An Experimental Investigation of Asymmetric Information in Common-Value Auctions*

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Abstract

This paper considers the role of information in first-price, sealed-bid, common-value auctions. We consider three information structures in such auctions: (1) symmetric information in which bidders hold no private information; (2) asymmetric information in which only one bidder observes a private signal; (3) symmetric information in which each bidder observes a private signal. We find that bidders who observe a private signal tend to overbid relative to Nash equilibrium predictions. Uninformed bidders, however, tend to underbid relative to the Nash equilibrium. When both bidders observe a private signal, bidders overbid such that they often fall victim to the winner's curse. When neither bidder observes a private signal, the winner's curse is much less prevelant. This suggests that the prevelence of the winner's curse in previous studies may be an artifact of private information. The information rent of informed bidders facing uninformed bidders is greater than predicted by theory despite overbidding relative to the Nash equilibrium bid function.

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1 Introduction

In much of the auction literature, bidders are assumed to be ex ante symmetrically informed. However, in many situations such an assumption is problematic. For example, in many auctions experienced dealers bid against non-dealers. In such an auction, it is natural to assume that dealers have more information than non-dealers; that is, bidders are asymmetrically informed.

One of the earliest and well known models analyzing auctions with asymmetrically informed bidders is found in Engelbrecht-Wiggans, Milgrom and Weber (1983) (hereafter EMW). EMW derive the unique equilibrium of a first-price, common-value auction in which one of the bidders observes an informative signal regarding the realized common value of the object for sale.[1] The other bidders know only the joint distribution from which the signal and realized value are drawn, which is common knowledge. Thus, the uninformed bidders hold only public information, while the informed bidder holds private information. This information structure guarantees that, in equilibrium, the uninformed bidders have expected profits of zero, and the informed bidder has a positive expected profit. Further, this information asymmetry reduces the expected revenue of the auction relative to a symmetric information framework.

Several papers model information asymmetry in common-value auctions by varying the quality of information while allowing each bidder to hold private information. Hausch (1987) and Campbell and Levin (2000) show that less informed bidders earn positive expected profit in equilibrium, provided they hold some private information. Campbell and Levin (2000) also demonstrate that a seller's expected revenue can benefit from an information asymmetry between the bidders.

This paper experimentally investigates the role of asymmetric information in two-bidder, first-price, sealed-bid, common-value auctions by varying the number of bidders who receive a signal regarding the value of the good prior to bidding.

[1] A correction to their proof of uniqueness is found in Dupra (2006).

In one treatment bidders know only the distribution from which the value of the good is drawn; no bidder holds any private information. In another, each bidder observes a conditionally independent signal of the common value of the good. In the asymmetric information treatment, only one of the bidders receives such a signal; the other bidder holds no private information. Our asymmetric information treatment is theoretically analyzed in EMW.

We find several interesting results. First, bidders who observe a signal overbid relative to the Nash equilibrium prediction on average, regardless of whether or not the other bidder observes a signal. Conversely, bidders who do not observe a signal underbid relative to Nash equilibrium predictions on average. Indeed, when neither bidder observes a signal, the average bid is 42% below the predicted bid.

This result cannot be explained by risk aversion, since the degree of risk aversion required to induce such behavior is unreasonably large. Further, limited liability of losses does not explain this behavior, since the balance held by bidders is much more than the value of the good is able to be, even in later rounds. We interpret this result in terms of overconfidence. We suggest that providing bidders with a signal induces overconfidence. That is, bidders who observe a private signal become overconfident regarding the value of their signal and overbid accordingly. This exemplifies the hypothesis that "a little knowledge is a dangerous thing."[2]

The effect of an information asymmetry among bidders is ambiguous, because of the systematic overbidding of informed bidders, and underbidding of uninformed bidders. In particular, the effect of an information asymmetry depends on the symmetric information structure against which it is compared. We find that the revenue generated by an auction in which both bidders observe a signal is higher than when only one bidder observes a signal; the informed bidder earns a substantial information rent. However, the dramatic underbidding when no bidder is informed results in much lower revenue than predicted. This result is surprising, since this

[2] Alexander Pope first addressed this hypothesis by writing: "A little learning is a dangerous thing; drink deep, or taste not the Pierian spring: there shallow draughts intoxicate the brain, and drinking largely sobers us again."

treatment is predicted to generate the highest revenue. That is, revenue is lowest when bidders hold no private information.

Observed bidder payoffs also deviate from theoretical predictions in interesting ways. In particular, when neither bidder observes a signal both bidders underbid significantly and, on average, earn a substantial payoff a result.[3] Conversely, when both bidders observe a signal, bidders overbid relative to the Nash equilibrium, such that they earn less than theoretical predictions. Lastly, when only one bidder observes a private signal, the informed bidder earns a substantial information rent, despite overbidding relative to Nash predictions. This is because the uninformed bidder, on average, bids less than the expected value of the good. When the informed bidder observes a signal above this expected value, she can still win the auction by bidding substantially less than the expected value, and earn a significant payoff as a result.

This bidding behavior has dramatic implications regarding the winner's curse. Experimental investigations of common-value auctions with symmetrically informed bidders are numerous.[4] Inexperienced bidders consistently fall victim to the winner's curse.[5] However, throughout the literature, bidders are provided with private signal as to the value of the good.[6] Our results suggest that the persistent winner's curse

[3] The only difference between auctions in which both bidders observe a private signal and auctions in which neither bidder observes a private signal is the information structure. Since bidders overbid when both bidders observe a signal, and underbid when both bidder do not observe a signal, the fact that bidders earn such a large payoff when neither bidder observe private signals is unlikely to be the result of collusion.

[4] Kagel and Levin (2002) provides an overview of this literature.

[5] Once bidders gain sufficient experience, bidders fall victim much less frequently. However, they continue to overbid relative to the Nash equilibrium bid function. Further, this phenomenon is not driven by a small subset of aggressive bidders who overbid such that the average bid is greater than the value of the good conditional on winning. While this overbidding varies across bidders, most inexperienced bidders fall victim to the winner's curse, and earn negative profits as a result.

[6] An exception is Bazerman and Samuelson (1983) which reports the result of classroom experiments in which bidders were asked to guess the value of a commodity (either an unknown quantity of coins or paper clips) and place a bid. Each participant bid in four different auctions. A winner's curse is observed. Hovever, the number of bidders per auction was high (between 34 and 54), and an increase in the number of bidders has typically increases how aggresively participants bid. Also, bidders only particpated in four auctions; they did not have an opprotunity to learn. Lastly, the

observed throughout the literature may be an artifact of this private signal.

In research of particular relevance to this paper, Kagel and Levin (1999) report the results of an experiment in which one of the bidders in a first-price auction observes a more precise estimate of the common value of the good than other bidders, but all bidders hold some private information. Our design differs in that our uninformed bidders do not hold private information. Interestingly, the predicted results of these models differ considerably. For the parameters employed in Kagel and Levin (1999), seller revenue is expected to be higher than in a symmetric information environment where all bidders have equally precise estimates. Our design that predicts seller revenue will fall relative to both our symmetric information treatments. Note that Kagel and Levin (1999) compare their asymmetric information treatment to a single symmetric information structure.

Further, the theoretical predictions against which Kagel and Levin compare their experimental data employ different assumptions regarding bidders. In particular, in their asymmetric information treatment they test a model which assumes that bidders are boundedly rational such that they employ an affine bid function. In their symmetric information treatment (every bidder observes an equally precise estimate of the value of the good) bidders are assumed to be unboundedly rational. Indeed, the bid function against which the data is compared is nonlinear. In our design, we test Nash equilibrium predictions with unboundedly rational bidders; we have closed form solutions of the Nash equilibrium in each treatment.

Harrison and List (2008) test the same model used in Kagel and Levin (1999), but change the population from which the participants are drawn. They perform the same laboratory experiments as Kagel and Levin (1999), but recruit participants from attendees (dealers and non-dealers) of a sport-card show. They also run a field experiment testing the asymmetric information structure using unopened packs of sport cards as the good for sale. They find the winner's curse is much less prevalent among dealers.

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pool of participants was made up of MBA students. Casari *et al.* (2007) finds that business majors are much more susceptible to the winner's curse than other majors.

The remainder of the paper is organized as follows. Section 2 describes our experimental design. Section 3 contains the theoretical predictions. Section 4 provides our experimental results. Section 5 contains the conclusion. Appendix A contains derivations of theoretical predictions, and Appendix B provides a sample set of instructions.

2 Experimental Design

Within a group of ten, participants are randomly and anonymously matched into pairs. Each pair participates in a two-bidder, first-price, sealed-bid auction. Each bidder submits a bid. The bidder who submits the highest bid wins the auction and receives the good (in the event of equal bids, both bidders have a 50% chance of obtaining the good) and pays her bid. Only the winner pays her bid. Participants are randomly and anonymously rematched after each round. This process is repeated for thirty rounds.[7]

In each auction a good with a common but uncertain value is available. The common value, x, is a realization of the random variable X, which is uniformly distributed with support $[25, 225]$. The realized value of the good is not observed by bidders before placing their bids. The distribution of X is common knowledge. We employ a 3×1 between-subject design which varies the information observed by bidders prior to placing their bids.

1. *Symmetric information with only public information (SPUB).*—Neither bidder observes any information regarding x beyond the distribution of X. As such, no bidder holds any private information, and information is symmetric.

[7]Since matching of participants occured within groups of ten, and thirty rounds were conducted, participants were inevitably matched together more than once. However, participants were anonymously matched such that they were unable to build a reputation. Further, each session was ususally run with twenty or thirty participants, and participants were not informed that they would only interact within a group of ten.

Table 1
3×1 between-subject design

	First-price auctions.
Symmetric information with only public information	5 groups of 10 participants
Symmetric information with private signals	5 groups of 10 participants
Asymmetric Information	5 groups of 10 participants

2. *Symmetric information with private signals (SPRIV).*—Each bidder privately observes a signal. These signals, z_1 and z_2, are independently drawn from a uniform distribution with support $[x - 8, x + 8]$. In this treatment both bidders hold private information in the form of their signal. Information is symmetric in that each signal is an equally precise estimate of x.

3. *Asymmetric information (ASYM).*—One of the bidders is randomly chosen to be the informed bidder, who privately observes a signal. This signal, z_I, is drawn from a uniform distribution with support $[x - 8, x + 8]$. The other bidder does not observe a signal; all the information available to them was common knowledge. Since the informed bidder is randomly determined in each auction, bidders change roles throughout each session.

In each of these three treatments, the information structure of the auction is common knowledge. That is, if a bidder observes a signal, this fact, as well as the distribution from which the signal is drawn, is common knowledge. At the conclusion of each auction each bidder observes both bids, the earnings of both bidders, their own balance and, if applicable, the private signal(s) (participant numbers are suppressed).[8] This design is illustrated in Table 1.

Examining two-bidder auctions makes sense for several reasons. First, in ASYM auctions the equilibrium bid function of the informed bidders does not depend on

[8] Armantier (2004) finds that the ex post observation of bids, earnings and signals "homogenizes behavior, and accelerates learning toward the Nash equilibrium" in common-value auctions with the SPRIV information structure. Futher, this level of ex post observation has been widely used throughout the literature, so this increases the comparability of our results with previous studies

the number of bidders. The expected payoffs of ASYM bidders (and hence, expected revenue) also do not depend on the number of bidders either. In SPUB auctions Nash equilibrium bids and expected revenue are invariant to the number of bidders. Since we are interested in the role of information, we leave the test of these comparative statics to future research. Second, SPRIV auctions have been extensively examine in the experimental literature, but we are unaware of any study which examines this information structure in a two-bidder context. Thus, our SPRIV treatment provides insight not already found in the literature.

All sessions were run at the Economic Research Laboratory (ERL) at Texas A&M University, and our participants were matriculated undergraduates of the institution. The sessions were computerized using z-Tree (Fischbacher 2007). Participants were separated by dividers such that they can not interact outside of the computerized interface. They were provided with instructions, which were read aloud by an experimenter.[9] After they instructions were read, questions were answered privately. Each participant then individually answered a set of questions to ensure understanding of the experimental procedure; their answers were checked by an experimenter who also answered any remaining questions. Participants were provided with a history sheet which allowed them to keep track of bids, earnings and. if applicable, signal(s) in each round. Each session lasted approximately two hours. Each participant began with a starting balance of $20 to cover any losses; no participant went bankrupt. At the end of all thirty rounds, each participant was paid their balance, as well as a show-up fee of $5. The bids, signals and values were all denominated in Experimental Dollars (ED), which were exchanged for cash at a rate of 160ED/$1. The average payoff was $26.91, with a range of $23.31 and $32.33.

[9] The instructions for the ASYM treatment are found in Appendix B. Instructions for the remaining treatments are available upon request.

3 Theororetical Predictions

3.1 Symmetric Information With Only Public Information

If both bidders hold only public information, the distribution of X is the only information regarding x available to bidders before placing their bids. Assuming risk-neutral bidders, the unique Nash equilibrium of this auction is for both bidders to bid $E(X) = 125$. To see this, note that if either bidder were to bid above 125, they would earn negative expected profits upon winning. For any bid $b < 125$, the other bidder would have an incentive to bid $b + \epsilon < 125$, and earn a positive expected profit. As only the bidder to whom the good is allocated pays her bid, the expected revenue generated by an auction, $E\left(R^{SPUB}\right) = 125$ and the expected profit of bidder i, $E\left(\Pi_i^{SPUB}\right) = 0$.

3.1.1 Winner's Curse in SPUB Auctions

Note that the Nash equilibrium in a SPUB auction also represents a break-even bidding strategy. That is, conditional upon winning, bidding less than 125 guarantees an expected profit greater than zero whereas bidding above 125 yields a negative expected profit. Bidding above a break-even biding threshold is widely referred to as the winner's curse.[10] We adopt this terminology, although this threshold is not constant across information structures.

3.2 Symmetric Information With Private Signals

Each bidder i receives a private signal z_i. The signals are independently drawn from a uniform distribution on $[x - 8, x + 8]$.[11] The symmetric equilibrium of this game

[10] See, e.g., Kagel and Levin (2002).

[11] These assumptions are widely used throughout the experimental literature on first-price, common-value auctions. Examples include Casari *et al.* (2007), Kagel and Richard (2001) and Kagel and Levin (1999). Our setup differs in the parameter choice as well as in the number of bidders.

can be obtained by suitably specializing the results in Milgrom and Weber (1982).[12] This gives the symmetric risk neutral Nash equilibrium bid function to be

$$\gamma(z_i) = \begin{cases} \frac{1}{3}(z_i - 58) & \text{if} \quad z_i \in [17, 33) \\ z_i - 8 + g(z_i) & \text{if} \quad z_i \in [33, 217) \\ \frac{z_i}{3} + 142 + h(z_i) & \text{if} \quad z_i \in [217, 233] \end{cases}$$

where $g(z_i) = \frac{16}{3}\exp\left[\frac{1}{8}(33 - z_i)\right]$ is the nonlinear portion of the bid function when $z_i \in [33, 217)$, and $h(z_i) = \frac{4096}{3(z_i-201)^2\exp(23)} - \frac{4096}{3(z_i-201)^2}$ is the nonlinear part of the bid function when $z_i \in [217, 233]$.

Notice that the equilibrium bid function is monotonically increasing. Bidders shade their bids in equilibrium. Intuitively, this can be seen as arising for two reasons. First, in first-price auctions, bidders shade their bids to what they expect the second highest signal holder to bid, conditional on their own signal being the highest signal. Second, in common-value auctions, bidders take into account that the bidder with the highest signal will win the auction. Although z_i is an unbiased estimate of x, in equilibrium bidder i uses z_i as a first order statistic because conditional on winning bidder i has the highest signal.

The expected payoff of bidder i who observes z_i is:

$$\Pi_i^{SPRIV}(z_i) = \begin{cases} 0 & \text{if} \quad z_i \in [17, 33) \\ \frac{8}{3}\left(1 - \exp\left(\frac{33-z_i}{8}\right)\right) & \text{if} \quad z_i \in [33, 217) \\ \frac{z_i}{3} - \frac{217}{3} - \frac{128}{3(z_i-201)\exp(23)} + \frac{128}{3(z_i-201)} & \text{if} \quad z_i \in [217, 233]. \end{cases}$$

[12] The derivations of the symmetric Nash equilibrium bid function, are found in Appendix A. Similar derivations can be found in Kagel and Levin (2002) (Appendix to Chapter 6), and in Kagel and Richard (2001). Derivations of expected revenue and bidders' expected payoffs are also in Appendix A.

Bidder i enjoys a positive expected payoff when $z_i > 33$. This is the private information rent to the bidder. The ex ante expected payoff of bidder i, $E\left(\Pi_i^{SPRIV}\right)$, is found by integrating over $\Pi_i^{SPRIV}(z_i)$ with respect to F_{Z_i}, which yields: $E\left(\Pi_i^{SPRIV}\right) = 2.5$.[13] We refer to this as the information rent a bidder earns in a SPRIV auction.

The expected revenue of this auction is, $E\left(R^{SPRIV}\right) = 2\ E\left(\Pi_i^{SPRIV}\right) = 120$. SPRIV auctions generate lower expected revenue that SPUB auctions due to the private information held by the bidders in the former.

3.2.1 Winner's Curse in SPRIV Auctions

Bidders fall victim to the winner's curse when they bid more than the expected value of the good conditional on having won the auction (the break even bidding strategy).. In an SPRIV auction, each bidder receives a signal regarding x. Since the equilibrium bid function is monotonically increasing in the signal, the winner's curse is found when bids exceed the expected value of the good conditional on having the highest signal. That is, bidder i falls victim to the winner's curse when she bids more than $E(X_0 \mid z_i > z_j)$.[14] This threshold is:

$$E(X_0 \mid z_i > z_j) = \begin{cases} \frac{1}{3}(z_i + 58) & \text{if} \quad z_i \in [17, 33) \\ z_i - \frac{8}{3} & \text{if} \quad z_i \in [33, 217) \\ \frac{z_i(z_i+257)-92570}{3(z_i-201)} & \text{if} \quad z_i \in [217, 233]. \end{cases}$$

3.3 Asymmetric Information

One bidder observes a signal before placing her bid. We refer to this bidder as the informed bidder. The signal is a realization of Z_I which is uniformly distributed on

[13] Throughout the paper, decimal numbers are rounded off to two decimal places.

[14] The derivation of $E(X_0 \mid z_i > z_j)$ can be found in Appendix A.

$[x-8, x+8]$. The distribution function of Z_I is F_{Z_I}. The other bidder holds no private information. We refer to this bidder as the uninformed bidder. Engelbrecht-Wiggans *et al.* (1983) provide the unique, risk neutral Nash equilibrium of this game.[15] The risk neutral Nash equilibrium bid function of an informed bidder is given by

$$\beta(z_I) = \begin{cases} \frac{z_I}{3} + \frac{58}{3} & \text{if} \quad z_I \in [17, 33) \\ \\ \frac{z_I}{2} + \frac{75}{6} + m(z_I) & \text{if} \quad z_I \in [33, 217) \\ \\ \frac{z_I}{3} + \frac{442}{3} + n(z_I) & \text{if} \quad z_I \in [217, 233] \end{cases}$$

where $m(z_I) = \frac{32}{3(z_I - 25)}$ is the nonlinear portion of the equilibrium bid function when $z_I \in [33, 217)$ and $n(z_I) = \frac{1}{3}\left(\frac{15200}{z_I - 313} - \frac{8800}{z_I - 153}\right)$ is the nonlinear portion of the equilibrium bid function when $z_I \in [217, 233]$.

In equilibrium, the uninformed bidder employs a mixed strategy with the distribution function Q, with support on $[25, 125]$. The probability that the uninformed bidder will bid no more than b is given by:

$$\begin{aligned} Q(b) &= \text{Prob}\left[\beta(Z_I) \leq b\right] \\ &= F_{Z_I}\left(\beta^{-1}(b)\right). \end{aligned}$$

The uninformed bidder will not bid more than $E(X)$, because this would ensure negative expected profits upon winning the auction.

Since, in equilibrium, the uninformed bidder employs a mixed strategy, it must be the case that the expected payoff of any bid in the support of this strategy yields the same expected payoff. Engelbrecht-Wiggans *et al.* (1983) demonstrate that the uninformed bidder wins only when the informed bidder's signal indicates that x is low, such that the expected payoff of an uninformed bidder is zero, conditioned on

[15] The derivations of the bidding strategy, equilibrium payoffs and expected revenue for the distributions we use are found in Appendix A.

winning the auction. This implies that the ex ante expected payoff of the uninformed bidder, $E\left(\Pi_U^{ASYM}\right)$, is zero.

Let $q(z_I) \equiv E(X \mid z_I)$. Since $q(z_I)$ is monotonically increasing in z_I, the distribution function of this random variable is just $F_{Z_I}\left(q^{-1}(\cdot)\right)$, where $q^{-1}(\cdot)$ is the inverse of $q(\cdot)$. The expected payoff of the informed bidder, when z_I is observed, is $\Pi_I^{ASYM}(z_1) = \int_{25}^{q(z_I)} F_{Z_I}\left(q^{-1}(s)\right) ds$. This yields

$$\Pi_I^{ASYM}(z_I) = \begin{cases} \frac{(z_I-17)^3}{38400} & \text{if} \quad z_I \in [17, 33) \\ \frac{1811+3z_I(z_I-50)}{1200} & \text{if} \quad z_I \in [33, 217) \\ \frac{12015737-143667z_I+699z_I^2-z_I^3}{38400} & \text{if} \quad z_I \in [217, 233]\,. \end{cases}$$

Integrating over $\Pi_I^{ASYM}(z_I)$ with respect to F_{Z_I} yields the ex ante expected profit of the informed bidder, $E\left(\Pi_I^{ASYM}\right) = 33.23$. We refer to this as the informed bidder's information rent in an ASYM auction. This large information rent is largely due to the fact that the upper bound of the support of the uninformed bidder's equilibrium mixed strategy is 125. The ex ante expected revenue of an ASYM auction, $E\left(R^{ASYM}\right)$, is equal to $E(X) - E\left(\Pi_I^{ASYM}\right) - E\left(\Pi_U^{ASYM}\right) = 91.77$.

3.3.1 Winner's Curse in ASYM Auctions

Since the uninformed bidder has an expected payoff of zero for any bid $b \in [25, 125]$, 125 is a break-even strategy for uninformed ASYM bidders. Bidding above 125 ensures negative expected profit upon winning, while bidding below 125 yields an expected payoff of zero conditional on winning the auction. That is, if an uninformed bidder bids above 125, she is said to fall victim to the winner's curse.

The expected value of the good conditional on z_I is the same as the expected value of the good conditional on z_I *and* having won the auction. Winning the auction does not provide the informed bidder additional information regarding x.

Table 2: Revenue ranking of information structures in decreasing order

Information structure	**Ex ante expected revenue**
SPUB	125
SPRIV	120
ASYM	91.77

Therefore, the break-even bidding strategy for an informed ASYM bidder is to bid:

$$E(X \mid z_I) = \begin{cases} \frac{z_I+33}{2} & \text{if} \quad z_I \in [17, 33) \\ z_I & \text{if} \quad z_I \in [33, 217) \\ \frac{z_I+217}{2} & \text{if} \quad z_I \in [217, 233]. \end{cases}$$

So, if an informed bidder bidder bids above $E(X \mid z_I)$, she is said to fall victim to the winner's curse.

3.4 Testable Hypotheses

The revenue generated by auctions has garnered significant interest in the literature. Much of this attention has focused on the revenue ranking of auction formats, holding the information structure constant. Since the revenue predictions of an auction format are not invariant to the information structure, we test the predicted revenue ranking of different information structures within a single auction format. The ex ante expected revenue of each treatment is found above. Notice that $E\left(R^{ASYM}\right) < E\left(R^{SPRIV}\right) < E\left(R^{SPUB}\right)$. If both bidders observe a private signal, they are predicted to earn a positive payoff which reduces expected revenue relative to a SPUB auction. Additionally, the introduction of asymmetric information sharply reduces expected revenue in a ASYM auction below that of a SPRIV auction.

Table 3: Ranking of ex ante expected bidder payoffs in decreasing order

Bidders	**Ex ante expected payoffs**
ASYM-Informed	32.23
SPRIV	2.5
SPUB	0
ASYM-Uninformed	0

Since auctions are constant sum games between the seller and the bidders, revenue and bidder payoffs are closely related. When there is an information asymmetry as modeled in an ASYM auction, the decrease in revenue relative to either symmetric information structure must improve the expected payoffs of at least one bidder. Who gets this decrease in revenue, the informed bidder, the uninformed bidder or both? There are a number of predictions with regards to bidder payoffs which we test. The ex ante expected payoffs of bidders are found above. Notice that, $E\left(\Pi_U^{ASYM}\right) = E\left(\Pi_i^{SPUB}\right) < E\left(\Pi_i^{SPRIV}\right) < E\left(\Pi_I^{ASYM}\right)$. These hypotheses are summarized in Table 2 and Table 3.

Since $E\left(\Pi_U^{ASYM}\right) = E\left(\Pi_i^{SPUB}\right)$, a bidder who does not observe a private signal has an expected profit of zero, regardless of whether or not the other bidder observes a signal. This implies that, in equilibrium, the ex ante expected payoff of a bidder who observes a signal is a measure of the value of that signal, given the information structure of the game. That is, an informed bidder's ex ante expected payoff represents the expected information rent associated with the signal. Since $E\left(\Pi_i^{SPRIV}\right) < E\left(\Pi_1^{ASYM}\right)$, the information rent associated with a signal is greater if the other bidder is uninformed.

Table 4: Revenue aggregated over all rounds and sessions

Treatment	**Average observed revenue (standard deviation)**	**Average predicted revenue (standard deviation)**
SPUB	84.06	125
	(21.87)	(0)
SPRIV	112.36	110.67
	(55.94)	(55.01)
ASYM	88.96	88.24
	(37.33)	(21.87)

4 Experimental Results

4.1 Revenue

Table 4 reports summary statistics of revenue. Average predicted revenue was calculated using the realized value of the signal(s) and x.

There are three revenue ranking predictions, which we test using the nonparametric robust rank order test on session-level data.[16] Predictions are borne out between SPRIV and ASYM auctions, where at least one bidder holds private information; we find strong support for the prediction that $E\left(R^{ASYM}\right) < E\left(R^{SPRIV}\right)$ (robust rank-order test, $\acute{U} = n.d.$, $p = 0.004$).[17] Predictions regarding SPUB auctions, however, are off. We find that $E\left(R^{SPRIV}\right) > E\left(R^{SPUB}\right)$ (robust rank-order test, $\acute{U} = n.d.$, $p = 0.004$). Further, our data does not support the prediction that $E\left(R^{ASYM}\right) < E\left(R^{SPUB}\right)$. Rather, we are unable to reject revenue equivalence between these treatments (robust rank order test, $\grave{U} = -0.473$, n.s.).

Clearly, the observed effect on revenue of an asymmetry as modeled in ASYM

[16] The critical values of the robust rank order test are found in Feltovich (2003).

[17] The highest average revenue observed within a group of ten participants in any SPUB session is lower than the lowest average reveune observed within a group of ten participants any SPRIV session. As such, the test statistic of the robust rank order test is not defined. We denote such a test statistic as $\acute{U} = n.d.$.

auctions depends on the symmetric information structure. While theory predicts that the information asymmetry will reduce revenue relative to both SPUB and SPRIV information structures, we find that this only holds true relative to the SPRIV structure.

This is in contrast to the results reported in Kagel and Levin (1999) and Harrison and List (2008). They employed a design in which each bidder observed a private signal, and one bidder observed a perfectly precise signal. This was compared to a symmetric information structure as in our SPRIV treatment. Theory predicts that such an information asymmetry will increase the expected revenue relative to the SPRIV case, and their experimental results are consistent with that prediction. Our results suggest that this type of information asymmetry would increase revenue relative to a SPUB information structure as well.

4.2 Bidder Payoffs

Table 5 reports summary statistics of bidder payoffs per auction. Note that uninformed bidders in ASYM auctions are losing money on average. Despite this, 96.4% of these bidders bid positive amounts. Indeed, the percentage of uninformed ASYM bids below twenty is lower in the last ten periods than in the first ten.

We find, in keeping with theoretical predictions, that the average payoff of informed ASYM bidders is significantly greater that the average payoff of SPUB bidders (robust rank order test, $\acute{U} = 7.19$, $p = 0.008$) and SPRIV bidders (robust rank order test, $\acute{U} = n.d.$, $p = 0.004$). Thus, informed ASYM bidders earn a significant information rent on average and are significantly better off than in either symmetric information structure.

SPUB bidders earn more than SPRIV bidders (robust rank order test, $\acute{U} = n.d.$, $p = 0.004$) and uninformed ASYM bidders (robust rank order test, $\acute{U} = n.d.$, $p = 0.004$). Additionally, we are unable to reject that uninformed ASYM bidders and SPRIV bidders obtain the same payoffs on average (robust rank order test, $\grave{U} = 1.136$,

Table 5: Bidder payoffs aggregated over all rounds and sessions

Bidders	**Average observed payoffs (standard deviation)**	**Average predicted payoffs (standard deviation)**
SPUB	15.74	0
	(45.71)	(0)
ASYM-Informed	28.37	27.29
	(37.39)	(27.7)
ASYM-Uninformed	−1.81	0
	(23.63)	(0)
SPRIV	1.59	2.43
	(5.66)	(0.69)

Table 6: Information rents aggregated across all rounds and sessions

Bidders	**Average observed information rent (standard deviation)**	**Average predicted information rent (standard deviation)**
ASYM-Informed	12.63	27.29
	(37.39)	(27.7)
SPRIV	3.40	2.43
	(5.66)	(0.69)

n.s.). That is, we find that a SPRIV bidder would not be significantly worse off than if she did not observe a signal, and would be significantly better off if both bidders did not observe a signal.

Uninformed ASYM bidders earn less than informed ASYM bidders (Wilcoxon matched pairs test, $z = -6.13$, $p = 0.000$).[18]

Since bidders who do not observe a signal are, on average, not earning zero payoffs, the value of an observed signal is not accurately measured by the expected payoff

[18] In the ASYM treatment, participants switched roles throughout the experiment. To test the prediction that $E\left(\Pi_U^{ASYM}\right) < E\left(\Pi_I^{ASYM}\right)$, the average payoff of a participant when she was informed was matched with the average payoff of a participant when she was uninformed, for a total of 50 matched pairs.

of the bidder who observes said signal. The ex ante expected value of an informed ASYM bidder's signal is the difference between the ex ante expected payoff of an informed ASYM bidder and that of a SPUB bidder. Likewise, the ex ante expected value of a SPRIV bidder's signal is the difference between the ex ante expected payoff of a SPRIV bidder and that of an uninformed ASYM bidder. That is, the ex ante expected information rent associated with a signal is the difference between the ex ante expected payoff of a bidder who observes the signal and that of a bidder who does not observe the signal, given whether or not the other bidder observes a signal.

Table 6 reports summary statistics of this measure of information rent, aggregated over all rounds and sessions. While the average payoffs of uninformed ASYM bidders and SPRIV bidders are not significantly different, the average value of a SPRIV bidder's signal is positive. The positive average payoff of SPUB bidders drives the value of an informed ASYM bidder's signal down, but on average it is positive and larger than that of a SPRIV bidder.

4.3 Winner's Curse

A bidder is said to fall victim to the winner's curse regardless of whether she actually won the auction in which they bid. That is, the winner's curse is defined for all bidders; a victim of the winner's curse has negative expected profits if they were to win the auction.

Table 7 contains summary statistics of the winner's curse where the winner's curse is defined as the observed bid less the break-even bid. Thus, a positive winner's curse indicates that the observed bid is above the break-even bid.

There are several things worth noting. First, on average, bidders in all information structures do not fall victim to the winner's curse. In the symmetric treatment with private signals the percentage of bidders who are cursed is significantly lower in our experiment than in other studies. Table 8 summarizes the frequency with which inexperienced bidders fall victim to the winner's curse in the literature. This

Table 7: Winner's curse aggregated across all rounds and sessions

Bidders	**Frequency of winner's curse: All bidders**	**Frequency of winner's curse: Winning bidders**	**Frequency the high (or only) signal holder wins**
SPUB	1.6%	3.2%	NA
	(24/1500)	(24/750)	NA
ASYM-Informed	6%	6.9%	65.5%
	(45/750)	(34/491)	(491/750)
ASYM-Uninformed	3.3%	9.7%	NA
	(28/750)	(25/259)	NA
SPRIV	30.9%	45.3%	72.3%
	(464/1500)	(340/750)	(542/750)

NA = not applicable.
The decimal numbers in parentheses are standard deviations.
The fractions in parentheses are relative frequencies.

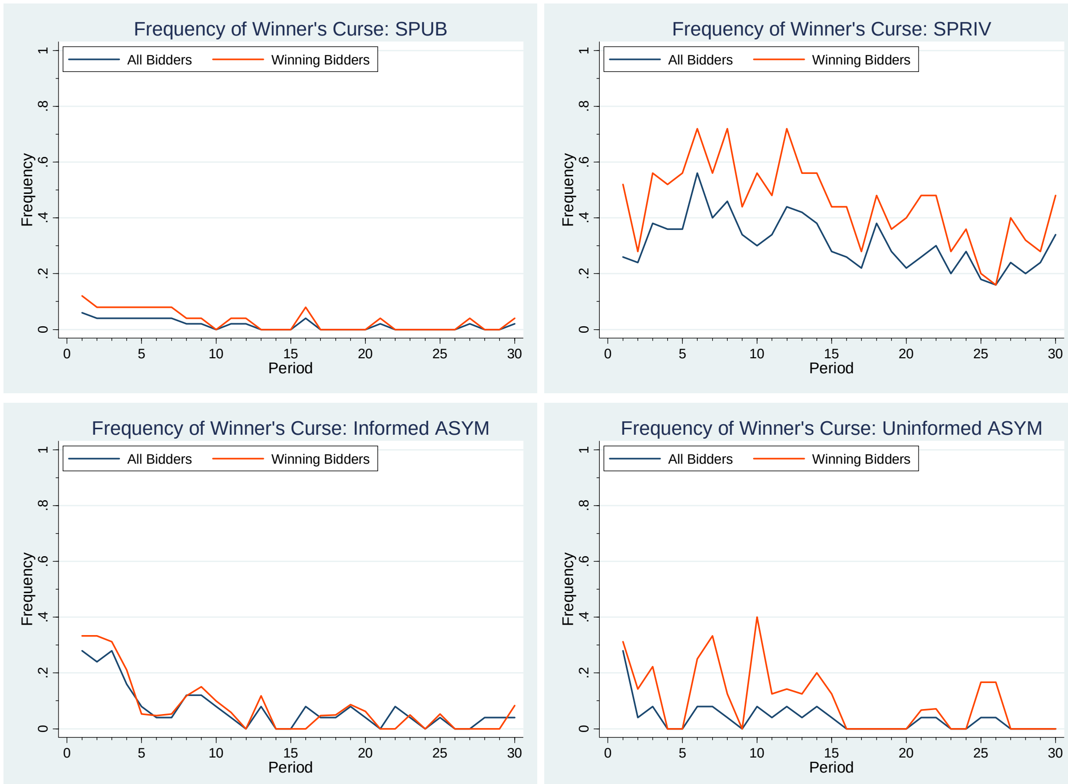
difference is attributable to the fact that we examine two bidder auctions, while the rest of the literature has examined auctions with a larger number of bidders.[19] As number of bidders increases the adverse selection problem increases; in order to win the auction a bidder's estimate must be the largest of a larger number of signals, driving the break-even bidding strategy down. Thus a bidding strategy which may not lead to being cursed with a small number of bidders may do so with a larger number of bidders. Further, bidders tend to bid more aggressively when there is a larger number of bidders.[20] Second, the frequency with which SPRIV bidders fall victim to the winner's curse is dramatically different than that of SPUB bidders.

Figure 1 illustrates how the bidders' susceptibility to the winner's curse changes as they gain experience. Note that the frequency with which bidders fall victim to the winner's curse decreases as bidders gain experience. However, even in the last periods, many SPRIV bidders are cursed. In contrast, very few SPUB bidders

[19] $n \in \{4, 6, 7\}$ are typical. Frequently, n is varied. Examples include Kagel *et al.* (1989) and Kagel and Levin (1986).

[20] This behavior has been observed in many studies. See Kagel and Levin (2002).

Figure 1: Frequency of the winner's curse depending on the period



fall victim to the winner's curse in later periods. This is also true of informed and uninformed ASYM bidders.

Figure 2 contains box plots which illustrate how the magnitude of the winner's curse is related to the signals observed by SPRIV and informed ASYM bidders. As we can see, the magnitude of a SPRIV bidder's signal has little effect on the magnitude of the winner's curse for all bidder's or the winning bidders. This is not surprising. since each bidder knows that x is within $8ED$'s of their signal. Bidding $x - 8ED$ guarantees a payoff of at least zero conditional on winning the auction; this implies that the break-even bid is within $8ED$ of their signal. Interestingly, the magnitude of the winner's curse for informed ASYM bidders is decreasing in the observed signal. This is because uninformed ASYM bidders typically bid a low

Figure 2: Magnitude of the winner's curse depending on the signal

Table 8: Frequency of the winner's curse in the existing literature

			Frequency of winner's curse		
Paper	**Journal**	**Information Structure**	**All Bidders**	**Winning Bidders**	**Number of bidders**
Casari *et al.* (2007)	AER	SPRIV	43.9	66.2	6
Kagel and Levin (1986)	AER	SPRIV	–	71.4	7
Kagel and Levin (1986)	AER	SPRIV	–	31.9	4
Kagel and Levin (1999)	Econometrica	SPRIV	60.5	70.9	4
Kagel and Levin (1999)	Econometrica	SPRIV	52.3	76.6	7
Kagel and Levin (1999)	Econometrica	INSIDER[a]	57.5	78.7	4
Kagel and Levin (1999)	Econometrica	INSIDER[a]	83.9	92.9	7
Kagel *et al.* (1989)	EI	SPRIV	59.4	81.8	5-10[b]
Dyer *et al.* (1989)	EJ	SPRIV	55	66	4
Garvin and Kagel (1994)	JEBO	SPRIV	56.3	75.3	4
Garvin and Kagel (1994)	JEBO	SPRIV	49.8	75.4	6,7
Lind and Plott (1991)	AER	SPRIV	–	59.5[c]	–

[a]One bidder is perfectly informed, while the remaining bidders observe noisy signals.
[b]The number of bidders decreased as participants went bankrupt.
[c]This is the percentage of winning bidders who realized a negative payoff.

amount, allowing informed ASYM bidders to bid far below their break-even bid for high values of the good, and still obtain it.

The most significant result regarding the winner's curse is the stark difference between the two symmetric information structures studied: SPUB and SPRIV. SPRIV bidders, who observe a signal, are much more susceptible to the winner's curse than SPUB bidders, who do not observe a signal.

4.4 Bidding

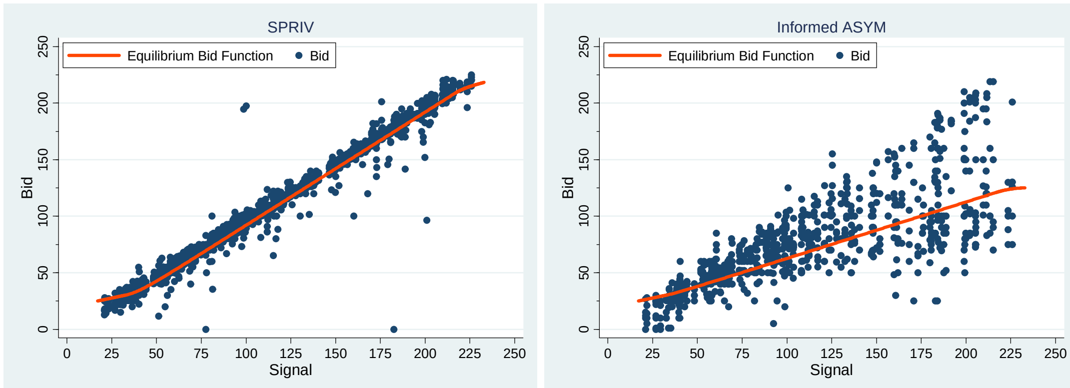
We next turn to the question of how bidders bid relative to the Nash equilibrium predictions. Table 9 gives summary statistics on bidding aggregated across all rounds and sessions. We find that SPUB bidders underbid relative to Nash predictions (sign test, $w = 50$, $p < 0.001$).[21] Further, SPRIV bidders overbid relative to Nash predictions (sign test, $w = 39$, $p < 0.001$). Informed ASYM bidders also overbid relative to Nash predictions (sign test, $w = 31$, $p = 0.0595$).[22] Figure 3 plots the equilibrium bid functions of SPRIV and informed ASYM bidders over a scatterplot of the respective experimental data from all periods and sessions. The SPRIV data closely tracks the equilibrium bid function. The informed ASYM data does not follow as closely, which is largely a result of the increased variance in overbidding as the signal increases. Notice that there are a substantial number of bids at or just below the 45° line, meaning that many bidders bid close to their signal.

Uninformed ASYM bidders are predicted to play a mixed strategy with support $[25, 125]$. As such, we do not have a point prediction for Nash bidding. However, comparing the expected value of the equilibrium mixed strategy with the observed

[21] The unit of observation in this test is the individual participant. That is, the averge bid of a participant averaged over all periods is compared with the average Nash equilibrium bid. This unit of observation was used for all tests regarding bidding.

[22] The Wilcoxon signed-rank test assumes that the underlying distribution is symmetric, and is more powerful than the sign test as a result. Consequently, the Wilcoxon signed-rank test finds that informed ASYM bidders overbid relative to Nash predictions with a higher degree of confidence ($z = 2.891$, $p = 0.0038$).

Figure 3: Equilibrium bid functions and observed bids



average bid demonstrates that, on average, uninformed ASYM bidders are bidding below the expected value of the equilibrium mixed strategy. To test whether the observed distribution of uniformed ASYM bids conforms to the predicted mixed strategy, we employ the nonparametric Kolmogorov–Smirnov test, which strongly rejects the null (Kolmogorov–Smirnov test, $D = 0.6323$, $p < 0.001$). Figures 4 and 5 provide further insight. Figure 4 provides the observed cumulative distribution of uninformed ASYM bids (aggregated over all periods and sessions) relative to the distribution function of the equilibrium mixed strategy. Notice that the observed distribution is almost entirely to the left of the Nash equilibrium mixed strategy. Figure 5 gives these observed distributions, but restricts attention to the first and last ten periods. Notice that there are fewer bids of zero, and fewer bids above the break-even bid of 125 in the last ten periods.

The above analysis of uninformed ASYM bidding uses aggregate data. At the individual participant level, are uninformed ASYM bidders mixing at all? Analyzing the individual data clearly demonstrates that they are not. Individual participants tend to choose the same bid in consecutive instances of being uninformed. Individual participants of the ASYM treatment chose their modal uninformed bid an average of 29% of the instances in which they are uninformed. Additionally, 82% of uninformed ASYM bids are integers, and 59.47% of uninformed ASYM bids are multiples of five.

Figure 4: Uninformed ASYM cumulative distribution (all periods)

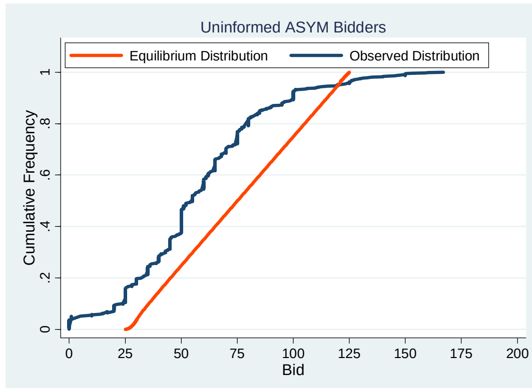
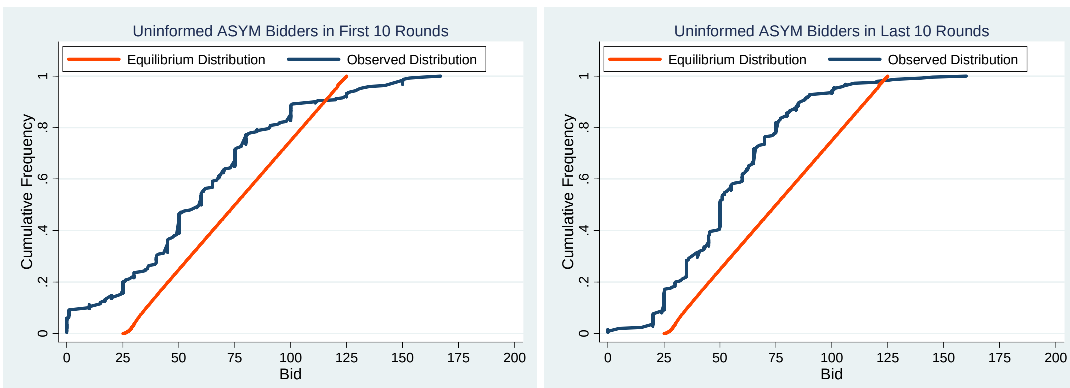


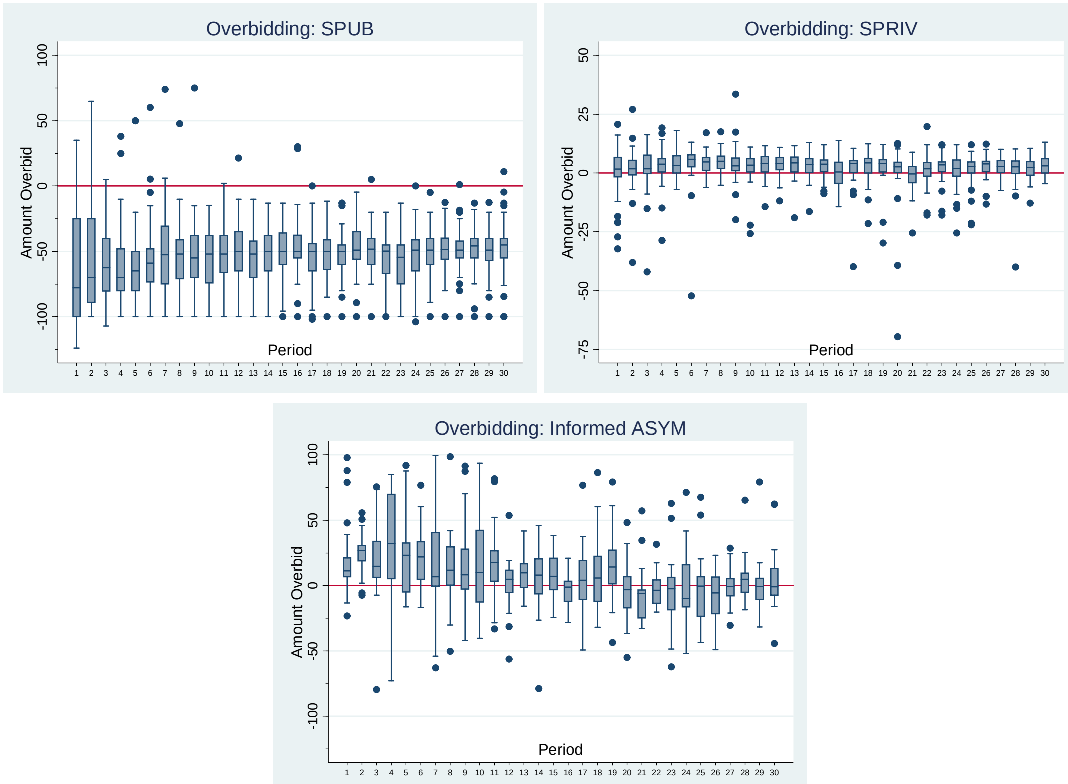
Figure 5: Uninformed ASYM cumulative distribution (first and last ten periods)



This is strong evidence against the prediction that uninformed ASYM bidders are mixing continuously on the interval $[25, 225]$, much less mixing according to $Q(b)$.

To summarize, in line with previous experimental findings, bidders who observe a signal overbid relative to the Nash equilibrium on average. However bidders who do not observe a signal bid below the expected Nash equilibrium bid, on average. Indeed, the magnitude by which uninformed bidders bid below Nash predictions is stunning. SPUB bidders bid a full 42% below Nash predictions. While underbidding has been observed in independent private value auctions when bidders have low valuations, this is, as far as we know, the first observed underbidding in single-unit

Figure 6: Overbidding depending on the period

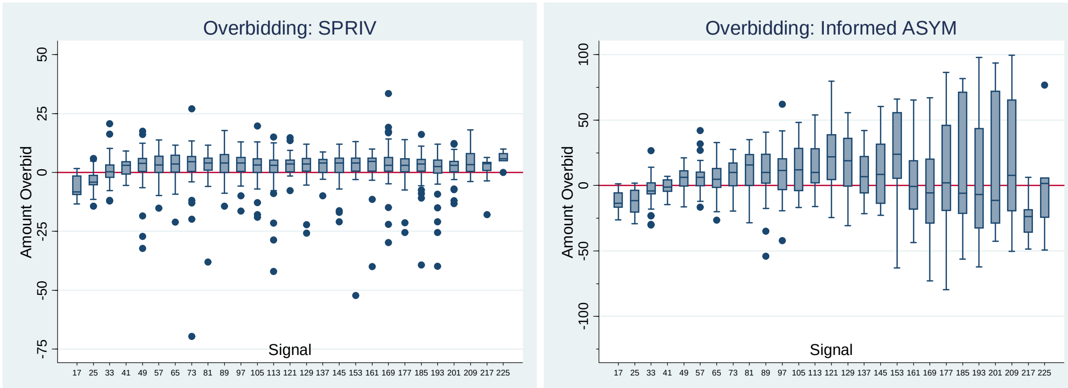


common-value auctions.

Figure 6 illustrates how overbidding relative to the Nash equilibrium evolves over time for bidders whose equilibrium bidding strategy is pure. Median overbidding of informed ASYM bidders declines as bidders gain experience. It is important to note, however, that substantial overbidding persists throughout the experiment. In stark contrast, SPUB bidders bid dramatically less than the Nash predictions. While this underbidding decreases in early rounds, median underbidding does not dramatically change in later rounds.

Figure 7 yields insight into how the signal a SPRIV or an informed ASYM bidder observes is related to overbidding. The variance of overbidding by informed ASYM

Figure 7: Overbidding depending on the signal



bidders is clearly positively related to the signal the bidder observes. The same does not hold for SPRIV bidders.

4.5 Estimating Bid Functions

In estimating bid functions, we employ a random effects Tobit estimation to control for correlation of participant behavior over time, and the fact that bids were restricted to be within the interval $[0, 225]$. In estimating bid functions, we restrict our attention to observations in which the observed signal (or the signal that a bidder would have observed had she been informed) is in the interval $[33, 217)$, where the majority of observations lie. Following Casari *et al.* (2007), we employ specifications with and without gender and learning interaction. For the SPUB treatment, the specification without gender interaction is given by

$$bid_{it} = \beta_0 + \beta_1 z_{it} + \beta_2 M_i + \beta_3 \ln(1+t) + \alpha_i + \epsilon_{it},$$

where z_{it} is the (unobserved) signal, M_i is equal to one if the participant is a male, and $\ln(1+t)$ captures learning. We include z_{it} as a test of whether or not the signal which is observed by a bidder in the corresponding SPRIV auction has any explanatory value in the SPUB auction. The specification which included gender

Table 9: Bids relative to the Nash equilibrium aggregated over all rounds and sessions

Bidders	**Average bid**	**Average Nash equilibrium bid**	**Average percent over Nash**	**Frequency of positive bids**
SPUB	72.57	125	−42%	100%
	(23.62)	(0.00)	(0.11)	(1500/1500)
SPRIV	108.34	105.93	3%	99.9%
	(55.99)	(55.03)	(0.11)	(1498/1500)
ASYM-Informed	77.94	69.54	10%	100%
	(41.84)	(27.65)	(0.35)	(750/750)
ASYM-Uninformed	57.81	75.23[a]	−23%	96.4%
	(30.99)	(28.64)	(0.42)	(723/750)

[a]This is the expected value of the equilibrium mixed strategy.
The decimal numbers in parentheses are standard deviations.
The fractions in parentheses are relative frequencies.

interaction is given by

$$bid_{it} = \beta_0 + \beta_1 z_{it} + \beta_2 M_i + \beta_3 \ln(1+t) + \beta_4 M_i \ln(1+t) + \alpha_i + \epsilon_{it}.$$

For the SPRIV treatment, the specification without gender interaction is given by

$$bid_{it} = \beta_0 + \beta_1 z_{it} + \beta_2 M_i + \beta_3 \ln(1+t) + \beta_4 g(z_{it}) + \alpha_i + \epsilon_{it},$$

where $g(z_{it})$ is the nonlinear portion of the SPRIV equilibrium bid function when $z_{it} \in [33, 217)$. Likewise the SPRIV specification with the gender and learning interaction is given by

$$bid_{it} = \beta_0 + \beta_1 z_{it} + \beta_2 M_i + \beta_3 \ln(1+t) + \beta_4 M_i \ln(1+t) + \beta_5 g(z_{it}) + \alpha_i + \epsilon_{it}.$$

When estimating bid functions for uninformed ASYM bidders, the specification without the gender and learning interaction is

$$bid_{it} = \beta_0 + \beta_1 z_{it} + \beta_2 M_i + \beta_3 \ln(1+t) + \alpha_i + \epsilon_{it},$$

where $m(z_{it})$ is the nonlinear portion of the informed ASYM equilibrium bid function when $z_{it} \in [33, 217)$. With the gender and learning interaction the specification is

$$bid_{it} = \beta_0 + \beta_1 z_{it} + \beta_2 M_i + \beta_3 \ln(1+t) + \beta_4 M_i \ln(1+t) + \alpha_i + \epsilon_{it}.$$

These specifications for uninformed ASYM bidders allows us to test whether or not the (unobserved) signal that is observed by the analogous bidder in the SPRIV treatment has any explanatory value. $+\beta_4 m(z_{it})$

When estimating bid functions for informed ASYM bidders, the specification without the gender and learning interaction is

$$bid_{it} = \beta_0 + \beta_1 z_{it} + \beta_2 M_i + \beta_3 \ln(1+t) + \beta_4 m(z_{it}) + \alpha_i + \epsilon_{it},$$

where $m(z_{it})$ is the nonlinear portion of the informed ASYM equilibrium bid function when $z_{it} \in [33, 217)$. With the gender and learning interaction the specification is

$$bid_{it} = \beta_0 + \beta_1 z_{it} + \beta_2 M_i + \beta_3 \ln(1+t) + \beta_4 M_i \ln(1+t) + \beta_5 m(z_{it}) + \alpha_i + \epsilon_{it}.$$

Lastly, we jointly estimate the bid function with and without the gender and learning interaction. Without this interaction the specification is

$$
\begin{aligned}
bid_{it} &= \beta_0 + \beta_1 z_{it} + \beta_2 M_i + \beta_3 \ln(1+t) \\
&\quad + \beta_4 SPRIV_{it} + \beta_5 AINF_{it} + \beta_6 AUNF_{it} \\
&\quad + \beta_7 SPRIV_{it} z_{it} + \beta_8 AINF_{it} z_{it} + \beta_9 AUNF_{it} z_{it} \\
&\quad + \beta_{10} SPRIV_{it} M_i + \beta_{11} AINF_{it} M_i + \beta_{12} AUNF_{it} M_i \\
&\quad + \beta_{13} SPRIV_{it} \ln(1+t) + \beta_{14} AINF_{it} \ln(1+t) + \beta_{15} AUNF_{it} \ln(1+t) \\
&\quad + \beta_{16} SPRIV_{it} g(z_{it}) + \beta_{17} AINF_{it} m(z_{it}) + \alpha_i + \epsilon_{it},
\end{aligned}
$$

where $SPRIV_{it}$ is a dummy variable for the SPRIV bidders, $AINF_{it}$ is a dummy for informed ASYM bidders and $AUNF_{it}$ is a dummy for uninformed ASYM bidders. With the gender and learning interaction, the specification is

$$
\begin{aligned}
bid_{it} &= \beta_0 + \beta_1 z_{it} + \beta_2 M_i + \beta_3 \ln(1+t) + \beta_4 M_i \ln(1+t) \\
&\quad + \beta_5 SPRIV_{it} + \beta_6 AINF_{it} + \beta_7 AUNF_{it} \\
&\quad + \beta_8 SPRIV_{it} z_{it} + \beta_9 AINF_{it} z_{it} + \beta_{10} AUNF_{it} z_{it} \\
&\quad + \beta_{11} SPRIV_{it} M_i + \beta_{12} AINF_{it} M_i + \beta_{13} AUNF_{it} M_i \\
&\quad + \beta_{14} SPRIV_{it} \ln(1+t) + \beta_{15} AINF_{it} \ln(1+t) + \beta_{16} AUNF_{it} \ln(1+t) \\
&\quad + \beta_{17} SPRIV_{it} M_i \ln(1+t) + \beta_{18} AINF_{it} M_i \ln(1+t) + \beta_{19} AUNF_{it} M_i \ln(1+t) \\
&\quad + \beta_{20} SPRIV_{it} g(z_{it}) + \beta_{21} AINF_{it} m(z_{it}) + \alpha_i + \epsilon_{it}.
\end{aligned}
$$

Tables10 contains estimated bid functions without the gender and learning interaction, and Table 11 contains estimated bid functions with the gender and learning interaction.

Notice that, as expected, the (unobserved) signal is not significant in the estimated SPUB and uninformed ASYM bid functions. Conversely, the (observed) signal is highly significant in the estimated bid function for SPRIV bidders. Indeed, the coefficient of the signal is only slightly less than one for SPRIV bidders. Further, the nonlinear part of the bid function ($g(z_{it})$) is not significant. A similar result is

Table 10: Estimated bid functions without gender interaction (standard errors in parentheses)

	SPUB	**SPRIV**	**Informed ASYM**	**Uninformed ASYM**	**Joint**
z_{it}	-0.014	0.989^{***}	0.568^{***}	-0.022	-0.014
	(0.011)	(0.005)	(0.018)	(0.021)	(0.010)
$\ln(1+t)$	4.400^{***}	-0.084	-12.072^{***}	-5.113^{***}	4.400^{***}
	(0.846)	(0.356)	(1.420)	(1.627)	(0.793)
M_i	-0.734	-2.137^{***}	-5.260^{***}	-3.317	-0.734
	(1.211)	(0.474)	(1.915)	(2.384)	(1.135)
$g(z_{it})$	–	0.093	–	–	–
		(0.089)			
$m(z_{it})$	–	–	-0.199	–	–
			(0.208)		
$SPRIV_{it}$	–	–	–	–	-65.359^{***}
					(3.543)
$AINF_{it}$	–	–	–	–	-14.645^{***}
					(4.368)
$AUNF_{it}$	–	–	–	–	12.477^{***}
					(4.346)
$SPRIV_{it}z_{it}$	–	–	–	–	1.000^{***}
					(0.015)
$AINF_{it}z_{it}$	–	–	–	–	0.582^{***}
					(0.018)
$AUNF_{it}z_{it}$	–	–	–	–	-0.008
					(0.018)
$SPRIV_{it}\ln(1+t)$	–	–	–	–	-4.491^{***}
					(1.127)
$AINF_{it}\ln(1+t)$	–	–	–	–	-16.470^{***}
					(1.375)
$AUNF_{it}\ln(1+t)$	–	–	–	–	-9.644^{***}
					(1.376)
$SPRIV_{it}M_i$	–	–	–	–	-1.411
					(1.613)
$AINF_{it}M_i$	–	–	–	–	-4.560^{**}
					(2.004)
$AUNF_{it}M_i$	–	–	–	–	-2.318
					(2.001)
$AINF_{it}m(z_{it})$	–	–	–	–	-0.209
					(0.177)
$SPRIV_{it}g(z_{it})$	–	–	–	–	0.101
					(0.211)
Constant	63.100^{***}	-2.254^{**}	48.496^{***}	75.194^{***}	63.100^{***}
	(2.652)	(1.105)	(4.448)	(5.160)	(2.485)

*Significant at the 0.10 level.
**Significant at the 0.05 level.
***Significant at the 0.01 level.

Table 11: Estimated bid functions with gender interaction (standard errors in parentheses)

	SPUB	**SPRIV**	**Informed ASYM**	**Uninformed ASYM**	**Joint**
z_{it}	-0.014	0.989^{***}	0.568^{***}	-0.022	-0.014
	(0.011)	(0.005)	(0.018)	(0.021)	(0.010)
$\ln(1+t)$	3.350^{***}	-0.288	-12.929^{***}	-6.262^{**}	3.349^{***}
	(1.247)	(0.524)	(2.197)	(2.615)	(1.169)
M_i	-5.797	-3.054^{*}	-8.815	-8.212	-5.797
	(4.580)	(1.791)	(7.218)	(9.044)	(4.292)
$M_i \ln(1+t)$	1.945	0.352	1.371	1.873	1.945
	(1.697)	(0.663)	(2.684)	(3.339)	(1.590)
$g(z_{it})$	–	0.093	–	–	–
		(0.089)			
$m(z_{it})$	–	–	-0.202	–	–
			(0.208)		
$SPRIV_{it}$	–	–	–	–	-67.574^{***}
					(4.847)
$AINF_{it}$	–	–	–	–	-15.148^{**}
					(6.166)
$AUNF_{it}$	–	–	–	–	12.547^{**}
					(6.139)
$SPRIV_{it}z_{it}$	–	–	–	–	1.000^{***}
					(0.015)
$AINF_{it}z_{it}$	–	–	–	–	0.583^{***}
					(0.018)
$AUNF_{it}z_{it}$	–	–	–	–	-0.018
					(0.018)
$SPRIV_{it}\ln(1+t)$	–	–	–	–	-3.641^{**}
					(1.695)
$AINF_{it}\ln(1+t)$	–	–	–	–	-16.287^{***}
					(2.173)
$AUNF_{it}\ln(1+t)$	–	–	–	–	-9.666^{***}
					(2.153)
$SPRIV_{it}M_i$	–	–	–	–	-2.753
					(6.100)
$AINF_{it}M_i$	–	–	–	–	-3.096
					(7.566)
$AUNF_{it}M_i$	–	–	–	–	-1.814
					(7.582)
$SPRIV_{it}M_i\ln(1+t)$	–	–	–	–	-1.600
					(2.260)
$AINF_{it}M_i\ln(1+t)$	–	–	–	–	-0.557
					(2.810)
$AUNF_{it}M_i\ln(1+t)$	–	–	–	–	-0.200
					(2.802)
$AINF_{it}m(z_{it})$	–	–	–	–	-0.211
					(0.177)
$SPRIV_{it}g(z_{it})$	–	–	–	–	0.100
					(0.211)
Constant	65.839^{***}	-1.719	50.703^{***}	78.207^{***}	65.839^{***}
	(3.569)	(1.495)	(6.199)	(7.446)	(3.344)

*Significant at the 0.10 level.
**Significant at the 0.05 level.
***Significant at the 0.01 level.

found for informed ASYM bidders; the coefficient of the signal is positive and highly significant, and the nonlinear portion of the bid function $(m(z_{it}))$ in not significant. The magnitude of the coefficient for informed ASYM bidders is less than for SPRIV bidders; while bidders are not bidding according to the equilibrium bid functions, informed ASYM bidders do reduce their bids relative to the signal to account for uninformed ASYM bidders' bidding below 125, on average.

Interestingly, the results regarding learning differ substantially across treatments. In SPUB auction, participants are learning to bid closer to equilibrium as they gain experience. Since they are, on average, underbidding relative to the Nash equilibrium, this means that they are increasing their bid as they gain experience. In the ASYM treatment, both informed and uninformed bidders are reducing their bids as they gain experience. In the case of informed ASYM bidders this corresponds to bidding closer to the Nash equilibrium, but for uninformed ASYM bidders this means that as they gain experience they increase how much they underbid relative to the Nash equilibrium. Given that uninformed ASYM bidders are losing money on average, this is not surprising. In the case of SPRIV bidders, learning is not significant. This is in contrast to previous studies, which typically find that bidders in this information structure learn to bid closer to equilibrium as they gain experience.[23]

We find that when bidder's hold private information there is a significant gender difference, but that when they do not hold private information, this difference is not significant. Namely, males bid less than females when they hold private information. We find that the interaction between gender and learning is not significant for any type of bidders. Casari et al. (2007) examine gender differences in an SPRIV information structure and find that males bid less than females, but that females learn faster than males. Since we do not find evidence of learning in SPIRIV auctions, the fact that there is not a significant gender difference in learning is not surprising.

Notice that the dummy variables for types of bidders are all highly significant

[23] See e.g., Casari *et al.* (2007).

when the bid functions are estimated jointly. Also, gender differences are largely insignificant between types of bidders.

5 Conclusion

We experimentally investigate the role of asymmetric information in first-price common-value auctions by varying the information available to bidders before placing their bids. We compare three information structures. In the first, no bidders hold any private information regarding the uncertain value of the good (SPUB). In the second, both bidders privately observe noisy signals regarding the value of the good (SPRIV). In the third, only one bidder observes a noisy signal; the other bidder does not hold private information (ASYM).

The most surprising result is that bidders who do not hold private information underbid relative to the Nash predictions, while bidders who hold private information overbid relative to the Nash predictions. Indeed the underbidding by uninformed bidders is dramatic. Bidders in the SPUB treatment bid 42% less than predicted by theory. Overbidding by informed bidders is a widely observed phenomenon in laboratory experiments, but the behavior of uninformed bidders has not been studied previous to this paper. Our results suggest that the overbidding typically observed may be an artifact of the private signal that is typically provided to subjects. As such, our result offer support for the hypothesis that "a little knowledge is a dangerous thing." That is, people who have a little information become overconfident.

Our results have significant implications regarding the widespread observation of the winner's curse in common-value auctions. In particular, we find that the winner's curse is almost entirely eliminated when bidders are not given private information. In addition, the winner's curse is largely eliminated when only one of the bidder's holds private information. This is despite the fact that the informed bidder overbids.

The observed bidding behavior also has significant effects on bidder payoffs. In particular, when neither bidder holds private information, bidders earn a substantial payoff, on average. When bidders both hold private information, bidder payoffs are positive, but quite small as a result of informed overbidding relative to Nash predictions. Note that informed ASYM bidders earn, on average, more than predicted despite overbidding relative to the Nash predictions.

Additionally, the observed bidding behavior has significant effects on the revenue ranking of the three information structures studied. Namely, the SPUB auction, which is predicted to have the highest revenue, is observed to have the lowest revenue because the uninformed bidders underbid. However, when both bidders hold private information, revenue is higher than when only one bidder holds private information, as predicted.

6 Appendix A

6.1 Preliminaries

The common value of the available good, x, is a realization of a random variable X with a uniform distribution with support $[\underline{x}, \overline{x}]$. The realization of this value, x, is not observed by the two bidders before placing their bids. However, the distribution from which it is drawn is common knowledge.

In a SPRIV auction, bidder $i \in \{1,2\}$ observes an estimate of the realized value of the good. Each estimate is the realization of X plus an error term X_i. This error term is $U(-\delta, \delta)$, and is independent of X and X_{-i}. That is, each estimate is a realization of $Z_i = X + X_i$.(We denote the distribution function of Z_i as F_{Z_i}). Notice that Z_i is independent of Z_{-i}, conditional on the realization of X. Throughout, we use f_A to denote the density function of the random variable A. A joint density function will be denoted as $f(\mathbf{x})$ where the vector $\mathbf{x}$ indicates the random variables for which $f(\mathbf{x})$ pertains.

Since Z_i is simply the sum of independent random variables, it's density function is easily calculated. To do so, we use the following, well known, formula:

$$\begin{aligned} f_{Z_i}(z_i) &= \int_{-\infty}^{\infty} f_X(z_i - x_i) f_{X_i}(x_i) \, dx_i \\ &= \int_{-\delta}^{\delta} f_X(z_i - x_i) f_{Xi}(x_i) \, dx_i \end{aligned}$$

This becomes a piecewise linear function:

$$f_{Z_i}(z_i) = \begin{cases} \int\limits_{-\delta}^{z_i-\underline{x}} \left(\frac{1}{2\delta(\overline{x}-\underline{x})}\right) dx_i = \frac{z_i+\delta-\underline{x}}{2\delta(\overline{x}-\underline{x})} & \text{if} \quad z_i \in [\underline{x}-\delta, \underline{x}+\delta) \\ \int\limits_{-\delta}^{\delta} \left(\frac{1}{2\delta(\overline{x}-\underline{x})}\right) dx_i = \frac{1}{(\overline{x}-\underline{x})} & \text{if} \quad z_i \in [\underline{x}+\delta, \overline{x}-\delta) \\ \int\limits_{z_i-\overline{x}}^{\delta} \left(\frac{1}{2\delta(\overline{x}-\underline{x})}\right) dx_i = \frac{\delta-z_i+\overline{x}}{2\delta(\overline{x}-\underline{x})} & \text{if} \quad z_i \in [\overline{x}-\delta, \overline{x}+\delta]. \end{cases}.$$

The distribution function of Z_i is

$$F_{Z_i}(c) = \begin{cases} \frac{(c-\underline{x}+\delta)^2}{4\delta(\overline{x}-\underline{x})} & \text{if} \quad c \in [\underline{x}-\delta, \underline{x}+\delta) \\ \frac{c-\underline{x}}{(\overline{x}-\underline{x})} & \text{if} \quad c \in [\underline{x}+\delta, \overline{x}-\delta) \\ \frac{\overline{x}-\underline{x}-\delta}{(\overline{x}-\underline{x})} + \frac{(\overline{x}+3\delta-c)(c-\overline{x}+\delta)}{4\delta(\overline{x}-\underline{x})} & \text{if} \quad c \in [\overline{x}-\delta, \overline{x}+\delta]. \end{cases}.$$

In a SPRIV auction, both bidders receive a signal. The joint density function of X, Z_1, and Z_2 is given by:

$$f(x, z_1, z_2) = \frac{1}{4\delta^2(\overline{x}-\underline{x})}.$$

In an ASYM auction, only one of the bidders observes a signal. Thus the joint distribution of X and Z_i is of interest. Integrating Z_j out of $f(x, z_1, z_2)$ yields:

$$f(x, z_i) = \int_{x-\delta}^{x+\delta} \frac{1}{4\delta^2(\overline{x}-\underline{x})} dz_j = \frac{1}{2\delta(\overline{x}-\underline{x})}.$$

The density function of x given the realized value of a bidders signal is:

$$f_X(x \mid z_i) = \begin{cases} \frac{1}{z_i+\delta-\underline{x}} & \text{if} \quad z_i \in [\underline{x}-\delta, \underline{x}+\delta) \\ \frac{1}{2\delta} & \text{if} \quad z_i \in [\underline{x}+\delta, \overline{x}-\delta) \\ \frac{1}{\delta-z_i+\overline{x}} & \text{if} \quad z_i \in [\overline{x}-\delta, \overline{x}+\delta]. \end{cases}$$

The joint density function of X and Z_j given that $Z_i = z_i$ is:

$$f(x, z_j \mid z_i) = \begin{cases} \frac{1}{2\delta(z_i+\delta-\underline{x})} & \text{if} \quad z_i \in [\underline{x}-\delta, \underline{x}+\delta) \\ \frac{1}{4\delta^2} & \text{if} \quad z_i \in [\underline{x}+\delta, \overline{x}-\delta) \\ \frac{1}{2\delta(\delta-z_i+\overline{x})} & \text{if} \quad z_i \in [\overline{x}-\delta, \overline{x}+\delta]. \end{cases}$$

The Prob$(z_i > z_j)$ is

$$F_{Z_j|Z_i}(z_j \mid z_i) = \begin{cases} \int_{\underline{x}-\delta}^{z_i} \frac{z_j+\delta-\underline{x}}{2\delta(z_i+\delta-\underline{x})} dz_j = \frac{z_i-\underline{x}+\delta}{4\delta} & \text{if} \quad z_i \in [\underline{x}-\delta, \underline{x}+\delta) \\ \int_{z_i-2\delta}^{z_i} \frac{z_j-z_i+2\delta}{4\delta^2} dz_j = \frac{1}{2} & \text{if} \quad z_i \in [\underline{x}+\delta, \overline{x}-\delta) \\ \int_{z_i-2\delta}^{\overline{x}-\delta} \frac{z_j-z_i+2\delta}{2\delta(\overline{x}-z_i+\delta)} dz_j + \int_{\overline{x}-\delta}^{z_i} \frac{1}{2\delta} dz_j = \frac{z_i-\overline{x}+3\delta}{4\delta} & \text{if} \quad z_i \in [\overline{x}-\delta, \overline{x}+\delta]. \end{cases}$$

6.2 Symmetric Information With Private Signals

The derivations to find the symmetric Nash equilibrium bid function can be found in Kagel and Levin (2002) and Kagel and Richards (2001). Assume that bidder $j \neq i$ bids according to the symmetric Nash equilibrium bid function, $\gamma(z_j)$. Consider bidder i who observes a signal z_i but bids as though he/she observed y. If $a(z_i) =$

$\max\left(\underline{x}, z_i - \delta\right)$ and $b\left(z_i\right) = \min\left(\overline{x}, z_i + \delta\right)$, then the expected payoff of such a bidder is as follows:

$$\begin{aligned}
\Pi\left(z_i, y\right) &= \int_{a(z_i)}^{b(z_i)} \left(x - \gamma\left(y\right)\right) F\left(y \mid x\right) f_X\left(x \mid z_i\right) dx \\
&= \int_{a(z_i)}^{b(z_i)} \left(x - \gamma\left(y\right)\right) \left(\frac{y - x + \delta}{2\delta}\right) \left(\frac{1}{b\left(z_i\right) - a\left(z_i\right)}\right) dx.
\end{aligned}$$

The revelation principle tells us that:

$$\frac{d\Pi\left(z_i, y\right)}{dy} \mid_{y=z_i} = 0.$$

Using the initial condition $\gamma\left(\underline{x} - \delta\right) = \underline{x}$ and assuming continuity of the equilibrium bid function yields the solution:

$$\gamma\left(z_i\right) = \begin{cases}
\underline{x} + \frac{1}{3}\left(z_i - \underline{x} + \delta\right) & \text{if} \quad z_i \in \left[\underline{x} - \delta, \underline{x} + \delta\right) \\
z_i - \delta + \frac{2\delta}{3} \exp\left[\frac{1}{\delta}\left(\underline{x} + \delta - z_i\right)\right] & \text{if} \quad z_i \in \left[\underline{x} + \delta, \overline{x} - \delta\right) \\
\frac{2\overline{x}^3 + z_i^3 + 3\delta z_i^2 - 9\delta^2 z_i + 12\delta\overline{x}(z_i + 3\delta) - 3\overline{x}^2(z_i + 5\delta) + \delta^3\left(8\exp\left[\frac{2\delta + \underline{x} - \overline{x}}{\delta}\right] - 35\right)}{3(z_i - \overline{x} + 3\delta)^2} & \text{if} \quad z_i \in \left[\overline{x} - \delta, \overline{x} + \delta\right].
\end{cases}$$

The expected payoff of bidder i when she observes a private signal z_i is

$$\begin{aligned}
\Pi_i^{SPRIV}\left(z_i\right) &= \int_{a(z_i)}^{b(z_i)} \left(x - \gamma\left(z_i\right)\right) F\left(z_i \mid x\right) f_X\left(x \mid z_i\right) dx \\
&= \int_{a(z_i)}^{b(z_i)} \left(x - \gamma\left(z_i\right)\right) \left(\frac{z_i - x + \delta}{2\delta}\right) \left(\frac{1}{b\left(z_i\right) - a\left(z_i\right)}\right) dx.
\end{aligned}$$

This simplifies to

$$\Pi_i^{SPRIV}(z_i) = \begin{cases} 0 & \text{if} \quad z_i \in [\underline{x}-\delta, \underline{x}+\delta) \\ \frac{\delta}{3}\left(1-\exp\left(\frac{\underline{x}-z_i+\delta}{\delta}\right)\right) & \text{if} \quad z_i \in [\underline{x}+\delta, \overline{x}-\delta) \\ \frac{\overline{x}^2+z_i^2+4z_i\delta+\delta^2\left(5-2\exp\left(2-\frac{(\overline{x}-\underline{x})}{\delta}\right)-2\overline{x}(z_i+2\delta)\right)}{3(z_i-\overline{x}+3\delta)} & \text{if} \quad z_i \in [\overline{x}-\delta, \overline{x}+\delta]. \end{cases}$$

Bidder i's ex ante expected payoff is obtained by integrating over z_i. This yields

$$\begin{aligned} E\left(\Pi_i^{SPRIV}\right) &= \int_{\underline{x}-\delta}^{\overline{x}+\delta} \Pi_i^{SPRIV}(z_i) f_{Z_i}(z_i) dz_i \\ &= \frac{\delta\left(3\underline{x}-3\overline{x}+\delta\left(13-12\ln(2)\right)\right)+3\delta^2\exp\left(\frac{2\delta+\underline{x}-\overline{x}}{\delta}\right)\left(\ln(16)-3\right)}{9\left(\underline{x}-\overline{x}\right)}. \end{aligned}$$

For the parameter's employed in our design, $E\left(\Pi_i^{SPRIV}\right) = 2.50019$. Since the ex ante expected revenue in an auction is the expected value of the good, minus the ex ante expected payoff's of the bidders, the ex ante expected revenue of a SPRIV auction, $E\left(R^{SPRIV}\right)$, is

$$\begin{aligned} E\left(R^{SPRIV}\right) &= \left(\frac{\overline{x}+\underline{x}}{2}\right) - \\ &\quad \frac{2\delta\left(3\underline{x}-3\overline{x}+\delta\left(13-12\ln(2)\right)\right)+6\delta^2\exp\left(\frac{2\delta+\underline{x}-\overline{x}}{\delta}\right)\left(\ln(16)-3\right)}{9\left(\underline{x}-\overline{x}\right)}. \end{aligned}$$

For the parameters in our design, this is $E\left(R^{SPRIV}\right) = 119.99962$.

6.2.1 Winner's Curse in SPRIV Auctions

In a SPRIV auction a bidder is said to fall victim to the winner's curse if she bids more than the expected value of the good conditional on winning the auction, which defines a break-even bidding strategy. If all bidder's bid according to a monotonically increasing bid function, the bidder with the highest signal wins the auction. Therefore, if bidders are bidding according to monotonically increasing bid function, bidders are said to fall victim to the winner's curse if they bid more that the expected value of the good conditional on having the largest signal. If bidder's do not use their signal as an order statistic for the value of the good, they will overestimate it, and will have negative expected profits upon winning the auction. In our design, if bidder i observes a signal z_i and bids more than $E(X \mid Z_i = z_i > z_j)$, then she is a victim of the winner's curse. When $z_i \in [\underline{x} - \delta, \underline{x} + \delta)$,

$$\begin{aligned} E(X \mid Z_i = z_i > z_j) &= \frac{1}{F_{Z_j|Z_i}(z_i \mid z_i)} \int_{\underline{x}-\delta}^{z_i} \int_{\underline{x}}^{z_j+\delta} x f_X(x, z_j \mid z_i)\, dx dz_j \\ &= \left(\frac{4\delta}{z_i - \underline{x} + \delta}\right) \int_{\underline{x}-\delta}^{z_i} \int_{\underline{x}}^{z_j+\delta} x \frac{1}{2\delta(z_i + \delta - \underline{x})} dx dz_j \\ &= \frac{1}{3}(z_i + 2\underline{x} + \delta). \end{aligned}$$

When $z_i \in [\underline{x} + \delta, \overline{x} - \delta)$,

$$\begin{aligned} E(X \mid Z_i = z_i > z_j) &= \frac{1}{F_{Z_j|Z_i}(z_i \mid z_i)} \int_{z_i-2\delta}^{z_i} \int_{z_i-\delta}^{z_j+\delta} x f_X(x, z_j \mid z_i)\, dx dz_j \\ &= 2 \int_{\underline{x}-\delta}^{z_i} \int_{\underline{x}}^{z_j+\delta} x \frac{1}{4\delta^2} dx dz_j \\ &= z_i - \frac{\delta}{3}. \end{aligned}$$

When $z_i \in [\overline{x} - \delta, \overline{x} + \delta]$

$$\begin{aligned} E(X \mid Z_i = z_i > z_j) &= \frac{1}{F_{Z_j|Z_i}(z_i \mid z_i)} \int_{z_i - 2\delta}^{z_i} \int_{z_i - \delta}^{z_j + \delta} x f_X(x, z_j \mid z_i)\, dx dz_j \\ &= \left(\frac{4\delta}{z_i - \overline{x} + 3\delta} \right) \int_{z_i - 2\delta}^{\overline{x} - \delta} \int_{z_i - \delta}^{z_j + \delta} x \frac{1}{2\delta(\overline{x} + \delta - z_i)} dx dz_j + \\ &\quad \left(\frac{4\delta}{z_i - \overline{x} + 3\delta} \right) \int_{\overline{x} - \delta}^{z_i} \int_{z_i - \delta}^{\overline{x}} x \frac{1}{2\delta(\overline{x} + \delta - z_i)} dx dz_j \\ &= \frac{(z_i + 5\delta)(z_i - \delta) + \overline{x}(z_i + 5\delta) - 2\overline{x}^2}{3(z_i - \overline{x} + 3\delta)}. \end{aligned}$$

That is,

$$E(X \mid Z_i = z_i > z_j) = \begin{cases} \frac{1}{3}(z_i + 2\underline{x} + \delta) & \text{if} \quad z_i \in [\underline{x} - \delta, \underline{x} + \delta) \\ z_i - \frac{\delta}{3} & \text{if} \quad z_i \in [\underline{x} + \delta, \overline{x} - \delta) \\ \frac{(z_i + 5\delta)(z_i - \delta) + \overline{x}(z_i + 5\delta) - 2\overline{x}^2}{3(z_i - \overline{x} + 3\delta)} & \text{if} \quad z_i \in [\overline{x} - \delta, \overline{x} + \delta]. \end{cases}$$

This is the threshold that defines the winner's curse in a SPRIV auction.

6.3 Asymmetric Information

Engelbrecht-Wiggans et. al. (1983) provides the unique equilibrium of this game. We denote the informed bidder as bidder I. In this equilibrium, when the informed bidder observes z_I she bids according to the function

$$\begin{aligned} \beta(z_I) &= E(E(X \mid Z_I) \mid Z_I \leq z_I) \\ &= \frac{1}{F_{Z_I}(z_I)} \int_{\underline{x} - \delta}^{z_I} E(X \mid Z_I = s) f_{Z_I}(s)\, ds. \end{aligned}$$

When $z_I \in [\underline{x}-\delta, \underline{x}+\delta)$, this is

$$\begin{aligned}
\beta(z_I) &= \frac{4\delta(\overline{x}-\underline{x})}{(c-\underline{x}+\delta)^2}\int_{\underline{x}-\delta}^{z_I}\left(\frac{\underline{x}+s+\delta}{2}\right)\left(\frac{s+\delta-\underline{x}}{2\delta(\overline{x}-\underline{x})}\right)ds \\
&= \frac{2\underline{x}+z_I+\delta}{3}.
\end{aligned}$$

When $z_I \in [\underline{x}+\delta, \overline{x}-\delta)$, this is

$$\begin{aligned}
\beta(z_I) &= \frac{(\overline{x}-\underline{x})}{z_I-\underline{x}}\left(\int_{\underline{x}-\delta}^{\underline{x}+\delta}\left(\frac{\underline{x}+s+\delta}{2}\right)\left(\frac{s+\delta-\underline{x}}{2\delta(\overline{x}-\underline{x})}\right)ds + \int_{\underline{x}+\delta}^{z_I} s\left(\frac{1}{(\overline{x}-\underline{x})}\right)ds\right) \\
&= \frac{z_I+\underline{x}}{2}+\frac{\delta^2}{6(z_I-\underline{x})}.
\end{aligned}$$

When $z_I \in [\overline{x}-\delta, \overline{x}+\delta]$ this is

$$\begin{aligned}
\beta(z_I) &= \left(\frac{4\delta(\overline{x}-\underline{x})}{4\delta(\overline{x}-\underline{x}-\delta)+(\overline{x}+3\delta-z_I)(z_I-\overline{x}+\delta)}\right)\int_{\underline{x}-\delta}^{\underline{x}+\delta}\left(\frac{\underline{x}+s+\delta}{2}\right)\left(\frac{s+\delta-\underline{x}}{2\delta(\overline{x}-\underline{x})}\right)ds + \\
&\quad \left(\frac{4\delta(\overline{x}-\underline{x})}{4\delta(\overline{x}-\underline{x}-\delta)+(\overline{x}+3\delta-z_I)(z_I-\overline{x}+\delta)}\right)\int_{\underline{x}+\delta}^{\overline{x}-\delta} s\left(\frac{1}{(\overline{x}-\underline{x})}\right)ds + \\
&\quad \left(\frac{4\delta(\overline{x}-\underline{x})}{4\delta(\overline{x}-\underline{x}-\delta)+(\overline{x}+3\delta-z_I)(z_I-\overline{x}+\delta)}\right)\int_{\overline{x}-\delta}^{z_I}\left(\frac{\overline{x}+s-\delta}{2}\right)\left(\frac{\overline{x}+\delta-s}{2\delta(\overline{x}-\underline{x})}\right)ds. \\
&= \frac{2\overline{x}^3+(z_I-\delta)^3+6\underline{x}^2\delta-3\overline{x}^2(z_I+\delta)}{3\left(\overline{x}^2+(z_I-\delta)^2+4\underline{x}\delta-2\overline{x}(z_I+\delta)\right)}.
\end{aligned}$$

That is, the equilibrium bid function for the informed bidder in an ASYM auction is

$$\beta(z_I) = \begin{cases} \frac{2\underline{x}+z_I+\delta}{3} & \text{if} \quad z_I \in [\underline{x}-\delta, \underline{x}+\delta) \\ \frac{z_I+\underline{x}}{2}+\frac{\delta^2}{6(z_I-\underline{x})} & \text{if} \quad z_I \in [\underline{x}+\delta, \overline{x}-\delta) \\ \frac{2\overline{x}^3+(z_I-\delta)^3+6\underline{x}^2\delta-3\overline{x}^2(z_I+\delta)}{3\left(\overline{x}^2+(z_I-\delta)^2+4\underline{x}\delta-2\overline{x}(z_I+\delta)\right)} & \text{if} \quad z_I \in [\overline{x}-\delta, \overline{x}+\delta]. \end{cases}$$

In equilibrium, the uninformed bidder will mix on the interval $[\underline{x}, E(X)]$ according to the following distribution function:

$$\begin{aligned} Q(b) &= \text{Prob}\left[\beta(Z_I) \leq b\right] \\ &= F_{Z_I}\left(\beta^{-1}(b)\right). \end{aligned}$$

So, the uninformed bidder will mix according using this distribution function:

$$Q(b) = \begin{cases} \frac{\left(\beta^{-1}(b)-\underline{x}+\delta\right)^2}{4\delta(\overline{x}-\underline{x})} & \text{if} \quad b \in \left[\beta(\underline{x}-\delta), \beta(\underline{x}+\delta)\right) \\ \frac{\beta^{-1}(b)-\underline{x}}{(\overline{x}-\underline{x})} & \text{if} \quad b \in \left[\beta(\underline{x}+\delta), \beta(\overline{x}-\delta)\right) \\ \frac{4\delta(\overline{x}-\underline{x}-\delta)+\left(\overline{x}+3\delta-\beta^{-1}(b)\right)\left(\beta^{-1}(b)-\overline{x}+\delta\right)}{4\delta(\overline{x}-\underline{x})} & \text{if} \quad b \in \left[\beta(\overline{x}-\delta), \beta(\overline{x}+\delta)\right]. \end{cases}$$

Engelbrecht-Wiggans et al (1983) shows that, in equilibrium, the uninformed bidder obtains an expected payoff of zero for any bid in the support of $Q(b)$. Let $q(z_I) := E(X \mid z_I)$. Since $q(z_I)$ is monotonically increasing in z_I, the distribution function of this random variable is just $F_{Z_I}(q^{-1}(\cdot))$, where $q^{-1}(\cdot)$ is the inverse of $q(\cdot)$. Engelbrecht-Wiggans et al (1983) shows that when the informed bidder observes z_I his/her expected payoff is

$$\Pi_I^{ASYM}(z_I) = \int_{\underline{x}}^{q(z_I)} F_{Z_I}\left(q^{-1}(s)\right) ds.$$

When $z_I \in [\underline{x}-\delta, \underline{x}+\delta)$ this is

$$\Pi_I^{ASYM}(z_I) = \int_{\underline{x}}^{q(z_I)} \frac{\left(q^{-1}(s)-\underline{x}+\delta\right)^2}{4\delta(\overline{x}-\underline{x})} ds = \frac{\left(z_I-\underline{x}+\delta\right)^3}{12\delta(\overline{x}-\underline{x})}.$$

When $z_I \in [\underline{x}+\delta, \overline{x}-\delta)$ this is

$$\begin{aligned} \Pi_I^{ASYM}(z_I) &= \int_{\underline{x}-\delta}^{\underline{x}+\delta} \frac{\left(q^{-1}(s)-\underline{x}+\delta\right)^2}{4\delta\left(\overline{x}-\underline{x}\right)} ds + \int_{\underline{x}+\delta}^{q(z_I)} \frac{q^{-1}(s)-\underline{x}}{\left(\overline{x}-\underline{x}\right)} ds \\ &= \frac{3\left(\underline{x}-z_I\right)^3-\delta^2}{6\left(\overline{x}-\underline{x}\right)}. \end{aligned}$$

If $z_I \in [\overline{x}-\delta, \overline{x}+\delta]$ this is

$$\begin{aligned} \Pi_I^{ASYM}(z_I) &= \int_{\underline{x}-\delta}^{\underline{x}+\delta} \frac{\left(q^{-1}(s)-\underline{x}+\delta\right)^2}{4\delta\left(\overline{x}-\underline{x}\right)} ds + \int_{\underline{x}+\delta}^{\overline{x}-\delta} \frac{q^{-1}(s)-\underline{x}}{\left(\overline{x}-\underline{x}\right)} ds \\ &\quad + \int_{\overline{x}-\delta}^{q(z_I)} \frac{4\delta\left(\overline{x}-\underline{x}-\delta\right)+\left(\overline{x}+3\delta-q^{-1}(s)\right)\left(q^{-1}(s)-\overline{x}+\delta\right)}{4\delta\left(\overline{x}-\underline{x}\right)} ds \\ &= \frac{\left(\overline{x}-z_I+\delta\right)^3}{24\delta\left(\overline{x}-\underline{x}\right)} + \frac{\left(\overline{x}+z_I-\delta\right)}{2} - \frac{\left(\overline{x}-\underline{x}\right)}{2}. \end{aligned}$$

That is, the expected payoff of an informed bidder is

$$\Pi_I^{ASYM}(z_I) = \begin{cases} \frac{\left(z_I-\underline{x}+\delta\right)^3}{12\delta\left(\overline{x}-\underline{x}\right)} & \text{if} \quad z_I \in [\underline{x}-\delta, \underline{x}+\delta) \\ \frac{3\left(\underline{x}-z_I\right)^3-\delta^2}{6\left(\overline{x}-\underline{x}\right)} & \text{if} \quad z_I \in [\underline{x}+\delta, \overline{x}-\delta) \\ \frac{\left(\overline{x}-z_I+\delta\right)^3}{24\delta\left(\overline{x}-\underline{x}\right)} + \frac{\left(\overline{x}+z_I-\delta\right)}{2} - \frac{\left(\overline{x}-\underline{x}\right)}{2} & \text{if} \quad z_I \in [\overline{x}-\delta, \overline{x}+\delta]. \end{cases}$$

The ex ante expected payoff of the informed bidder can be found by integrating over z_1. This yields

$$\begin{aligned} E\left(\Pi_I^{ASYM}\right) &= \int_{\underline{x}-\delta}^{\overline{x}+\delta} \Pi_I^{ASYM}(z_I)\, dz_I \\ &= \frac{5\left(\overline{x}-\underline{x}\right)^3-10\delta^2\left(\overline{x}-\underline{x}\right)+8\delta^3}{30\left(\overline{x}-\underline{x}\right)^2}. \end{aligned}$$

For the parameters employed in our design, $E\left(\Pi_I^{ASYM}\right) = 33.2301$. The ex ante expected revenue for the seller is found by subtracting the ex ante expected payoff of the informed bidder from the expected value of X. This yields

$$E\left(R^{ASYM}\right)=\left(\frac{\overline{x}+\underline{x}}{2}\right)-\frac{5\left(\overline{x}-\underline{x}\right)^{3}-10\delta^{2}\left(\overline{x}-\underline{x}\right)+8\delta^{3}}{30\left(\overline{x}-\underline{x}\right)^{2}}.$$

For the parameter values used in our design $E\left(R^{ASYM}\right)=91.7699$.

6.3.1 Winner's Curse in ASYM Auctions

Since the uninformed bidder has an expected payoff of zero for any bid $b\in\left[\underline{x},E\left(X\right)\right]$, $E\left(X\right)$ is a break-even strategy for uninformed ASYM bidders. Bidding above $E\left(X\right)$ ensures negative expected profit upon winning, while bidding below $E\left(X\right)$ yields an expected payoff of zero conditional on winning the auction. That is, if an uninformed bidder bids above $E\left(X\right)$, she is said to fall victim to the winner's curse.

The expected value of the good conditional on z_I is the same as the expected value of the good conditional on z_I *and* having won the auction. Winning the auction does not provide the informed bidder additional information regarding x. Therefore, the break-even bidding strategy for an informed ASYM bidder is to bid:

$$E\left(X\mid z_I\right)=\begin{cases}\frac{z_I+\delta+\underline{x}}{2} & \text{if}\quad z_I\in\left[\underline{x}-\delta,\underline{x}+\delta\right)\\ z_I & \text{if}\quad z_I\in\left[\underline{x}+\delta,\overline{x}-\delta\right)\\ \frac{z_I-\delta+\overline{x}}{2} & \text{if}\quad z_I\in\left[\overline{x}-\delta,\overline{x}+\delta\right].\end{cases}$$

So, if an informed bidder bidder bids above $E\left(X\mid z_I\right)$, she is said to fall victim to the winner's curse.

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7 Appendix B

Instructions for the ASYM treatment are found below.

Introduction

Welcome. This experiment is about decision making in markets. The following instructions describe the markets you will be in and the rules that you will face. The decisions you make during this experiment will determine how much money you earn. If you make good decisions, you can earn a substantial amount of money. You will be paid in cash privately at the end of our experiment.

It is important that you remain silent and do not look at other people's work. If you have any questions, or need assistance of any kind, please raise your hand and an experimenter will come to you. If you talk, laugh, exclaim out loud, etc., you will be asked to leave and you will not be paid. We expect and appreciate your cooperation.

We will go over these instructions with you. After we have read the instructions, there will be time to ask clarifying questions. When we are done going through the instructions, each of you will have to answer a few brief questions to ensure everyone understands.

Overview

Our experiment will consist of 30 rounds. In each of these rounds, you will be randomly paired with another participant in today's experiment. Both of you will be buyers in a market. In each market, there will be a single unit of an indivisible good for sale. As a buyer, your task is to submit a bid for the purchase of the good. You will receive earnings based on the outcome of the market. This process will be repeated until all 30 rounds have been completed.

Determination of Your Earnings

Each participant will receive a show-up fee of \$5. In addition, each participant in this experiment will start with a balance of $\$3,200$ "experimental dollars" (EDs). EDs will be traded in for cash at the end of the experiment at a rate of $\$160ED = \$1$. Your starting balance can increase or decrease depending on your payoffs in each round. That is, if you have a negative payoff in a round, this loss will be deducted from your balance. If you earn a positive payoff, this is added to your balance. You are permitted to bid more than your remaining balance. However, if after a round is completed your balance is less than or equal to zero, you will not be able to participate in any future rounds.

In each round, you and the other buyer in the market will submit a bid. The higher bid will have to be paid, and the buyer with the higher bid will receive the good. The buyer who submits the lower bid does not get the good, but does not pay his/her bid. That is, for each market, the buyer who submits the higher bid will receive:

$$\text{(Value of the good)} - \text{(Own bid)}$$

The person who submits the lower bid will receive:

$$0$$

If both buyers bid the same amount, then the winner is determined randomly, with both buyers having equal probability of receiving the good. You can think of this as a flip of a fair coin, which determines the winner in the event of a tie. Only the bidder who receives the good must pay his/her bid.

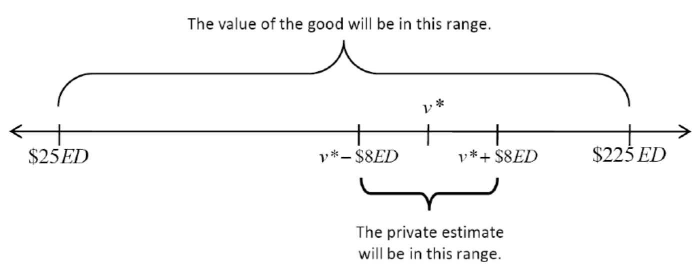
Notice that the buyer who submits the highest bid can end up with a negative payoff, if he/she bids more than the good is worth. No buyer is permitted to submit a bid that is lower than zero.

In each round, the value of the good, which we will denote as v^*, will not be known to the buyers. The value of this good will be between $\$25ED$ and $\$225ED$.

Any value between $\$25ED$ and $\$225ED$ is equally likely to be chosen as v^*. The value of the good in any given round is independent of the value in any other round. That is, the value of the good in one round will not have *any* effect on the value of the good in a different round.

Private Information

In each market, one of the two buyers will be randomly chosen to receive some private information about the value of the good (you can think of this as flipping a coin to determine which of the buyers will receive this information, where the probability of the coin landing on each side is 50%). The person who receives the private information will be given an estimate of the value of the good. The estimate will be a randomly chosen number that is within $\$8ED$ above or below the real value of v^* (see the illustration below). Any number between $v^* - \$8ED$, and $v^* + \$8ED$ is equally likely to be chosen as the estimate. For example, if you receive an estimate of $\$125ED$, then you know that v^* is between $\$117ED$ and $\$133ED$, inclusive. It is possible for the estimate to be a value below $\$25ED$ or above $\$225ED$, but the real value of v^* will always be between $\$25ED$ and $\$225ED$.



Rounds

As mentioned before, there will be 30 rounds in this experiment. In each round there will be several markets going on simultaneously, with two buyers in each market. After each round you will be randomly paired with another participant in today's experiment. This random assignment is done *every round* so that two buyers will probably not be in the same market together for two consecutive rounds. Further, this pairing is anonymous. That is, if you are a buyer in a given market, you do not know which of the other participants in the experiment is the other buyer in that market. Remember that these different markets and rounds are independent from all others, and from one another. The bids and the value of the good and the estimate in one market or round do not have any effect on other markets or rounds. Markets and rounds operate independently.

Summary

1. Each participant has a starting balance of $\$3,200ED$.

2. In every round, each participant will be a buyer in one market. Two participants are randomly assigned to a market in each round.

3. The value of the good, v^*, is unknown. It is known that it is somewhere between $\$25ED$ and $\$225ED$. Every value between $\$25ED$ and $\$225ED$ is equally likely to be v^*.

4. One buyer in a market is randomly chosen to receive an estimate of v^*. A buyer's estimate is not observed by the other buyer in the market. These estimates are randomly and independently drawn from the interval between $v^* - \$8ED$ and $v^* + \$8ED$, inclusive. Any number from this interval is equally likely to be chosen as the estimate.

5. In each market the high bidder gets $v^* -$ (Own bid), and the low bidder gets 0. This payoff is added to the balance of each bidder (a bidder's balance will go down if the value is negative, up if this value is positive, and remain unchanged if this value is zero).

6. Every participant will receive the show-up fee of \$5. Additionally, each participant will receive his/her balance at the end of all 30 rounds, based on the $\$3,200ED$ beginning balance and earnings in each market.

7. If a participant's balance should become negative at any point during this experiment, he/she will not be permitted to participate in future rounds.

If you have any questions, raise your hand and one of us will come help you. Please do not ask any questions out loud.

Questions

Before we begin the experiment, we would like you to answer a few questions that are meant to review the rules of today's experiment. Please raise your hand once you are done, and an experimenter will attend to you.

1. How many buyers are in each market? ____________
2. Who pays their bid in each market, the high bidder, the low bidder, or both? ____________
3. Each estimate must be within what range of v^*? ____________
4. Are you allowed to bid more than your current balance? ____________
5. For each market, how many buyers get to see an estimate of v^*? ____________
6. If the highest bid in a market is \$152.10ED, and the value of the good is revealed to be \$200.90ED, what is the winner's payoff for that market? ____________
7. What would the earnings from question six have been if the value of the good had been \$25.90ED? ____________
8. If Buyer 1 bids \$150.00ED, and Buyer 2 bids \$200.00ED, and the value of the good is revealed to be \$220.75ED, what are the payoffs for Buyer 1 and Buyer 2? ____________