riley and Samuelson (1981).

We are in general considering cases with a discontinuous density $f(\cdot)$ because it corresponds to our experimental design. However, it also makes it harder to work with (6) because it is more likely to have multiple roots. Such possibility can be ruled out by restricting the hazard rate of $F(\cdot)$ somewhat in order to guarantee a unique root of (6). This can be done by, for example, the means of the following assumption:

Assumption 1. *The equation $[1 - F(r)]/f(r) = r$ has a unique root $\overline{r} \in (0, 1)$ and the hazard rate of $F(\cdot)$ is continuous and non-decreasing on $[0, \overline{r}]$.*

Note that the distribution specification (1) and (2) used in our experimental implementation satisfies Assumption 1. Also note that Assumption 1 implies that $[1 - F(r)]/f(r) < r$ for all $r > \overline{r}$. We now obtain a more informative result for the optimal reserve price in the SPA:

Corollary 2. *Under the Assumption 1, there is a unique optimal reserve price $r^*_{SPA} \in (0, 1)$ in the SPA that is implicitly given by*

$$\frac{u(r^*_{SPA})}{u'(r^*_{SPA})} = \frac{1 - F(r^*_{SPA})}{f(r^*_{SPA})}.$$

Moreover, the optimal reserve price of a risk-averse auctioneer is strictly lower than the optimal reserve price of a risk-neutral auctioneer.

The second part of the result follows from the observation that $u(y)/u'(y) > y$ for all $y \in (0, 1]$ and $u(y)/u'(y)$ is strictly increasing in y. The comparative static with respect to bidder risk aversion corresponds to Theorem 3 in Waehrer, Harstad and Rothkopf (1998) and Theorem 2 in Hu, Matthews and Zou (2010).

Characterization of the optimal reserve price in the FPA is more difficult. However, useful comparisons between optimal reserve prices in the two auction formats can be obtained.

Proposition 5. *Suppose that Assumption 1 is satisfied. Then if both the bidders and the auctioneer are risk-neutral, the optimal reserve price in the FPA is the same as in the SPA. If either the bidders or the auctioneer (or all of them) are risk-averse, then any optimal reserve price in the FPA is strictly lower than the optimal reserve price in the SPA.*

Proof: See Appendix B.

If everyone is risk-neutral, this result corresponds to Proposition 3 of Riley and Samuelson (1981). If the bidders and/or the auctioneer are risk-averse, this result is a special case of Theorem 1 in Hu et al. (2010). Intuitively, incrementally increasing the reserve price has two effects on the distribution of revenue received by the auctioneer. On the upside, it increases bids of all bidders with $V > r$ in the FPA (Proposition 2) and payments of bidders with $V > r$ if the other bidder's valuation is below r in the SPA (Proposition 1). On the downside, it prices marginal highest-valuation bidders out of the auction, resulting in a revenue loss of r on the margin. However, whereas the utility loss from the downside is the same in both auction formats, the utility gain from the upside is larger in the SPA than in the FPA unless both the bidders and the auctioneer are risk-neutral, in which case the two utility gains coincide. The proof of Proposition 5 demonstrates that this difference may come either from risk aversion of the auctioneer or risk aversion of the bidders. First, because $s(V, r) > r$, for valuation combinations where an increase in the reserve price increases bids in the respective auction format, it does so at a higher level of revenue in the FPA compared to the SPA. Compared to a risk-neutral auctioneer, a risk-averse auctioneer values the former less on the margin than the latter due to concavity of $u(\cdot)$. Second, the bidder sensitivity to the reserve price captured by $s_2(V, \cdot)$ is lower for risk-averse bidders compared to the risk-neutral ones (Proposition 3) in the FPA, whereas it is unchanged by risk aversion in the SPA. As a result, bidder risk aversion reduces the size of the resulting bid increase in the FPA while it does not do so in the SPA.

Corollary 2 and Proposition 5 imply that the highest reserve price one should ever see in either the FPA or the SPA is the reserve price set by a risk-neutral auctioneer in the SPA. The following Corollary uses this observation to characterize an upper bound on the set of reserve prices one should observe in an equilibrium under our experimental distribution of valuations.

Corollary 3. *Under the distributional assumptions in (1) and (2), the optimal reserve price in either auction format does not exceed* $5/12 (\simeq 0.417)$.

The analysis of the reserve-price setting behavior implies also the following result:

Proposition 6. *Given any reserve price* r*, if bidders are risk-neutral, the expected revenue in the two auction formats is the same. Given any reserve price* r*, if bidders are risk-averse, the expected revenue in the FPA is greater than the expected revenue in the SPA.*

Proof: See Appendix B.

In case of risk-neutral bidders, this result corresponds to the standard Revenue Equivalence Theorem. In case of risk-averse bidders, this result corresponds to Theorem 4 in Maskin and Riley (1984). Intuitively, in the FPA, risk-averse bidders bid more given (V, r) if $V > r$ compared to risk-neutral bidders (Proposition 3), and hence the expected revenue is larger, whereas bids are unchanged with risk aversion in the SPA.

Although it may seem that Proposition 6 also suggests that, if bidders are risk-averse and the reserve prices are set optimally in each auction format, the average realized revenue in the FPA is higher than in the SPA, this is not necessarily the case since auctioneers maximize expected utility rather than expected revenue and the optimal reserve prices in the two formats are in general different.

We next turn to efficiency. There are two kinds of efficiency we consider. First, *sale efficiency* is defined as the probability with which the object is sold. This is because with the auctioneer having a zero valuation for the object and the bidders having positive valuations, it is always socially optimal if the object is sold. Second, *allocative efficiency* is defined as the probability, conditional on sale, that the object is allocated to the higher valuation bidder. Under the symmetric equilibria discussed above, we obtain the following result:

Proposition 7. *Sale efficiency is decreasing in the reserve price in either auction format. Allocative efficiency is equal to* 1 *in either auction format.*

This concludes the exposition of equilibrium theoretical background. In the next subsection, we use this theoretical framework to formulate of set of empirically testable hypotheses.

2.2 Hypotheses

In this subsection, we present a series of hypotheses that are motivated by the five questions we raised in the Introduction and for which the equilibrium theory presented in the previous subsection serves as a benchmark.

The first hypothesis pertains to the first question about how the presence of HA *per se*, rather than the fact that they set non-zero reserve prices, affects bidder behavior. The equilibrium theory predicts that the bidding behavior should be the same for the same reserve price, regardless of whether it is set by an experimenter or by a human auctioneer.

Hypothesis 1. *Conditional on near-zero reserve prices, bidder behavior in treatments with HA is the same as bidder behavior in treatments without HA in either auction format.*

The next set of hypotheses addresses the second question about whether bidder and auctioneer behavior accords to the equilibrium theory presented in the previous section. Concerning the bidders' behavior, we formulate the following hypotheses that are motivated by Propositions 1 and 2:

Hypothesis 2. *In the FPA, bidders with $V < r$ bid below r, bidders with $V = r$ do not bid above r and bidders with $V > r$ bid between r and V.*

Hypothesis 3. *In the SPA, bidders with $V < r$ bid below r, bidders with $V = r$ do not bid above r and bidders with $V > r$ bid at V.*

Hypothesis 4. *In the FPA, the bids of bidders with $V > r$ are strictly increasing with r given V.*

Hypothesis 5. *In the SPA, the bids of bidders with $V > r$ are invariant to r given V.*

Concerning the auctioneers' behavior, we formulate the following hypotheses that are motivated by Proposition 5 and Corollary 3:

Hypothesis 6. *In the SPA, auctioneers set a reserve price that is at least as large as the reserve price set by the auctioneers in the FPA.*

Hypothesis 7. *The reserve price set by auctioneers in either auction format does not exceed* $5/12$.

The next set of hypotheses is concerned with comparisons of revenue, sale efficiency and allocative efficiency across the two auction formats in the presence of HA conditional on a particular reserve price. Starting with revenue, the following hypothesis is based on Proposition 6:

Hypothesis 8. *Conditional on the reserve price, the average revenue in the FPA is at least as large as the average revenue in the SPA.*

Turning attention to sale efficiency, the equilibrium bidding theory predicts that the object will be sold if and only if there is at least one bidder with the valuation exceeding the reserve price or at least one bidder with the valuation equal to the reserve price and this bidder bids his valuation. As a result, the probability of sale, and hence sale efficiency, decreases with the reserve price. Importantly, all this is equally true in both auction formats. These observations motivate the following two hypotheses:

Hypothesis 9. *Sale efficiency is decreasing with the reserve price in either auction format.*

Hypothesis 10. *Conditional on the reserve price, sale efficiency is independent of the auction format.*

Regarding the allocative efficiency, the symmetry assumption in the equilibrium theory and the monotonicity of the bidding function in the own valuation predict that if sold, the object is always allocated to the higher valuation bidder, implying a sale efficiency of 100 percent, and this is equally true for any reserve price and for both auction formats. These observations motivate the following hypotheses:

Hypothesis 11. *Allocative efficiency is 100 percent in either auction format.*

Hypothesis 12. *Allocative efficiency is independent of the reserve price.*

Hypothesis 13. *Allocative efficiency is independent of the auction format.*

3 Experimental Design

In this section, we summarize the main features of our experimental design. Our data come from auction experiments, a post-experiment questionnaire, and additional data on course and major background collected from the University of Michigan Office of the Registrar. We ran these experiments between October 2001 and January 2002. In our previous papers (Chen et al. 2007, Chen, Katuščák and Ozdenoren 2009) based on these experiments, we focused on the behavior of bidders in sessions without auctioneers. In this paper, we focus on the behavior of bidders and auctioneers in previously non-analysed sessions where both types of auction participants are present.

All sessions were conducted using networked computers at the Research Center for Group Dynamics Laboratory at the University of Michigan. The subjects were recruited from an email list of Michigan undergraduate and graduate students, excluding graduate students in economics. Individual sessions lasted from 40 to 90 minutes, depending on a treatment.

3.1 Auctions

We employ a 2×2 factorial design. In the mechanism dimension, we use the FPA and the SPA, while in the auctioneer dimension we use treatments without auctioneers and with auctioneers. We conduct five independent sessions in each of the four treatments. Each session consists of eight bidders and, in sessions with auctioneers, four auctioneers. Table 1 summarizes features of the auction experiments, including mechanism, number of bidders and auctioneers, exchange rates and average payoffs. This design gives us a total of 160 bidders and 40 auctioneers evenly split between the FPA and the SPA, each acting 30 times (see below).

[Insert Table 1 about here.]

The process within each session is as follows. First, at the beginning of each session, subjects randomly draw a PC terminal number. Then each subject is given printed instructions (Appendix A). After the instructions are read aloud, each subject completes a set of Review Questions to test their understanding of the instructions. The experimenter then checks the responses and answers any questions. The instruction period varies from fifteen to thirty minutes, depending on the treatment and the presence of auctioneers. In sessions with auctioneers, the four auctioneers go to an adjacent lab after the instruction period. The bidders remain in the original lab, and everyone is now seated in front of their computer terminal.

Each session lasts for 30 rounds, without any practice rounds. In each round, subjects are randomly rematched into groups of two bidders and, in sessions with auctioneers, one auctioneer. Bidder valuations are generated as independent draws from either a low value distribution $F^1(\cdot)$ or a high value distribution $F^2(\cdot)$. The support set of these distributions is given by $\{1, 2, \cdots, 100\}$, and the respective densities, f^1 and f^2, are given by

$$f^1(x) = \begin{cases} \frac{3}{200} & \text{if} \quad x \in \{1, .., 50\} \\ \frac{1}{200} & \text{if} \quad x \in \{51, .., 100\} \end{cases} \tag{7}$$

$$f^2(x) = \begin{cases} \frac{1}{200} & \text{if} \quad x \in \{1, .., 50\} \\ \frac{3}{200} & \text{if} \quad x \in \{51, .., 100\} \end{cases} . \tag{8}$$

In all sessions, the probability that bidder valuation is drawn from $F^1(\cdot)$ is 0.70. All distributional assumptions are publicly announced during the instruction stage to all subjects. As a result, the compound distribution of valuations has a density

$$\overline{f}(x) = \begin{cases} \frac{3}{250} & \text{if} \quad x \in \{1, .., 50\} \\ \frac{2}{250} & \text{if} \quad x \in \{51, .., 100\} \end{cases} . \tag{9}$$

This is a discrete counterpart of the continuous distribution given by (2).[4]

Each round of auction consists of the following stages:

1. In sessions with auctioneers, each auctioneer sets a reserve price, which can be any integer between 1 and 100, inclusive.

2. Each bidder is informed of his own valuation and, in sessions with auctioneers, the reserve price of his auctioneer. Then each bidder simultaneously and independently submits a bid, which can be any integer between 1 and 100, inclusive. The bidders are instructed that they can submit any bid below the reserve price if they do not want to participate in the auction.

3. Bids are then collected in each group and the winner is the bidder with the higher bid, if at least meeting the reserve price. Any bid ties are broken by a fair tie-breaking device.

4. After each round of auction, each bidder receives the following feedback on his screen: his valuation, his bid, the reserve price (in sessions with auctioneers), the winning bid, whether he wins the auction, and his payoff. The payoff is equal to the difference between his value and the price if he wins, and zero otherwise. In sessions with auctioneers, each auctioneer receives the following feedback: indication of whether the object is sold, her reserve price, the bids in her group, and her payoff. The payoff is equal to the sale price if the object is sold, and zero otherwise.

[4]We use this particular framing of the compound distribution in order to be consistent with sessions that we ran in order to identify the effect of ambiguity on bidding. In these sessions, the respective weights placed on $F^1(\cdot)$ and $F^2(\cdot)$ were not announced to the bidders. The results are reported in Chen et al. (2007).

3.2 Survey and Registrar Information

At the end of the experiment, all participants complete a survey (Appendix B) to elicit demographic information, as well as a self-described personality assessment and identification of emotions experienced during the experiment. In addition, female subjects provide menstrual cycle information. For the demographic information, we elicit gender, race, age, and the number of siblings. We do not include the personality or emotion variables in the subsequent analysis, as they are likely to be endogenous to the outcome of the auction.[5] Likewise, due to a smaller sample size of auctioneers, we do not include the menstrual cycle variables in the subsequent analysis either.[6] In addition, we obtain subject majors from the University of Michigan Office of the Registrar, together with a list of courses our subjects took at the University of Michigan prior to participating in the experiment. We group academic majors into six different categories: Mathematics and Statistics, Science and Engineering, Economics and Business, Other Social Sciences, Humanities and Other, and Unknown. These categories cluster academic major types with a similar exposure to analytic and strategic reasoning.

Of the 200 subjects in the sample, 48% are women, the average subject age is 21 years, and subjects have on average 1.48 siblings. Regarding the ethnic/racial composition, 53% of subjects are White, 36% are Asian/Asian American, 5% are African American, 2% are Hispanic, 1% are Native, and 4% identify themselves as belonging to other ethnic/racial groups. Because of the relatively low number of non-white or non-Asian subjects, we group all other racial groups into the "Other" category in the subsequent analysis. Regarding the academic major, 24% of our subjects are Science and Engineering majors, followed by Economics and Business and Humanities and Other (each 11%), Other Social Sciences (8%), and Mathematics and Statistics (1%). Unfortunately, we do not have academic major information for 47% of our subjects.[7] Table 2 further breaks down these summary statistics by whether a subject is in the role of a bidder or an auctioneer and the type of auction. Using simple two-sample t-tests for the equality of means, we cannot reject the null hypothesis that bidders in auctions with and without human auctioneers have the same means of demographic variables and major indicators with the exception of Asian/Asian American indicator in the case of FPA and age and indicators for African American and Economics and Business major in the case of SPA. Hence, apart from analyzing unconditional differences, we will also analyze differences with conditioning on auctioneer and average bidder demographic and academic major variables.[8]

[Insert Table 2 about here.]

[5]The primary objective of eliciting this information was to study ambiguity attitude in our companion paper (Chen et al. 2007).

[6]We do, however, analyze the impact of the menstrual cycle and contraceptive pill usage on bidding in our companion paper (Chen et al. 2009).

[7]This is because we were either unable to match these subjects with the records at the Registrar's Office based on their identifying information (name and social security number), or, if we were able to do so, the available information was insufficient to determine the major category.

[8]A simple t-test also reveals that, both in the FPA and the SPA, bidder valuations are not significantly different between sessions with and without human auctioneers. Despite that, we will include a second-order polynomial in value as additional explanatory variables when conditioning on demographic and academic major variables.

4 Results

In this section, we examine our experimental dataset in order to test the hypotheses derived in Section 2.

4.1 Bidder Behavior

We begin by examining the Hypothesis 1. Figure 1 displays non-parametric estimates of the impact of the presence of HA on bids over the entire range of valuations. The top panel displays the difference between bids in the presence of HA and in the absence of HA for the FPA, whereas the bottom panel displays analogous comparisons for the SPA. Because in auctions with HA the reserve price is always at least 1, we cannot compare sessions with and without HA holding the reserve price exactly fixed at zero. Even if we could, an additional problem is that there is only a very limited number of observations in sessions with HA where the reserve price is set at its possible minimum. We therefore repeat the comparison for four degrees of "nearness" of reserve prices to zero: $r \leq 1$, $r \leq 5$, $r \leq 10$ and $r \leq 20$. The estimation is conducted using the lowess smoother with the tricube weighting function, proportional bandwidth of 50 percent of the sample and local averaging of predictions. The 95 percent confidence intervals are obtained by bootstrapping with draws clustered at session level.[9]

[Insert Figure 1 about here.]

Figure 1 shows that, in the FPA, in the presence of HA, bidders tend to bid less in the range of valuations approximately between 50 and 90, irrespective of the degree of nearness we use. In the SPA, there is little statistical difference in bids between the two groups when $r \leq 1$ or $r \leq 5$, but when $r \leq 10$ or $r \leq 20$, bidders in the presence of HA bid significantly less in the range of valuations approximately between 50 and 80. Based on the analysis of symmetric bidding equilibria in Section 2, if anything, one would expect higher bids in the FPA in the presence of HA due to slightly higher reserve prices and no difference in the SPA. Therefore Figure 1 presents evidence that the presence of HA *per se*, apart from the fact they set non-zero reserve prices, has an effect of the behavior of bidders, at least in the FPA and at least over a certain range of valuations, and this effect is negative.[10]

RESULT 1. *Conditional on near-zero reserve prices, in the presence of HA, in the FPA bidders bid less for a significant share of intermediate-to-higher valuations. In the SPA, the difference goes in the same direction, but its statistical significance is inconclusive. We therefore reject Hypothesis 1.*

[9] We implement the estimation procedure using the *lowess* command in Stata.

[10] It is not entirely clear what the sources of this bidding difference are. One could speculate that it may be due to bidders more frequently ending an auction round with a zero payoff because of being priced out by auctioneers, and hence becoming more profit-seeking and therefore lower-bidding when their valuation happens to exceed the reserve price. However, when we run a subject fixed effects regression of bids on the share of won auctions up until the previous round, controlling for valuation, its square, the reserve price and the interaction of the valuation and the reserve price, in both the FPA and the SPA the coefficient on the share variable is negative and statistically significant in auctions without HA and negative and statistically insignificant in auctions with HA. This is in contrary to the proposed speculation since the latter would imply a positive coefficient.

We next turn attention to examining Hypotheses 2-5 that are concerned with the question of whether bidder behavior accords with the equilibrium theory. Table 3 displays the distribution of bids relative to reserve prices and valuations in both the FPA and the SPA. It also displays the outcomes of tests of Hypotheses 2 and 3, where the standard errors of the estimated probabilities are adjusted for clustering at session level. In the FPA, bidding behavior is broadly consistent with equilibrium theory in that, conditional on a particular range of valuations ($V < r$, $V = r$, $V > r$), at least 95 percent of bids are in the predicted range. In addition, we cannot reject the Hypothesis 2 for $V < r$ and $V = r$, and we can barely reject it for $V > r$ only at the 10 percent significance level, and even then almost 99 percent of bids are in the predicted range. The situation is quite different in the SPA, where we observe a significant amount of overbidding, which reaches almost 42 percent when the valuation exceeds the reserve price.[11] This pattern of overbidding is consistent with previous results in the literature (Kagel et al. 1987, Kagel and Levin 1993, Harstad 2000). These observations are summarized in the following two results:

[Insert Table 3 about here.]

RESULT 2. *Bidding behavior in the FPA, relative to reserve prices and own valuations, is broadly consistent with the equilibrium theoretical prediction and we do not reject Hypothesis 2.*

RESULT 3. *In the SPA, there is a significant amount of overbidding, which is inconsistent with the dominant strategy prediction. Therefore we reject Hypothesis 3.*

For a comparison, in treatments without auctioneers, 3.9 percent of bids in FPA_8 are greater or equal to the bidder's valuation, which is statistically significantly different from zero (at 5 percent, standard errors clustered at session level). This is similar to our findings in FPA_{12}, except that there the fraction of bids in the predicted range is not significantly different from 1. In SPA_8, 49.8 percent of subjects overbid their valuation, a fraction that is even higher than in SPA_{12} with $V > r$.

We next proceed to examine the monotonicity of bids in the reserve price. Table 4 displays estimates of regressing bids on V and r and, in some specifications, also V^2 and the interaction term rV, using only observations for which $V > r$ and accounting for bidder fixed effects. The standard errors are adjusted for clustering at session level. Specifications (1)-(3) refer to the FPA and specifications (4)-(6) to the SPA. The results show that the reserve price has a positive and statistically significant impact on bids in the FPA but not in the SPA, irrespective of whether we use additional non-linearity controls or not. Hence the results are in both cases in line with the equilibrium theoretical predictions. These observations lead to the following two results:

[Insert Table 4 about here.]

RESULT 4. *In the FPA, bids of bidders with $V > r$ are increasing in the reserve price given V, so we do not reject Hypothesis 4.*

RESULT 5. *In the SPA, bids of bidders with $V > r$ are invariant to the reserve price given V, so we do not reject Hypothesis 5.*

[11] We have also investigated whether the pattern of overbidding for bidders with $V > r$ is systematically related to V and r. Running regressions with non-linearities and interactions, all of the slope coefficients are always jointly statistically insignificant, both when we do and when we do not control for subject fixed effects.

4.2 Auctioneer Behavior

In this subsection, we analyze the reserve-price setting behavior of the auctioneers. Figure 2 displays histograms of observed reserve prices in the FPA and the SPA, respectively. The average reserve price (standard deviation) is 39.8 (16.2) in the FPA and 41.0 (23.4) in the SPA. Using the t-test, clustering the standard errors at session level, these two means are statistically indistinguishable. We conclude that:

[Insert Figure 2 about here.]

RESULT 6. *The average reserve price in the FPA is statistically indistinguishable from the average reserve price in the SPA. We therefore do not reject Hypothesis 6, but note that, given the theoretical predictions, equality of reserve prices in the two auction formats obtains only under risk neutrality of both auctioneers and bidders.*

The vertical lines in Figure 2 mark the theoretical upper boundary on optimal reserve prices derived in Corollary 3. Clearly, this boundary is exceeded in a significant fraction of cases (42.5 percent in the FPA and 54.8 percent in the SPA). This is also visible in Figure 3 which plots the time series of the observed reserve prices in both auction formats. This figure also shows that while more reserve prices fall under the threshold in the late periods of the FPA, this is not the case in the SPA. We therefore obtain that:

[Insert Figure 3 about here.]

RESULT 7. *The reserve prices set by auctioneers frequently exceed the theoretical threshold of 5/12. We therefore reject Hypothesis 7.*

This finding invites a question of how auctioneers actually decide on what reserve price to set. In this regard, it would be interesting to see how the conditional empirical distribution of revenue varies across different reserve prices. In a sample with several hundred subjects, this could be achieved by a simple comparison or revenue distributions across different reserve prices. However, in a smaller sample size such as the one used here, this may be misleading because reserve prices are not necessarily independent of valuations within the sample. In particular, within each auction format, there are 600 valuation realizations and there are up to 100 possible reserve price choices, and hence sampling variation on valuation realizations could easily affect the empirical revenue distribution comparisons. We therefore adopt a parametric procedure that controls for variation in valuation realizations across different auctions. Specifically, pooling the data across both the FPA and the SPA, in the first stage we estimate the specification

$$\begin{aligned} y_{it} = & \sum_{j \in \{LL,LH,HH\}} D_{itj} \left(\alpha_{j1} + \alpha_{j2} \overline{V}_{it} + \alpha_{j3} \underline{V}_{it} + \alpha_{jr} r_{it} + \alpha_{j5} \overline{V}_{it} r_{it} + \alpha_{j6} \underline{V}_{it} r_{it} \right) \\ & + F_{it} \sum_{j \in \{LL,LH,HH\}} D_{itj} \left(\beta_{j1} + \beta_{j2} \overline{V}_{it} + \beta_{j3} \underline{V}_{it} + \beta_{jr} r_{it} + \beta_{j5} \overline{V}_{it} r_{it} + \beta_{j6} \underline{V}_{it} r_{it} \right) \\ & + \varepsilon_{it}, \end{aligned} \tag{10}$$

where i indexes auctioneers, t indexes periods, y is the revenue, r is the reserve price, F is an indicator for the FPA, $\overline{V}$ and $\underline{V}$ are the high and the low valuation realizations in the auction, respectively, D_{LL} is an indicator for $\overline{V} < r$, D_{LH} is an indicator for $\underline{V} \leq r \leq \overline{V}$, D_{HH} is an indicator for $r < \overline{V}$ and ε is the residual. That is, in each auction format, revenue conditional on the valuation pair and the reserve price is modeled as an affine function of the high and the low valuation interacted with an affine function of the reserve price. Then, in the second stage, using the estimates $\widehat{\alpha}$ and $\widehat{\beta}$, we compute the mean predicted revenue conditional on a reserve price r by taking the theoretical expectation of the right-hand side of (10), ignoring the residual, with respect to the theoretical distribution of valuations (specified in (9)). We also construct the standard deviation of revenue conditional on the reserve price. To do so, we first compute the theoretical variance of the right-hand side of (10) using the estimates $\widehat{\alpha}$ and $\widehat{\beta}$ and ignoring the residual, with respect to the theoretical distribution of valuations. Second, we compute squared regression errors from the first stage, regress them on the same right-hand side variables as in (10), obtain estimates $\widetilde{\alpha}$ and $\widetilde{\beta}$, and use these estimates to compute the mean predicted error conditional on a reserve price r by taking the theoretical expectation of the right-hand side of (10), ignoring the residual, with respect to the theoretical distribution of valuations. We then add together the two terms to estimate the variance of revenue conditional on the reserve price, and take a square root to estimate the standard deviation. We use analogous methodology to construct a prediction of sale efficiency by taking y to be the indicator variable for sale. For both outcome variables, estimates of differences between the FPA and the SPA and their standard errors are based purely on the estimate of the second line of (10) that involves $\widehat{\beta}$ and its estimated variance.

Figure 4 plots, separately for the FPA and the SPA, the resulting estimates of the mean revenue, the mean revenue plus and minus its standard deviation (truncated at zero) and sale efficiency, conditional on the reserve price. In the FPA, after rounding to the nearest integer, the maximum mean revenue is estimated to be 40 and it is reached for reserve prices between 26 and 45. In fact, the rounded revenue does not fall below 39 for reserve prices between 19 and 50, and does not fall below 36 for reserve prices between 1 and 65. That is, the mean revenue is fairly flat for a wide range of reserve prices. Importantly, though, the revenue standard deviation is U-shaped, except for a small decrease as the reserve price is nearing 100, with a minimum at $r = 16$. As a result, an empirically optimal reserve price for an auctioneer with mean-variance preferences is likely to be in the region of 16 to 26. We find that 12.7 percent of actual reserve prices are in this range. Hence many auctioneers, if endowed with mean-variance preferences, could increase their well-being by adjusting their reserve prices to fall into this range. A part of this suboptimal reserve price setting could be due to subjects experimenting in early periods. However, the fraction of reserve prices in the range of 16 to 26 is 15 percent in the last 10 periods, which constitutes only a mild increase over the baseline figure.

In the SPA, after rounding to the nearest integer, the maximum mean revenue is estimated to be 39 and it is reached for reserve prices between 41 and 47. In addition, the rounded revenue does not fall below 38 for reserve prices between 34 and 59, and does not fall below 37 for reserve prices between 29 and 64. Hence we again find that the mean revenue is fairly flat over a broad range of reserve prices. The standard deviation is again U-shaped, except for a modest decrease as the reserve price is nearing 100, with a minimum at $r = 26$. Therefore an empirically optimal reserve price for an auctioneer with mean-variance preferences is likely to be in the region of 26 to 41. We find that 17 percent of actual reserve prices are in this range. When focusing only on the last 10 periods, this fraction is 16.5 percent, barely different from the baseline figure. Hence again, many auctioneers, if endowed with mean-variance preferences, could increase their well-being by adjusting their reserve price to fall into this range.

[Insert Figure 4 about here.]

In order to shed more light on auctioneer learning, we estimate the regression model

$$\Delta r_{it} = \sum_{s=1}^{S} \left[\beta_s \Delta r_{it-s} + \gamma_s \Delta y_{it-s} + \delta_s \Delta r_{it-s} \Delta y_{it-s})\right] + f_i + \varepsilon_{it}, \tag{11}$$

where i indexes auctioneers, t indexes periods, Δ is the time change operator, r is the reserve price, y is the revenue, f denotes fixed effects and ε idiosyncratic disturbances, S is the maximum length of the time lag relevant for learning and β, γ and δ are coefficient vectors. If there is no learning based on previous payoff experiences, then we would expect not to be able to reject the hypothesis that $\delta_s = 0$. On the other hand, if such learning is present, we would expect that auctioneers increase their reserve price, *ceteris paribus*, if their past reserve price increases (decreases) led to positive (negative) revenue changes, and vice versa, suggesting that $\delta_s > 0$. We estimate (11) by least squares with standard errors adjusted for clustering at session level. Table 5 displays the estimates for the FPA (specifications (1)-(3)) and SPA (specifications (4)-(6)) for $S \in \{1, .., 4\}$. The estimate of δ_1 for both the FPA and the SPA is positive and statistically significant regardless of the number of lags used. The estimate of δ_2 is positive and marginally statistically significant only in the FPA. On the other hand, the estimates of δ_3 and δ_4 are positive and statistically significant only in the SPA. These results suggest a presence of learning from the recent past, in particular from two previous periods in the FPA and from up to four previous periods in the SPA. The estimates of β_s show that, within the same time frame, in case recent reserve price changes did not have much impact on the revenue, they tend to mean-revert. The estimates of γ_s in the FPA show that revenue changes from the previous two periods have little impact on current reserve price setting, but older revenue gains, if not accompanied by concurrent reserve price changes, encourage current increases in reserve prices. In the SPA, the estimates of γ_s show that the same is true in all four preceding periods.

[Insert Table 5 about here.]

4.3 Revenue and Efficiency Comparisons

In this sub-section, we move from the analysis of individual behavior to investigation of auction revenue and efficiency. The average auction revenue (and its standard error with clustering at session level) is 37.8 (1.01) in the FPA and 35.25 (0.7) in the SPA, with the difference of 2.56 (1.16) being statistically significant at the 6 percent level. When we additionally control for valuations, then the difference increases to 3.36 (0.98) and is statistically highly significant. For a comparison, in sessions without HA, the average revenue is 44.0 (1.37) in the FPA and 35.0 (1.20) in the SPA, with the difference of 9.0 (1.72) being statistically highly significant. When we additionally control for valuations, the difference is almost unchanged at 9.43 (1.09). Hence the FPA generates a higher expected revenue than the SPA both with and without HA, but the difference is smaller in the presence of HA.

[Insert Figure 5 about here.]

In the absence of HA, the observation that the FPA generates a higher average revenue than the SPA may serve as a direct policy recommendation for auction design for a revenue-maximizing seller. However, the revenue results for sessions with HA are affected by endogenous reserve price setting by the auctioneers, and hence the simple revenue comparisons do not account for different distributions of reserve prices in the FPA and the SPA. So we next turn attention to examining how the average revenue in the FPA and the SPA compares conditional on various reserve prices. In the top panel, Figure 5 plots the estimate of the difference between average revenue in the FPA and the SPA together with its 95-percent confidence interval conditional on various reserve prices. For reserve prices between 2 and 33, the FPA generates a statistically significantly higher revenue conditional on the reserve price than the SPA, whereas for other reserve prices the difference is statistically insignificant. The revenue difference is between 5 and 6 for reserve prices between 2 and 15, between 4 and 5 for reserve prices between 16 and 24, and between 3 and 4 for reserve prices between 25 and 32. The mean revenue over this range of valuations is between 36 and 40 for the FPA and between 30 and 37 for the SPA. As a result, the revenue difference constitutes a 10 to 20 percent increase of mean revenue relative to the SPA base. To conclude:

RESULT 8. *The FPA dominates the SPA in terms of the average revenue for the bottom third of reserve prices, constituting a 10 to 20 percent increase over the SPA baseline. The difference is statistically insignificant for other reserve prices. We therefore do not reject Hypothesis 8.*

We next turn attention to efficiency, starting with sale efficiency. Figure 4 shows that estimated sale efficiency is decreasing with the reserve price throughout the entire range. We have also conducted a formal test which shows that the slope of sale efficiency in the reserve price is negative and statistically significant at 95 percent for reserve prices between 7 and 72 in the FPA and between 6 and 98 in the SPA, and statistically insignificant otherwise.[12] Therefore we obtain:

RESULT 9. *Sale efficiency is decreasing with the reserve price in either auction format, statistically significantly so for majority of reserve prices. We therefore do not reject Hypothesis 9.*

The bottom panel of Figure 5 plots the estimate of the difference between sale efficiency in the FPA and the SPA together with its 95-percent confidence interval conditional on various reserve prices. For the range of reserve prices between 21 and 38, sale efficiency is significantly lower in the FPA compared to the SPA, the difference ranging between 1.4 and 4.5 percentage points. So we conclude that:

RESULT 10. *Sale efficiency higher in the SPA than in the FPA for a range of lower-to-medium reserve prices, with the difference ranging between 1.4 and 4.5 percentage points. The difference is statistically insignificant for other reserve prices. We therefore reject Hypothesis 10.*

[Insert Figure 6 about here.]

We next turn attention to allocative efficiency. The estimation procedure we use in this case is analogous to estimating equation (10) that we discussed before, with y being an indicator of sale

[12] The estimates and their standard errors are based on (10) with y being an indicator of sale. We first take the expectation of all regressors with respect to the theoretical distribution of valuations in (9), then difference these averages by the reserve price, and finally apply to this transformed equation the estimates of coefficiencts and their variance based on the original estimate of (10). The results are available from the authors upon request.

to the higher valuation bidder, but with three modifications. First, since allocative efficiency is defined only for auctions where sale takes place, when we take the expectation with respect to the theoretical distribution of valuations, we weight this distribution with the predicted sale efficiency for the given combination of the two valuations and the reserve price. Second, we restrict the estimation only to the range of reserve prices of up to 80, since sale happens very infrequently for higher reserve prices and hence the resulting estimates of sale efficiency are very imprecise for this region. Third, instead of basing the confidence interval on the estimated variance matrix of coefficient estimates, we use bootstrap with 1,000 replications and clustering at session level.

The two top panels of Figure 6 plot the average allocative efficiency together with its 95-percent confidence interval conditional on various reserve prices for the FPA and the SPA, respectively. The allocative efficiency is estimated to be between 80 and 95 percent in the FPA and between 92 and 94 percent in the SPA across the entire range of reserve prices. The estimated allocative efficiency is statistically significantly different from 100 percent at 2.5 percent significance level (one-sided test) for reserve prices between 13 and 73 in the FPA and all reserve prices in the SPA. We therefore obtain that:

RESULT 11. *For a range of reserve prices where allocative efficiency can be estimated with satisfactory precision, the average allocative efficiency is between 80 and 95 percent in the FPA and between 92 and 94 percent in the SPA. It is statistically significantly different from 100 percent for majority of reserve prices in the FPA and all reserve prices in the SPA. We therefore reject Hypothesis 11.*

Figure 6 also shows that allocative efficiency is, with a possible exception of high reserve prices in the FPA, quite flat in the reserve price. We also conducted a formal test of this "flatness" by computing the difference of the estimated allocative efficiency between two consecutive reserve prices and estimated a 95-percent confidence interval for this "derivative" using bootstrap with 1,000 replications. The results show that the slope of the estimated allocative efficiency in the reserve price is not statistically significantly different from zero for any reserve price in either of the two auction formats.[13] We therefore conclude that:

RESULT 12. *Allocative efficiency is independent of the reserve price in both auction formats. We therefore do not reject Hypothesis 12.*

Finally, the bottom panel of Figure 6 plots the estimated difference in allocative efficiency between the FPA and the SPA, together with its 95-percent confidence interval. We observe that this difference is not statistically significant for any reserve price, leading us to conclude that:

RESULT 13. *The average allocative efficiency is statistically indistinguishable across the two auction formats conditional on any reserve price. We therefore do not reject Hypothesis 13.*

For a comparison, the average allocative efficiency (and its standard error clustered at session level) in the sessions without HA is 89.5 (1.0) percent in the FPA and 89 (1.0) percent in the SPA, and the difference is not statistically significant.

[13]The results are available from the authors upon request.

5 Discussion and Conclusion

To summarize, focusing on auctions with HA, the results presented in the previous section reveal that the presence of HA decreases bids for near-zero reserve prices in the region of intermediate-to-higher valuations. We also find that bidders in the FPA behave in line with (equilibrium) theory in fundamental features of bidding behavior. In the SPA, bidders overbid in almost half of the relevant cases. Turning to auctioneer behavior, the average reserve price is the same in both auction formats and frequently exceeds the upper bound predicted by equilibrium theory. The FPA dominates the SPA in terms of the average revenue for the bottom third of reserve prices, but not otherwise. Sale efficiency is strongly decreasing with the reserve price in either auction format and is higher in the SPA for a range of lower-to-medium reserve prices, but not otherwise. Allocative efficiency reaches between 80 and 95 percent in the FPA and 92 to 94 percent in the SPA, but it is still statistically different from 100 percent except for very low and very high reserve prices in the FPA. Also, it is flat in the reserve price and statistically indistinguishable between the two auction formats.

The finding that the presence of HA has a negative impact on bids over a certain range of valuations is puzzling, and we do not have a good explanation for it. It does not seem to be driven by bidder "angst" to cash-in or rare profit opportunities, and it is inconsistent with bidder altruism toward auctioneers, although potentially consistent with spite. One way or another, this puzzle remains a topic for future research.

In regards to "excessively high" reserve prices from the theoretical standpoint, previous literature has considered explanations for why bidders overbid in second-price auctions, such as "spite" (Morgan, Steiglitz and Reis 1984) and the "joy of winning." In turn, when bidders in the SPA overbid their valuations and, potentially, even higher reserve prices, auctioneers may find it optimal to set higher reserve prices than if bidders bid their valuations. This could explain why many reserve price observations exceed the equilibrium theoretical upper bound in the SPA. However, it does not explain why the same is true in the FPA as well. One potential explanation for the latter is provided by Crawford, Kugler, Neeman and Pauzner (2009) who show that if bidders follow the k-level rationality behavior, the optimal reserve price of an auctioneer that rationally expects such behavior may exceed the highest predicted (under risk-neutrality) equilibrium reserve price. Again, we leave a deeper investigation of this possibility to future research.

APPENDIX A

Experiment Instructions for the FPA

Name________ PCLAB __ Total Payoff _____

Introduction

- You are about to participate in a decision process in which an object will be auctioned off for each group of participants in each of 30 rounds. This is part of a study intended to provide insight into certain features of decision processes. If you follow the instructions carefully and make good decisions you may earn a considerable amount of money. You will be paid in cash at the end of the experiment.
- *During the experiment, we ask that you please do not talk to each other.* If you have a question, please raise your hand and an experimenter will assist you.

Procedure

- You each have drawn a laminated slip, which corresponds to your PC terminal number. If the number on your slip is from PCLAB 2 to PCLAB 9, you will stay in this room and you will be a bidder for the entire experiment. If the number on your slip is from PCLAB 10 to PCLAB 13, you will go to Room 212 after the instruction, and you will be an auctioneer for the entire experiment.
- In each of 30 rounds, you will be *randomly* matched with two other participants into a group. Each group has an auctioneer and two bidders. You will not know the identities of the other participants in your group. Your payoff each round depends ONLY on the decisions made by you and the other two participants in your group.
- In each of 30 rounds, each bidder's **value** for the object will be randomly drawn from one of two distributions:
  - **High value distribution**: If a bidder's value is drawn from the high value distribution, then
    * with 25% chance it is randomly drawn from the set of integers between 1 and 50, where each integer is equally likely to be drawn.
    * with 75% chance it is randomly drawn from the set of integers between 51 and 100, where each integer is equally likely to be drawn.

    For example, if you throw a four-sided die, and if it shows up 1, your value will be equally likely to take on an integer value between 1 and 50. If it shows up 2, 3 or 4, your value will be equally likely to take on an integer value between 51 and 100.
  - **Low value distribution**: If a bidder's value is drawn from the low value distribution, then
    * with 75% chance it is randomly drawn from the set of integers between 1 and 50, where each integer is equally likely to be drawn.
    * with 25% chance it is randomly drawn from the set of integers between 51 and 100, where each integer is equally likely to be drawn.

    For example, if you throw a four-sided die, and if it shows up 1, 2 or 3, your value will be equally likely to take on an integer value between 1 and 50. If it shows up 4, your value will be equally likely to take on an integer value between 51 and 100.
  - Therefore, if your value is drawn from the high value distribution, it can take on any integer value between 1 and 100, but it is three times more likely to take on a higher value, i.e., a value between 51 and 100.

    Similarly, if your value is drawn from the low value distribution, it can take on any integer value between 1 and 100, but it is three times more likely to take on a lower value, i.e., a value between 1 and 50.
  - In each of 30 rounds, each bidder's value will be randomly and independently drawn from the high value distribution with 30% chance, and from the low value distribution with 70% chance. You will not be told which distribution your value is drawn from. The other bidders' values might be drawn from a distribution different from your own. In any given round, the chance that your value is drawn from either distribution does not affect how other bidders' values are drawn.

- Each round consists of the following stages:
  - Each auctioneer will set a minimum selling price, which can be any integer between 1 and 100, inclusive.
  - Bidders are informed of the minimum selling prices of their auctioneers, and then each bidder will simultaneously and independently submit a bid, which can be any integer between 1 and 100, inclusive. If you do not want to buy, you can submit any positive integer below the minimum selling price.
  - The bids are collected in each group and the object is allocated according to the rules of the auction explained in the next section.
  - Bidders will get the following feedback on their screen: your value, your bid, the minimum selling price, the winning bid, whether you got the object, and your payoff.

    Auctioneers will get the following feedback: whether you sold the object, your minimum selling price, the bids, and your payoff.
- The process continues.

Rules of the Auction and Payoffs

- **Bidders**: In each round,
  - if your bid is less than the minimum selling price, you don't get the object:
    Your Payoff = 0
  - if your bid is greater than or equal to the minimum selling price, and:
    - if your bid is greater than the other bid, you get the object and pay your bid:
      Your Payoff = Your Value - Your Bid;
    - if your bid is less than the other bid, you don't get the object:
      Your Payoff = 0.
    - if your bid is equal to the other bid, the computer will break the tie by flipping a fair coin. Therefore,
      - with 50% chance you get the object and pay your bid:
        Your Payoff = Your Value - Your Bid;
      - with 50% chance you don't get the object:
        Your Payoff = 0.
- **Auctioneers**: In each round, you will receive two bids from your group.
  - If both bids are less than your minimum selling price, the object is not sold, and :
    Your Payoff = 0;
  - if at least one bid is greater than or equal to your minimum selling price, you sell the object to the higher bidder and
    Your Payoff = the Higher Bid.
- For example, if the minimum selling price is 1, bidder A bids 25, and bidder B bids 55, since $55 > 1$ and $55 > 25$, bidder B gets the object. Bidder A's payoff = 0; bidder B's payoff = her value - 55; the auctioneer's payoff = 55.
- There will be 30 rounds. There will be no practice rounds. From the first round, you will be paid for each decision you make.
- Your total payoff is the sum of your payoffs in all rounds.
- Bidders: the exchange rate is $1 for ____________ points.
- Auctioneers: the exchange rate is $1 for ____________ points.

We encourage you to earn as much cash as you can. Are there any questions?

Review Questions: you will have ten minutes to finish the review questions. Please raise your hand if you have any questions or if you finish the review questions. The experimenter will check each participant's answers individually. After ten minutes we will go through the answers together.

1. Suppose your value is 60 and you bid 62.
   If you get the object, your payoff = __.
   If you don't get the object, your payoff = __.
2. Suppose your value is 60 and you bid 60.
   If you get the object, your payoff = __.
   If you don't get the object, your payoff = __.
3. Suppose your value is 60 and you bid 58.
   If you get the object, your payoff = __.
   If you don't get the object, your payoff = __.
4. In each of 30 rounds, each bidder's value will be randomly and independently drawn from the high value distribution with __% chance.
5. The minimum selling price is 30 and your bid is 25, your payoff = __.
6. True or false:
   (a) __If a bidder's value is 25, it must have been drawn from the low distribution.
   (b) __If a bidder's value is 60, it must have been drawn from the high distribution.
   (c) __You will be playing with the same two participants for the entire experiment.
   (d) __A bidder's payoff depends only on his/her own bid.
   (e) __If you are an auctioneer and your minimum selling price is higher than both bids, your payoff will be zero.

APPENDIX B

Proof of Proposition 2: Theorem 2 (and its proof) of Maskin and Riley (1984) establishes that, given a reserve price r, there is a unique symmetric Bayesian Nash equilibrium bidding strategy $s(V,r)$ for $V \geq r$ that satisfies (4), and in any such symmetric equilibrium, bidders with $V < r$ bid below r. Even though it is not explicitly stated, the Maskin and Riley's proof works not only for continuous $f(\cdot)$, but also for $f(\cdot)$ that is continuous up to a finite number of points (which is the case of our experimental design).

We only need to qualify this result in one detail. In a symmetric equilibrium, a bidder with $V = r$ is indifferent between bidding at r or below r, since the best payoff he can obtain is 0. For convenience, Maskin and Riley assume that such bidders bid r. But in light of our experimental design, they may also bid below r, and hence we explicitly allow for such behavior in the statement of the Proposition.

Furthermore, (4) implies that $s(\cdot,r)$ is continuous, differentiable and that $s_1(r,r) = 0$. As a result, $s(V,r) < V$ for $V \in (r,\varepsilon)$ for some $\varepsilon > 0$. Furthermore, it must be the case for all $V > r$ that $s(V,r) < V$. Suppose not. Because $s(\cdot,r)$ is continuous and $s(V,r) < V$ for $V \in (r,\varepsilon)$, there must exist $V' > r$ such that $s(V',r) = V'$ and $s(V,r) < V$ for all $V \in (r,V')$. But then it must be the case that $s_1(\cdot,r)$ is greater than 1 arbitrarily close to V' from below. However, since continuity of $s(\cdot,r)$ implies that

$$\lim_{V \uparrow V'} h[V - s(V,r)] = 0,$$

this would require

$$\lim_{V \uparrow V'} f(V) = \infty,$$

a contradiction to the assumption that $f(\cdot)$ is bounded. Finally, the finding that $s(V, r) < V$ for all $V > r$ implies, via (4), that $s_1(V, r) > 0$ for all $V > r$, and hence $r < s(V, r)$ for all $V > r$. As a result, (3) follows.

Regarding $s(V, r)$ being weakly increasing in r, suppose, by contradiction, that there exist reserve prices r' and r'' with $r' < r''$ and a valuation $V' > r''$ such that $s(V', r') > s(V', r'')$. Because $s(\cdot, r)$ is continuous for any r and, by (3), $s(r'', r') < r'' = s(r'', r'')$, there must be exist a valuation $V_0 \in (r'', V')$ such that $s(V_0, r') = s(V_0, r'')$ and $s(V, r') > s(V, r'')$ for all $V \in (V_0, V']$. But then, since $h(\cdot)$ is strictly increasing, (4) implies that

$$\begin{aligned} s(V', r'') &= s(V_0, r'') + \int_{V_0}^{V'} \frac{f(x)}{F(x)} h[x - s(x, r'')] dx \\ &> s(V_0, r') + \int_{V_0}^{V'} \frac{f(x)}{F(x)} h[x - s(x, r')] dx \\ &= s(V', r'), \end{aligned}$$

a contradiction. Hence $s(V, r)$ must be weakly increasing in r.

Proof of Corollary 1: With risk-neutral bidders, $h(y) \equiv y$, and hence equation (4) implies that

$$s_1(V, r) = \frac{f(V)}{F(V)}[V - s(V, r)].$$

This is equivalent to

$$s_1(V, r)F(V) + s(V, r)f(V) = f(V)V,$$

or

$$\frac{\partial}{\partial x} s(x, r)F(x) = f(x)x.$$

Integrating both sides from r to V and using the initial condition $s(r, r) = r$, we obtain that

$$s(V, r)F(V) = rF(r) + \int_r^V xf(x)dx. \tag{12}$$

Integrating by parts,

$$\begin{aligned} \int_r^V xf(x)dx &= [xF(x)]_{x=r}^V - \int_r^V F(x)dx \\ &= VF(V) - rF(r) - \int_r^V F(x)dx. \end{aligned}$$

Substituting into (12) and dividing through by $F(V)$, we obtain (5).

Proof of Proposition 3: Suppose that bidders are symmetrically risk-averse. First, we are going to argue that $s^{RN}(V, r) \leq s(V, r)$ for all $V > r$, where $s^{RN}(\cdot, \cdot)$ is given by (5). Suppose not, i.e., there exists $V' > r$ such that $s^{RN}(V', r) > s(V', r)$. Then, since $s^{RN}(r, r) = s(r, r)$, by continuity of $s(\cdot, r)$, there must exist $V_0 \in [r, V')$ such that $s^{RN}(V_0, r) = s(V_0, r)$ and $s^{RN}(V, r) > s(V, r)$ for all $V \in (V_0, V']$. But then, since $h(y) > y$ for all $y > 0$, (3) and (4) imply that

$$\begin{aligned} s(V', r) &= s(V_0, r) + \int_{V_0}^{V'} \frac{f(x)}{F(x)} h[x - s(x, r)] dx \\ &> s^{RN}(V_0, r) + \int_{V_0}^{V'} \frac{f(x)}{F(x)} h[x - s^{RN}(x, r)] dx \\ &> s^{RN}(V_0, r) + \int_{V_0}^{V'} \frac{f(x)}{F(x)} [x - s^{RN}(x, r)] dx \\ &= s^{RN}(V', r), \end{aligned}$$

a contradiction. Hence it must be the case that $s^{RN}(V, r) \leq s(V, r)$ for all $V > r$.

Second, we are going to argue that $s^{RN}(V, r) < s(V, r)$ for all $V > r$. Suppose not, i.e., there exists $V' > r$ such that $s^{RN}(V', r) = s(V', r)$. Note that since $h(y) > y$ for all $y > 0$, (4) implies that it cannot be the case that $s^{RN}(V, r) = s(V, r)$ for all $V \in [r, V']$, and hence there must exist $V_0 \in (r, V')$ such that $s^{RN}(V_0, r) < s(V_0, r)$. Define

$$\underline{h} \equiv \min_{y \in [V' - s(V', r), V' - s^{RN}(V_0, r)]} \frac{h(y)}{y}.$$

Note that, due to continuity of $h(\cdot)$, $\underline{h}$ is well-defined. Also, since $h(y) > y$ for all $y > 0$, $\underline{h} > 1$. Now note that, due to continuity of $s^{RN}(\cdot, r)$ and $s(\cdot, r)$, the function $[V - s^{RN}(V, r)]/[V - s(V, r)]$ is continuous in V on $[V_0, V']$, it is more than 1 at $V = V_0$ and equal to 1 at $V = V'$. As a result, there must exist $V'' \in (V_0, V')$ such that

$$\frac{V - s^{RN}(V, r)}{V - s(V, r)} < \underline{h}$$

for all $V \in [V'', V']$. But then we have that

$$\begin{aligned} s(V', r) &= s(V'', r) + \int_{V''}^{V'} \frac{f(x)}{F(x)} h[x - s(V, x)] dx \\ &> s^{RN}(V'', r) + \int_{V''}^{V'} \frac{f(x)}{F(x)} \underline{h}[x - s(V, x)] dx \\ &> s^{RN}(V'', r) + \int_{V''}^{V'} \frac{f(x)}{F(x)} [x - s^{RN}(V, x)] dx \\ &= s^{RN}(V', r) \end{aligned}$$

a contradiction. Hence it must be the case that $s^{RN}(V, r) < s(V, r)$ for all $V > r$.

Regarding the properties of $s_2(V, r)$ with respect to bidder risk aversion, it follows from (5) that for risk-neutral bidders,

$$s_2^{RN}(V, r) = \frac{F(r)}{F(V)}. \tag{13}$$

Now consider risk-averse bidders. Equation (4) implies that

$$s_1(x,r) = \frac{f(x)}{F(x)} h[x - s(x,r)],$$

and hence

$$s_1(x,r)F(x) + s(x,r)f(x) = \{h[x - s(x,r)] + s(x,r)\} f(x).$$

Integrating both sides with respect to x between r and V and rearranging gives

$$s(V,r) = \frac{rF(r)}{F(V)} + \frac{1}{F(V)} \int_r^V \{h[x - s(x,r)] + s(x,r)\} f(x)dx.$$

Differentiating both sides with respect to r then gives, for $V > r$,

$$s_2(V,r) = \frac{F(r)}{F(V)} + \frac{1}{F(V)} \int_r^V \{1 - h'[x - s(x,r)]\} s_2(x,r)f(x)dx. \tag{14}$$

Since $h'(y) > 1$ for all $y > 0$, $1 - h'[x - s(x,r)] < 0$ for all $x \in (r,V]$. Also, since $s(V,\cdot)$ is weakly increasing (Proposition 2), it must be the case that $s_2(x,r) \geq 0$. As a result, the integral term on the right-hand side is non-positive and is equal to zero if and only if $s_2(x,r) = 0$ almost everywhere on $x \in [r,V]$. If $r = 0$, then the first term on the right-hand side is 0 and so, since $s_2(V,0) \geq 0$, it must be the case that $s_2(V,0) = 0$ everywhere on $V \in (0,1]$. If $r > 0$, it must be the case that

$$s_2(V,r) \leq \frac{F(r)}{F(V)} = s_2^{RN}(V,r),$$

with equality if and only if $s_2(x,r) = 0$ almost everywhere on $x \in [r,V]$. But the latter cannot be the case because (14) would then imply that $s_2(V',r) = F(r)/F(V') > 0$ for all $V' \in (r,V]$, a contradiction. As a result, if $r > 0$, it must be the case that

$$s_2(V,r) < \frac{F(r)}{F(V)} = s_2^{RN}(V,r). \tag{15}$$

Proof of Proposition 4: In the SPA, Proposition 1 implies that the expected utility of the auctioneer when setting a reserve price r is given by

$$\begin{aligned} EU_{SPA}(r) &= \int_r^1 u(V)d\left[2F(V) - F^2(V)\right] + 2u(r)F(r)[1 - F(r)] \\ &= 2\int_r^1 u(V)[1 - F(V)]f(V)dV + 2u(r)F(r)[1 - F(r)]. \end{aligned}$$

The first term corresponds to cases when none of the two valuations fall short of r ($2F(V) - F^2(V) = 1 - [1 - F(V)]^2$ is the cumulative distribution function of the second highest valuation), whereas the second term corresponds to cases when exactly one of the valuations fall short of r.

Hence

$$\begin{aligned} EU'_{SPA}(r) &= -2u(r)F(r)f(r) + 2u'(r)F(r)[1-F(r)] \\ &= 2u'(r)F(r)f(r)\left[\frac{1-F(r)}{f(r)} - \frac{u(r)}{u'(r)}\right]. \end{aligned} \tag{16}$$

Note that $[1-F(r)]/f(r)$, which is the inverse of the hazard rate, is strictly positive at $r = 0$ and equal to 0 at $r = 1$. On the other hand, $u(r)/u'(r)$ is equal to 0 at $r = 0$ and is strictly increasing. Therefore the bracketed term is positive at $r = 0$ and negative at $r = 1$. As a result, $EU'_{SPA}(0) = 0$, there exists $\varepsilon > 0$ such that $EU'_{SPA}(r) > 0$ on $r \in (0, \varepsilon)$ (because $f(\cdot)$ is bounded) and $EU'_{SPA}(1) < 0$, implying that any optimal reserve price r^*_{SPA} must be in the interior. But then it must be the case that $EU'_{SPA}(r^*_{SPA}) = 0$ if $f(\cdot)$ is continuous at r^*_{SPA} or $\lim_{r\uparrow r^*} EU'_{SPA}(r^*_{SPA}) \leq 0$ and $\lim_{r\downarrow r^*} EU'_{SPA}(r^*_{SPA}) \geq 0$ if $f(\cdot)$ is discontinuous at r^*, which is equivalent to (6). Furthermore, if $F(\cdot)$ displays a non-decreasing hazard rate, then $[1-F(r)]/f(r)$ is weakly decreasing, and hence there is a unique optimal reserve price.

Proof of Proposition 5: In the FPA, Proposition 2 implies that the expected utility of the auctioneer when setting reserve price r is given by

$$\begin{aligned} EU_{FPA}(r) &= \int_r^1 u[s(V,r)]dF^2(V) \\ &= 2\int_r^1 u[s(V,r)]F(V)f(V)dV, \end{aligned}$$

since $F^2(\cdot)$ is the cumulative distribution function of $\max\{V_1, V_2\}$. Hence

$$EU'_{FPA}(r) = -2u(r)F(r)f(r) + 2\int_r^1 u'[s(V,r)]s_2(V,r)F(V)f(V)dV.$$

Then, using (16), we obtain that

$$EU'_{FPA}(r) - EU'_{SPA}(r) = 2\int_r^1 u'[s(V,r)]s_2(V,r)F(V)f(V)dV - 2u'(r)F(r)[1-F(r)].$$

If both the bidders and the auctioneer are risk-neutral, then $u'(\cdot) = 1$ and, from (13), $s_2(V,r) = F(r)/F(V)$, and hence $EU'_{FPA}(r) = EU'_{SPA}(r)$ for all $r \in [0,1]$. As a result, the optimal reserve prices in the FPA and the SPA coincide.

If the bidders are risk-averse, then (15) implies that $s_2(V,r)F(V) < F(r)$ for all $r > 0$. If the auctioneer is risk-averse, then the concavity of $u(\cdot)$ and the fact that $s(V,r) > r$ for all $V > r$ imply that $u'[s(V,r)] < u'(r)$ for all $V > r$. In either of these two cases, or if both apply, it follows that $EU'_{FPA}(r) < EU'_{SPA}(r)$ for all $r \in (0,1]$. In addition, under the Assumption 1, Corollary 2 implies that the optimal reserve price in the SPA is unique and interior. As a result, any optimal reserve price in the FPA must be strictly lower than the optimal reserve price in the SPA.

Proof of Proposition 6:

In the SPA, Proposition 1 implies that the expected payment of a bidder with valuation V is 0 if $V \leq r$ and is equal to

$$EP_{SPA}(V, r) = rF(r) + \int_r^V xf(x)dx$$

if $V > r$. In the FPA, Proposition 2 and Corollary 1 imply that, with bidders being risk-neutral, the expected payment of a bidder with valuation V is 0 if $V \leq r$ and is equal to

$$\begin{aligned} EP_{FPA}(V, r) &= s(V, r)F(V) \\ &= VF(V) - \int_r^V F(x)dx \\ &= rF(r) + \int_r^V xf(x)dx \end{aligned}$$

if $V > r$. As a result, conditional on any (V, r) except when $V = r$, the expected payment of a bidder is the same in either auction format, and hence so is the overall expected revenue given a reserve price r.

When bidders are risk-averse rather than risk-neutral, bidding in the SPA is unaffected, but bidders bid more given any V in excess of r (Proposition 3). As a result, the expected payment of a bidder with a valuation V is strictly higher in the FPA compared to the SPA, and hence so is the overall expected revenue.

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Table 1: Features of Experimental Sessions

Auction Mech.	No. of Bidders	No. of Auct's	Treatment Abbreviation	Exch. Rates (points/$)		No. of Sessions	Average Payoffs	
				Bidders	Auct's		Bidders	Auct's
FPA	8	0	FPA_8	20		5	$12.37	
	8	4	FPA_{12}	12	60	5	$17.64	$18.91
SPA	8	0	SPA_8	20		5	$19.08	
	8	4	SPA_{12}	12	60	5	$20.65	$17.62

Table 2: Means of Demographics Variables and Academic Majors by Auction Type

	Bidders				Auctioneers	
	FPA_8	FPA_{12}	SPA_8	SPA_{12}	FPA_{12}	SPA_{12}
Demographics:						
Female	0.48	0.45	0.44	0.50	0.45	0.60
Age	20.7	20.0	23.0***	20.5***	21.1	20.9
Number of Siblings	1.45	1.53	1.68	1.53	1.45	0.95
White	0.43	0.58	0.43	0.60	0.55	0.65
Asian/Asian American	0.48**	0.23**	0.45	0.38	0.25	0.25
African American	0.05	0.05	0.08*	0.00*	0.10	0.05
Hispanic	0.00	0.05	0.00	0.00	0.05	0.05
Native	0.00	0.05	0.00	0.00	0.00	0.00
Other Ethnicity	0.05	0.05	0.05	0.03	0.05	0.00
Major:						
Mathematics and Statistics	0.03	0.00	0.00	0.03	0.00	0.00
Science and Engineering	0.30	0.23	0.20	0.20	0.25	0.30
Economics and Business	0.08	0.05	0.25**	0.05**	0.15	0.05
Other Social Sciences	0.03	0.05	0.03	0.08	0.20	0.20
Humanities and Others	0.05	0.10	0.15	0.13	0.05	0.15
Unknown	0.53	0.58	0.38	0.53	0.35	0.30

Note: Asterisks denote a statistically significant difference in the t-test of means when comparing sessions with and without human auctioneers (* at 10% level, ** at 5% level and *** at 1% level).

Table 3: Bidding Behavior in Relation to Reserve Prices and Valuations

Treatment Event	Count *Pctg.*	Bidding Behavior Count *Pctg. of Bidding Cond. On Event*						Test	Est. Stat. (Std. Error)	P-value
		$b<r$	$b=r$	$b>r$	$r<b<V$	$V=b$	$b>V$			
FPA_{12}	543	534	2	7				$P(b<r\|V<r)=1$	0.983	0.285
$V<r$	*45.3*	*98.3*	*0.4*	*1.3*					(0.013)	
FPA_{12}	20	3	16	1				$P(b\leq r\|V=r)=1$	0.95	0.350
$V=r$	*1.7*	*15.0*	*80.0*	*5.0*					(0.045)	
FPA_{12}	637	1	58		572	3	3	$P(r\leq b<V\|V>r)=1$	0.989	0.095
$V>r$	*53.1*	*0.2*	*9.1*		*89.8*	*0.5*	*0.5*		(0.005)	
SPA_{12}	550	501	10	39				$P(b<r\|V<r)=1$	0.911	0.045
$V<r$	*45.8*	*91.1*	*1.8*	*7.1*					(0.031)	
SPA_{12}	15	5	9	1				$P(b\leq r\|V=r)=1$	0.933	0.298
$V=r$	*1.3*	*33.3*	*60.0*	*6.7*					(0.056)	
SPA_{12}	635	5	4		83	277	266	$P(b=V\|V>r)=1$	0.436	0.000
$V>r$	*52.9*	*0.8*	*0.6*		*13.1*	*43.6*	*41.9*		(0.051)	

Note: Standard errors are adjusted for clustering at session level.

Table 4: Bid Monotonicity in Reserve Price

Explanatory Variable	Dependent variable: bid					
	FPA			SPA		
	(1)	(2)	(3)	(4)	(5)	(6)
V	0.395***	0.464**	0.477***	0.929***	1.009***	0.970***
	(0.030)	(0.137)	(0.093)	(0.019)	(0.075)	(0.101)
r	0.464***	0.458***	0.427**	0.032	0.030	0.104
	(0.051)	(0.047)	(0.153)	(0.030)	(0.030)	(0.066)
$V^2 \times 10^{-2}$		-0.054	-0.074		-0.069	-0.019
		(0.101)	(0.073)		(0.062)	(0.094)
$rV \times 10^{-2}$			0.043			-0.100
			(0.212)			(0.089)
Obs.	637	637	637	635	635	635
Bidders	40	40	40	40	40	40
R^2	0.77	0.77	0.77	0.87	0.87	0.87

Notes:

1. Bidder fixed effects estimates with standard errors adjusted for clustering at session level.
2. Statistically significant at: * 10%, ** 5%, *** 1%.

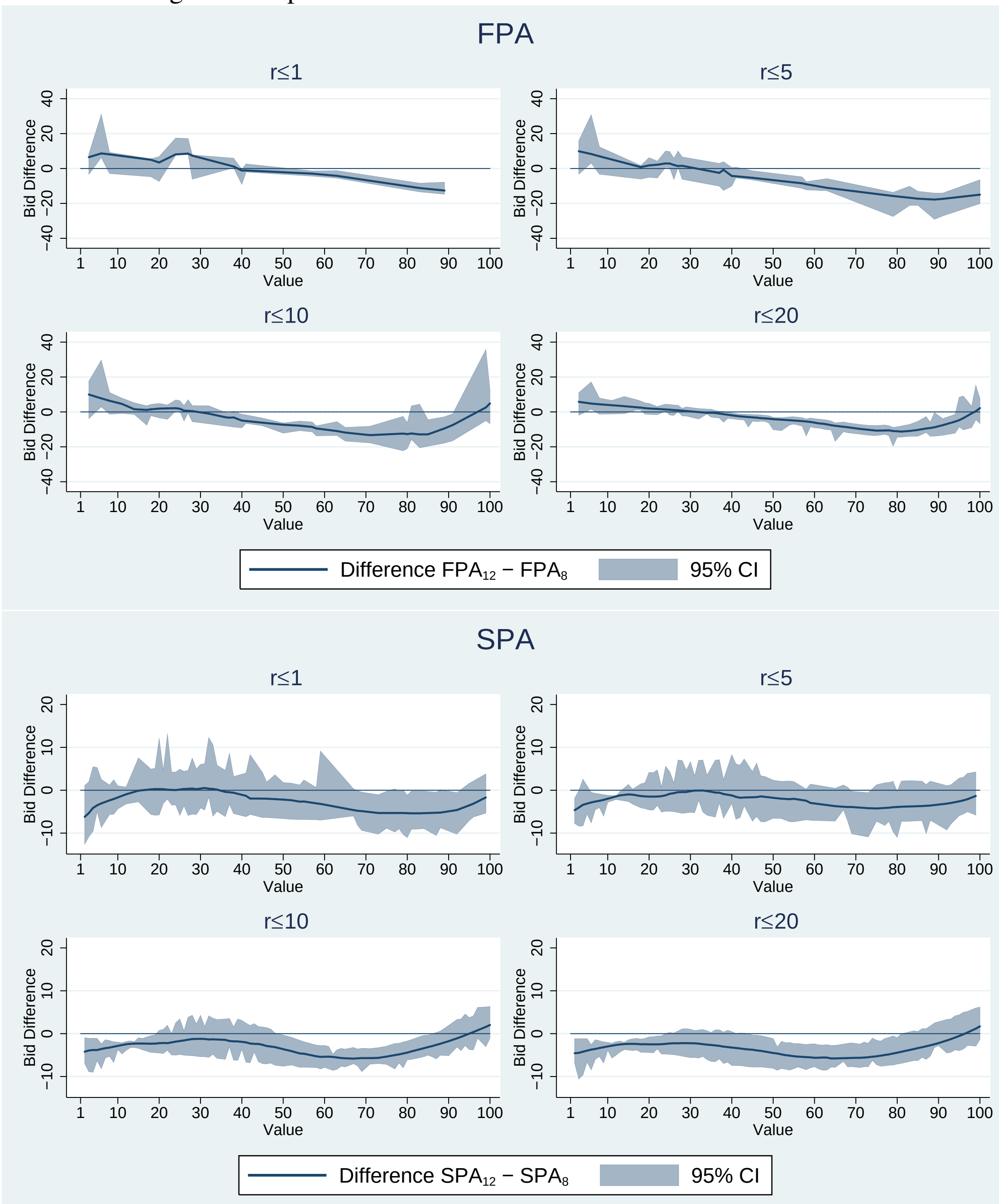
Table 5: Learning in Reserve Price Setting

	Dependent variable: Δr_{it}							
	FPA				SPA			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Δr_{it-1}	-0.470***	-0.569***	-0.593***	-0.591***	-0.461***	-0.553***	-0.619***	-0.662***
	(0.062)	(0.090)	(0.110)	(0.122)	(0.036)	(0.025)	(0.028)	(0.038)
$\Delta y_{it-1} \times 10^{-2}$	0.546	1.992	2.790	4.107	3.198	3.363**	5.300**	5.819**
	(1.824)	(2.063)	(2.340)	(2.121)	(1.596)	(1.137)	(1.637)	(1.835)
$\Delta r_{it-1}\Delta y_{it-1} \times 10^{-2}$	0.235**	0.196**	0.277**	0.278*	0.601***	0.457***	0.469***	0.443***
	(0.055)	(0.061)	(0.082)	(0.106)	(0.055)	(0.034)	(0.044)	(0.058)
Δr_{it-2}		-0.229***	-0.297**	-0.315**		-0.212***	-0.323***	-0.387***
		(0.048)	(0.073)	(0.092)		(0.041)	(0.042)	(0.034)
$\Delta y_{it-2} \times 10^{-2}$		1.951	3.981	5.417*		2.092	6.249**	8.143**
		(1.221)	(2.554)	(2.245)		(1.262)	(1.706)	(1.943)
$\Delta r_{it-2}\Delta y_{it-2} \times 10^{-2}$		0.384*	0.417*	0.394*		0.152	-0.007	-0.018
		(0.175)	(0.180)	(0.165)		(0.149)	(0.162)	(0.186)
Δr_{it-3}			-0.096	-0.138			-0.184**	-0.271**
			(0.076)	(0.098)			(0.064)	(0.081)
$\Delta y_{it-3} \times 10^{-2}$			3.396	5.984**			7.532**	10.909**
			(1.699)	(1.332)			(1.952)	(2.551)
$\Delta r_{it-3}\Delta y_{it-3} \times 10^{-2}$			0.135	0.156			0.315**	0.221*
			(0.141)	(0.167)			(0.080)	(0.095)
Δr_{it-4}				-0.072				-0.136**
				(0.067)				(0.042)
$\Delta y_{it-4} \times 10^{-2}$				4.986**				5.568**
				(1.720)				(1.331)
$\Delta r_{it-4}\Delta y_{it-4} \times 10^{-2}$				-0.197				0.188***
				(0.180)				(0.031)
Observations	560	540	520	500	560	540	520	500
Auctioneers	20	20	20	20	20	20	20	20
R^2	0.21	0.27	0.29	0.30	0.22	0.27	0.32	0.34

Notes:

1. Auctioneer fixed effects estimates of (11) for $S \in \{1, .., 4\}$ with standard errors adjusted for clustering at session level.
2. Statistically significant at: * 10%, ** 5%, *** 1%.

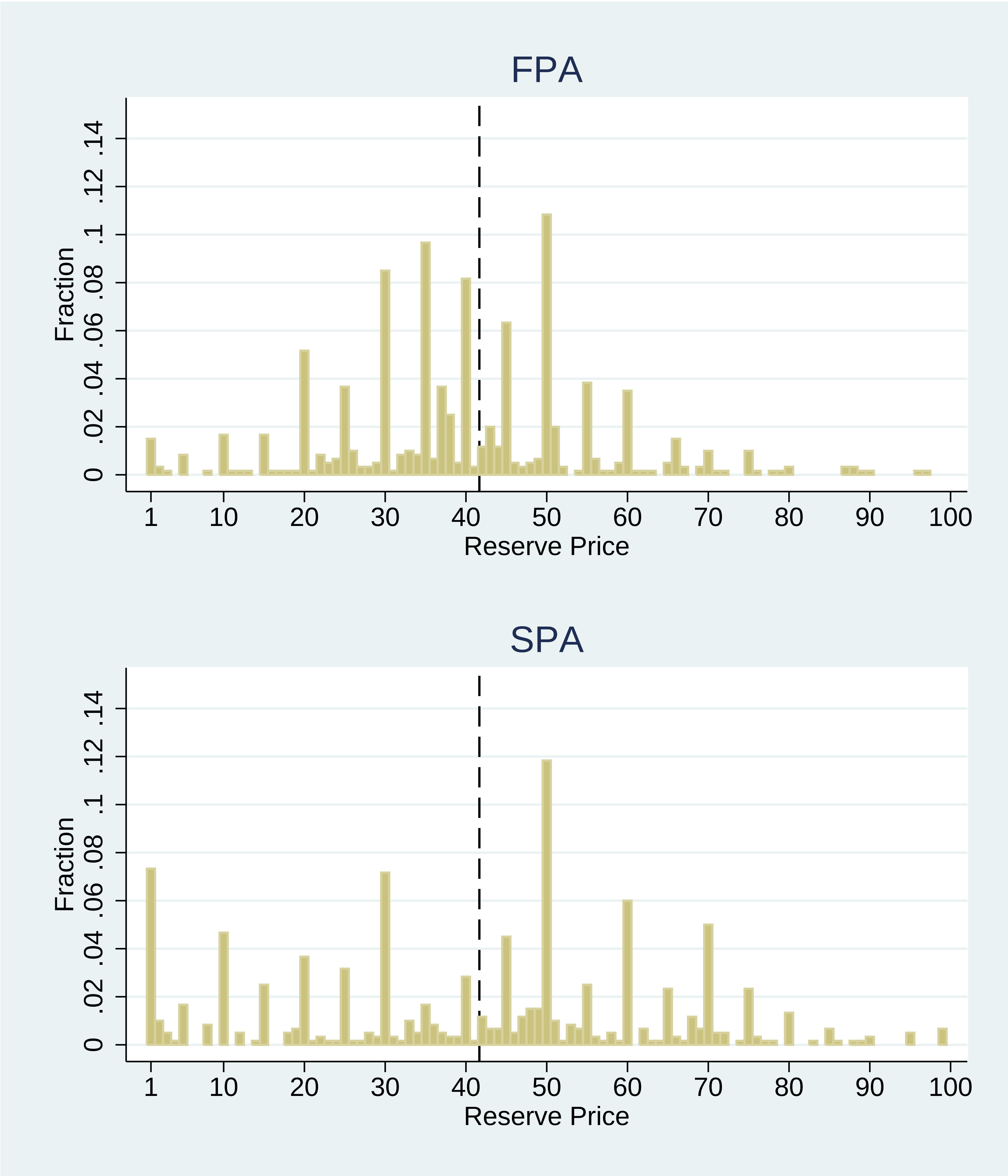
Figure 1: Impact of the Presence of Human Auctioneers on Bids



Notes:

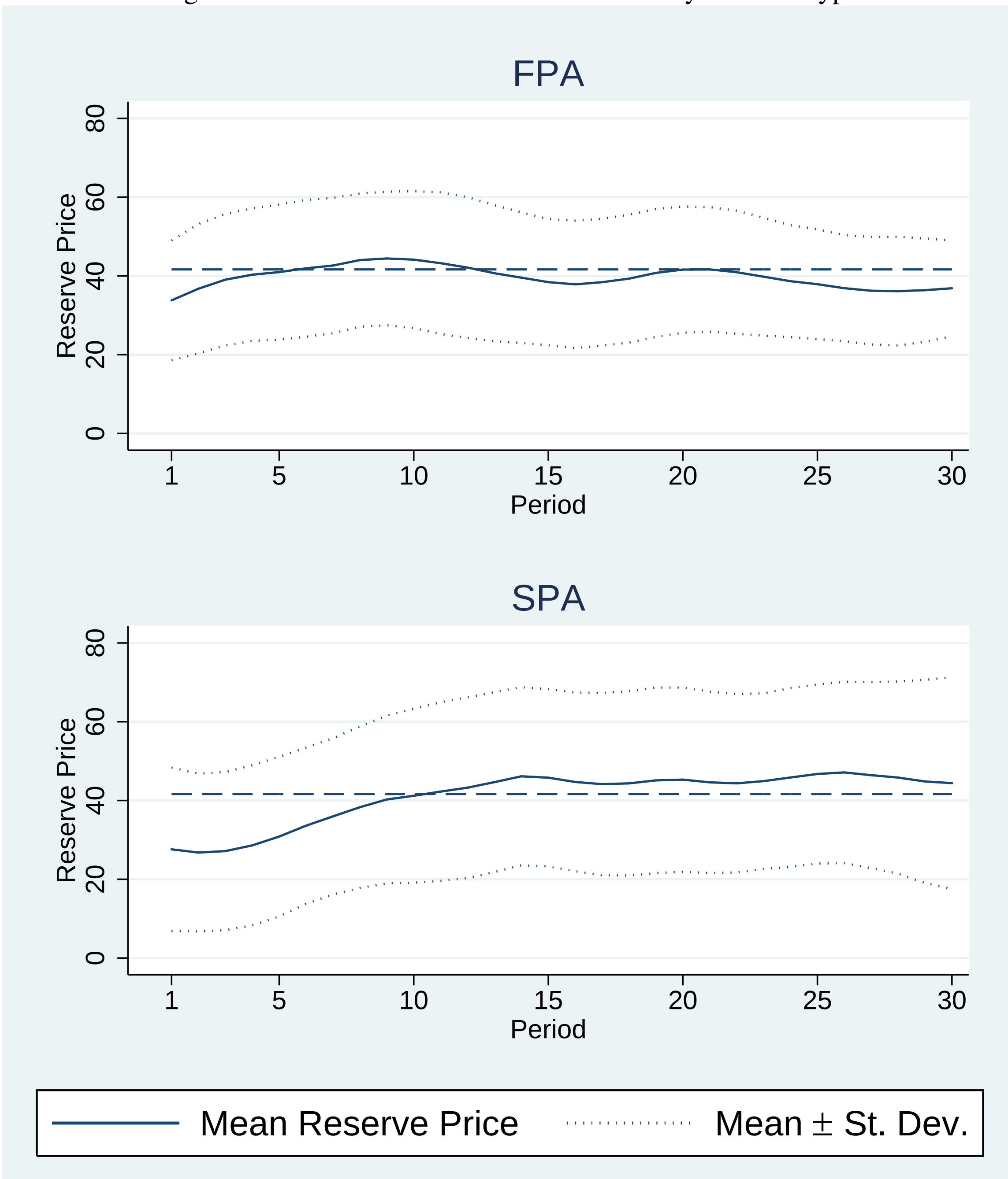
1. In constructing these plots, all observations from FPA_8 and SPA_8 are used, whereas only observations with r up to a certain threshold (as indicated above the plots) and $V > r$ are used.
2. The mean revenue difference estimates are obtained using the lowess smoother with the tricube weighting function, proportional bandwidth of 50 percent of the sample and local averaging of predictions.
3. The confidence intervals are obtained by bootstrapping with 1,000 replications and clustering at session level.

Figure 2: Histogram of Reserve Prices by Auction Type



Note: The dashed line corresponds to the equilibrium upper bound on reserve prices of $5/12$ (Corollary 3).

Figure 3: Time-Series Plot of Reserve Prices by Auction Type

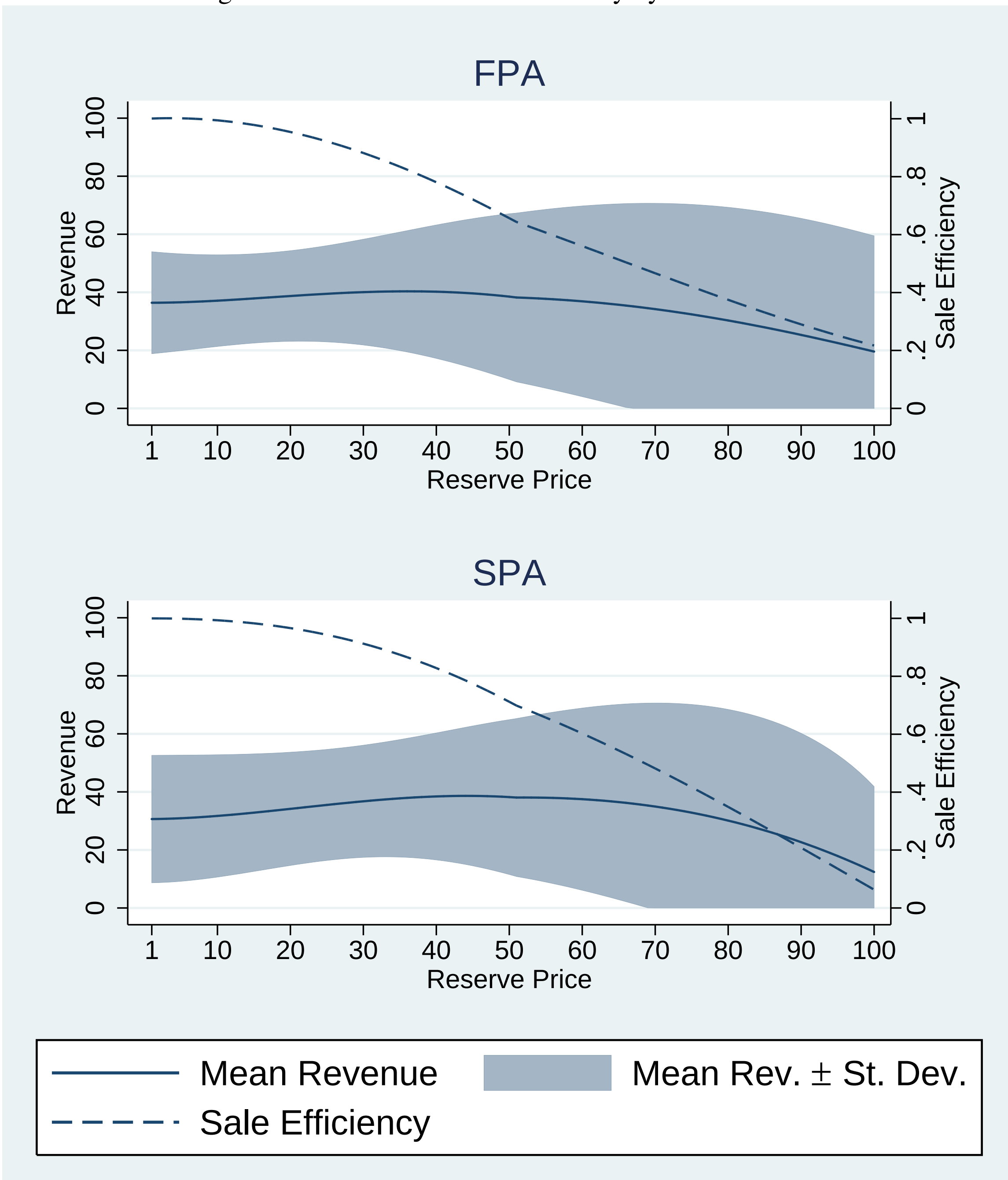


Notes:

1. Mean reserve price as well as its standard deviation estimates are obtained using the lowess smoother with the tricube weighting function, proportional bandwidth of 20 percent of the sample and local averaging of predictions.

2. The dashed line corresponds to the equilibrium upper bound on reserve prices of $5/12$ (Corollary 3).

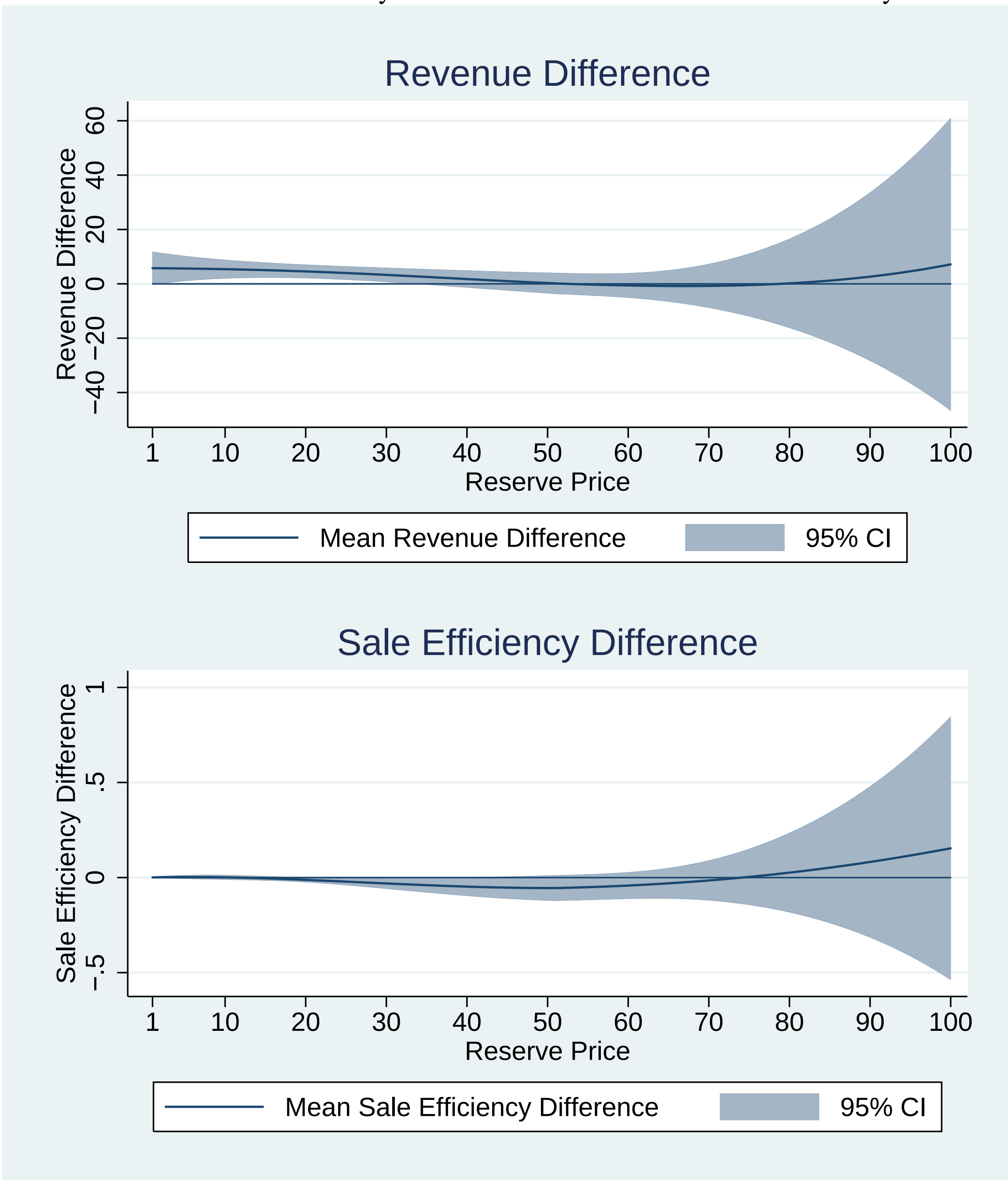
Figure 4: Revenue and Sale Efficiency by Reserve Price



Notes:

1. The estimates are based on equation (10) and estimation details are described in the main text.
2. The confidence intervals are based on standard errors adjusted for clustering at session level.

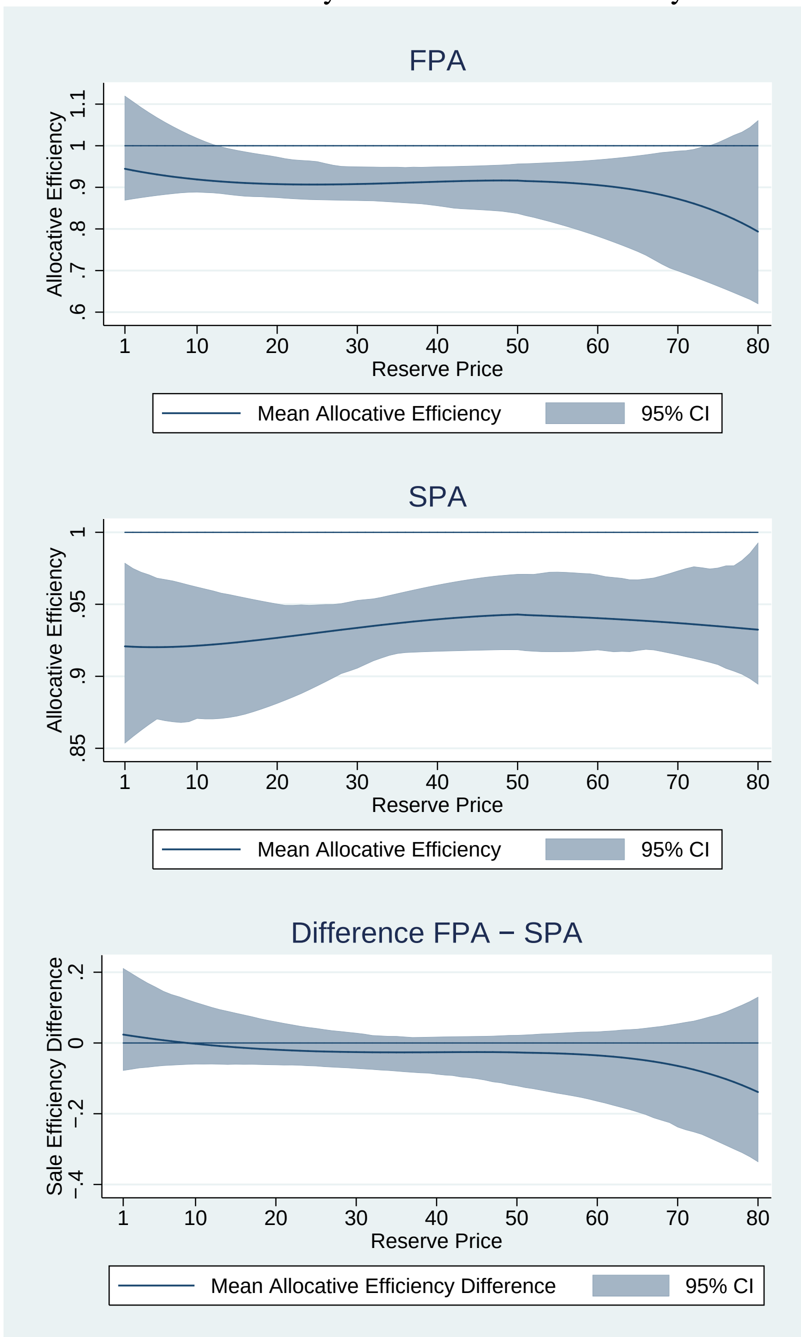
Figure 5: Revenue and Sale Efficiency Difference between the FPA and the SPA by Reserve Price



Notes:

1. The estimates are based on equation (10) and estimation details are described in the main text.
2. The confidence intervals are based on standard errors adjusted for clustering at session level.

Figure 6: Allocative Efficiency in the FPA and the SPA by Reserve Price



Notes:

1. The estimates are based on equation (10) and estimation details are described in the main text.
2. The confidence intervals are obtained by bootstrapping with 1,000 replications and clustering at session level.