Auctions: Experiments
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John H. Kagel
and
Dan Levin
Ohio State University

Abstract: Experiments permit rigorous testing of auction theory. In single-unit private value auctions the Revenue Equivalence Theorem fails, but the comparative static predictions of Nash bidding theory hold, indicating that bidders are responsive to the primary economic forces at work in the theory. In single-unit common value auctions inexperienced bidders invariably suffer from a "winner's curse," and the comparative static predictions of the Nash bidding model fail. More experienced bidders do substantially better. Recent research dealing with Internet auctions, mixed private and common value auctions, and multi-unit demand auctions are surveyed as well.

Auctions: Experiments: Experimental work in auctions interacts with theory, providing a basis for testing and modifying theoretical developments. It has advantages and disadvantages relative to empirical work with field data, so that we view the two as complimentary. Experimental work is used increasingly as a test-bed for new auction formats such as the Federal Communication Commission's (FCC) sale of spectrum (air-wave) rights.

Until recently most of theoretical and experimental work was devoted to single-unit demand auctions. With the success of the FCC's spectrum auctions much of the interest has shifted to auctions in which individual bidders demand multiple units. Experimental work in this area is still in its infancy. In keeping with the historical development of the field we first report on single-unit demand auctions and then move to multi-unit demand auctions and Internet auctions.

Single-unit, private-value auctions: Initial experimental research on auctions focused on the independent private values (IPV) model investigating the Revenue Equivalence Theorem. In the IPV model each bidder knows his valuation of the item with certainty, bidders' valuations are drawn independently from each other, and bidders know the distribution from which their rivals' values are drawn (but not their values) and the number of bidders. Under the revenue equivalence theorem the four main auction formats – first- and second-price sealed-bid auctions, English and Dutch auctions – yield the same average revenue for risk neutral bidders.[1] Further, the first-price sealed-bid and Dutch auctions are theoretically isomorphic – they yield the same revenue for each auction trial regardless of risk preferences – with the second-price sealed-bid and English clock auction isomorphic to

[1] The Dutch auction starts with a high price which is lowered until a bidder accepts at that price. In English auctions price starts low and increases until only one bidder is left standing and pays the price where the next to last bidder dropped out. In a first- (second-) price sealed-bid auction the high bidder wins the item and pays the highest (second-highest) bid.

each. These isomorphisms are particularly attractive as it is hard to control bidders' risk preferences.

An experimental session typically consists of several auction periods under a given auction institution. Subjects' valuations are determined randomly prior to each auction period (by the experimenter) and are private information. Valuations are typically independent and identical draws (iid) from a uniform distribution. In each period the high bidder earns a profit equal to his value less the auction price; other bidders earn zero profit. Bids are commonly restricted to be nonnegative and rounded to the nearest penny. Theory does not specify what information feedback bidders ought to get after each auction, which usually differs between different experimenters, with at least the auction price announced, along with their own earnings.

Strategic equivalence usually fails between the relevant auction formats: Coppinger et al. (1980) and Cox et al. (1982) found higher prices in first-price compared to Dutch auctions (about 5% higher) with these differences holding across auctions with different numbers of bidders. Further, bidding was significantly above the RNNE in the first-price auctions for all numbers of bidders (n) > 3, which is consistent with risk averse bidders.

Kagel, et al. (1987) reported failures of strategic equivalence in second-price and English clock auctions with prices in the second-price auctions averaging 11% *above* the dominant strategy price, in contrast to market prices tending to converge rapidly to the dominant strategy price in the clock auctions.[2] Bidding above the dominant strategy in second-price auctions is relatively wide spread, with 62% of all bids above the dominant strategy price, 30% of all bids essentially at the dominant strategy price (within 5 cents of it), and 8% of all bids below it (Kagel and Levin, 1993). Bidding above the dominant strategy in second-price auctions is attributable to a number of factors: (i) It is sustainable in that average profits are positive, (ii) the dominant strategy is not that obvious, and (iii) the feedback from losses that would promote more precise conformity with the dominant bidding strategy is weak (Kagel et al., 1987). Subsequent research generalizes the superiority of the clock auction format over the sealed-bid format to Vickrey style auctions in which bidders demand multiple units, provided there is information about drop-out prices (Kagel et al., 2004). The closer conformity to equilibrium outcomes in the clock auctions results from both the information inherent in observing others' drop out prices and the ability of the clock to provide this information in a highly salient way (Kagel and Levin, 2001; Kagel, et al., 2004).

Efficiency in private value auctions can be measured by the percentage of auctions won by the high value holder. In Cox et al. (1982) 88% of the first-price auctions were Pareto efficient compared to 80% of the Dutch auctions. In contrast, efficiency in first- and second-price auctions may be quite comparable; e.g., 82% of the first-price auctions and 79% of the second-price auctions reported in Kagel and Levin (1993) were Pareto efficient. More work needs to be devoted to comparing efficiency across auction institutions.

A number of papers have explored bidding above the RNNE in first-price sealed-bid auctions questioning the risk aversion interpretation. This has generated some heated debate (see the xxxx, 1992 issue of the *American Economic Review).* Isaac and James (2000) compare estimates of risk preferences from first-price auctions compared to the

[2] In clock auctions price rises by fixed increments with bidders counted as active until they drop out (and are not permitted to reenter the auction). This format insures clear information flows as a consequence of announcing irrevocable drop-out prices.

Becker-DeGroot-Marshak (BDM) procedure for comparably risky choices. The Spearman rank correlation coefficient between individual subject risk parameters are significantly *negatively* correlated under the two institutions, as subjects whose bids in the first-price auction are relatively risk neutral remain risk neutral under BDM, and those who are relatively risk averse in the first-price auction become relatively risk loving under BDM. The net result is that *aggregate* measures of risk preferences show that bidders are risk averse in the first-price auction but risk neutral, or moderately risk loving, under the BDM procedure. Although it is well know from the psychology literature that different elicitation procedures will yield somewhat different quantitative predictions, a negative correlation between measures seems rather astonishing.[3] Neugebauer and Selten (in press) compare different information feedback treatments (i) only information regarding whether a bidder won the auction or not, (ii) the market price (the usual feedback) whether winning or not, and (iii) the market price and the highest rival's bid in case of winning the auction. They find that average bids are highest under treatment (ii) and exceed the RNNE for every given market size. In contrast, bidding above the RNNE does not occur consistently, or is not as strong, in the other two treatments. They use "learning direction theory" to argue that the information feedback in (ii) promotes bidding above the RNNE. However, the result for treatment (iii) contrasts with results from Kagel et al. (1987) and Dyer et al. (1989a) who find consistent bidding above the RNNE when providing bidders with all bids and resale values following each auction. Perhaps the best conclusion at this point is that subjects act "as if" risk averse in first-price auctions, while the underlying basis of their behavior remains open to interpretation.

In spite of the deviations from equilibrium outcomes that have been reported, the comparative static implications of the IPV model tend to be satisfied (albeit with varying levels of noise) Bidding in first-price auctions increases regularly in response to increased numbers of bidders. For example, in a series of first-price auctions with $n = 5$ or 10, 86% of subjects increased their bids with $n = 10$, with the majority of these increases (60%) being statistically significant, and no with subjects decreasing their bids by a statistically significant amount (Battalio et al., 1990). Bidding in response to increased numbers of rivals would seem to be a natural reaction, and can be rationalized by plausible ad hoc rules of thumb.

Kagel and Levin (1993) provide a more stringent test of the comparative static implications of the IPV model using a third-price auction in which the high bidder wins the item and pays the third highest bid. In this case the model predicts that bids will be *above* values and will be *reduced* in response to increases in *n*. In third-price auctions 85-90% of all bids are above value compared to 58-67% in second-price auctions and less than 0.5% in first-price auctions. Further, comparing auctions with $n = 5$ and 10 (i) in first-price auctions *all* bidders increased their bids on average (average increase of \$0.65 per auction; $p < .01$), (ii) in second-price auctions the majority of bidders did not change their bids on average (average decrease of \$0.04; $p > .10$), and (iii) in third-price auctions 46% of all subjects *decreased* their bids on average (average decrease of \$0.40 per auction; $p < .05$). Further, even stronger qualitative support for the theory is reported when the calculations are restricted to valuations lying in the top half of the domain of valuations (where bidders have a realistic chance of winning and might be expected to take bidding more seriously).

[3] See Dorsey and Razzolini (2003) for a similar investigation.

Thus, although a number of bidders in third-price auctions clearly err in response to increased numbers of rivals by increasing, or not changing, their bids, the change in pricing rules has relatively large and statistically significant effects on bidder's responses in the *direction* that Nash equilibrium bidding theory predicts. This experiment also illustrates one of the great strengths of the experimental method as there are no third-price outside the lab, where it was developed for the explicit purpose of providing unusual, counter-intuitive predictions to use in testing the theory. The results are increased confidence in the fundamental "gravitational" forces underlying the theory, in spite of violations of its point predictions. The latter could be the result of some uncontrolled factor impacting on behavior and/or simple miscalibration on subjects' part.

Single-unit common value auctions: In common value auctions the value of the item is the same to all bidders. What makes the auction interesting is that bidders receive signals that are related to (affiliated with) the value of the item but do not know its true value. Mineral rights auctions (e.g., outer continental shelf – OCS - oil lease auctions), are usually modeled as common value auctions. There is a common value element to most auctions. Bidders for an oil painting may purchase for their own pleasure, a private value element, but also for investment and eventual resale, the common value element.

Experimental research in common value auctions has focused on the "winner's curse." Although all bidders obtain unbiased estimates of the item's value, they typically win in cases where they have the highest signal value. Unless this adverse selection problem is accounted for, it will result in winning bids that produce below normal or negative profits, a disequilibrium phenomenon. Oil companies claim they fell prey to the winner's curse in early OCS lease sales, with similar claims made in a variety of other settings (e.g., free agency markets for professional athletes and corporate takeovers). Economists are naturally skeptical of such claims as they involve out-of-equilibrium play.

Experiments clearly confirm the presence of a winner's curse for inexperienced bidders under a variety of circumstances and with a variety of subject populations: your average undergraduate or MBA student (Bazerman and Samuelson, 1983; Kagel and Levin, 1986), extremely bright (Cal Tech) undergraduates (Lind and Plott, 1991), experienced professionals in a laboratory setting (Dyer et al, 1989b), and auctions in which it is common knowledge that one bidder knows the value of the item with certainty (Kagel and Levin, 1999). Further, comparative static tests of the theory show that bidders are not simply miscalibrated, but that the theory's comparative static implications are systematically violated when bidders suffer from a winner's curse; e.g., bidder responses to additional information or increased numbers of rivals..

Kagel et al. (1989) find that inexperienced bidders suffer a pervasive winner's curse in first-price, sealed-bid auctions: For the first nine auctions, profits averaged -$2.57 compared to the RNNE prediction of $1.90, with only 17% of all auctions having positive profits. This is not a simple matter of bad luck as 59% of all bids, and 82% of the high bids, were above the expected value conditional on winning the auction. Although public information in first-price auctions is predicted to raise seller's revenue it fails to do so for inexperienced bidders as subjects use the information to lower their bids, thereby reducing revenue (Kagel and Levin, 1986). Similarly, "public information" fails to raise revenue in English clock auctions when bidders suffer from a winner's curse (Levin et al., 1996). Further, experienced bidders appear to adjust to the winner's curse through a "hot stove"

learning process, with the losses generating lower bids but no real understanding of the adverse selection. As a result, increases in *n* generate higher individual bids, although theory predicts a slight reduction (Kagel and Levin, 1986). Efforts to explain the winner's curse in terms of limited liability for losses and/or the "joy of winning" fail as well (Kagel and Levin, 1991; Holt and Sherman, 1994). In short, inexperienced subjects do not perform well in pure common value auctions.

Experienced subjects learn to overcome the worst effects of the winner's curse, earning positive average profits. But these rarely exceed 65% of the RNNE profit and virtually all subjects are *not* best responding to their rivals' overly aggressive bids (Kagel and Richard, 2001). However, once bidders overcome the worst effects of the winner's curse public information raises sellers' revenue, English auctions raise more revenue than sealed-bid auctions, and a number of other comparative static implications of the theory are satisfied (Kagel and Levin, 2002). Experienced bidders learn to overcome the winner's curse through a combination of individual subject learning and market selection effects whereby bankrupt bidders self-select out of further experimental sessions. Ability as measured by composite SAT/ACT scores matter in terms of avoiding the winner's curse, with the biggest and most consistent impact resulting from those with *below median* scores being more susceptible to the winner's curse. Economics and business majors consistently bid more aggressively than others, and women, at least initially, are much more susceptible to a winner's curse than men. However, there is still a winner's curse even for the best calibrated demographic and ability groups (Casari et al., 2005).

Experiments Combining Common-Value and Private-Value Elements: Goree and Offerman (2002) provide the only experimental study to date in which the object's expected value depends on both private and common value elements. (The difficulty here is how to combine private and common value information into a single statistic that maps into a bid.) Actual bids lie in-between the RNNE benchmark of fully rational bidding and the Naive benchmark in which subjects completely fail to account for the winner's curse. The winner's curse effect is more important the less important a bidder's private value is relative to the common value. Realized efficiency is roughly at the level predicted under the RNNE, with the winner's curse only cutting into bidder profits as most bidders suffer from a winner's curse of roughly the same magnitude.

In an almost common value auction one bidder, the advantaged bidder, has an added private value for the item, unlike the regular bidders who only care about the common value. With only two bidders, even a tiny private value advantage is predicted to have an explosive effect in second-price sealed-bid auctions: The advantaged bidder always wins the auction and revenue decreases dramatically as regular bidders lower their bids to protect against a winner's curse. This effect extends to a variety of English auctions with more than two bidders, which raises serious concerns about the English auction format (Klemperer, 1998). Three experiments have looked at almost common value auctions using both second-price sealed-bid and clock auctions (Avery and Kagel, 1987; Rose and Levin, 2004; and Rose and Kagel, 2005). In all cases the response to the private value advantage has been proportional rather than explosive. This is true even with experienced bidders who earn a respectable share of RNNE profits in pure common value first-price and clock auctions (Rose and Kagel, 2005). The apparent reason for these failures is that bidders' do not fully appreciate the adverse selection effect

conditional on winning, which is exacerbated with a private-value advantage. As such the behavioral mechanism underlying the explosive effect is not present, and there are no forces at work to replace it. These results do not demonstrate that explosive effects will not be present outside the lab with sophisticated bidders. But it makes us quite skeptical that a small private value advantage will have an explosive effect under the conditions the theory specifies.

Internet Auctions: Internet auctions provide new opportunities to conduct experiments to study old and new puzzles. Lucking-Reiley (1999) has used the Internet to sell collectable trading cards under the four standard auction formats, testing the revenue equivalence theorem. He finds that Dutch auctions produce 30% higher revenue than first-price auctions, a reversal of previous laboratory results, and that English and second-price auctions produce roughly equivalent revenue. These results are interesting but lack the controls present in more standard laboratory experiments; i.e, there may well be a common value element to the trading cards and Dutch auctions provide an opportunity to use the game cards immediately, which cannot be done until the fixed closing date in the first-price auctions. Garratt et al. (2004) conduct a second-price auction recruiting subjects with substantial experience bidding on eBay. Using induced valuations, they find that average bids are close to valuations, but those with prior experience as *sellers* tend to underbid and those with prior experience as *buyers* tend to overbid.

In eBay auctions which have a fixed closing time many bidders snipe (submit bids seconds before the closing time), while others increase their bids over time in response to higher bids. This seems puzzling since eBay has a number of characteristics similar to a second-price auction. In addition, there is substantially more last minute bidding for comparable (private-value) items in eBay than in Amazon auctions which automatically extends the deadline in response to last minute bids. Roth and Ockenfels (2001) argue that sniping results from the fixed deadline in eBay, suggesting at least two rational reasons for sniping. Because there are differences between eBay and Amazon other than their ending rules, they conduct a laboratory experiment in which the only difference between auction institutions is the ending rule – a dynamic eBay auction with a .8 (1.0) probability that a late bid will be accepted (eBay.8 and eBay1, respectively) and an Amazon style auction with a .8 probability that a late bid will be accepted, in which case the auction is automatically extended (Ariely et al., in press). The results show quite clearly that there is more late bidding in both eBay auctions than in the Amazon auction. Further, there is significantly more late bidding in eBay1 than in eBay.8, which at least rules out one possible rational explanation for sniping – implicit collusion on the part of snipers in an effort to get the item at rock bottom prices since not all last minute bids will be recorded (due to congestion) at the web site.

Salmon and Wilson (2005) investigate the Internet practice of second-chance offers to non-winning bidders when selling multiple (identical) items. They compare a two-stage game with a second-price auction followed by an ultimatum game between the seller and the second-highest bidder versus a sequential English auction. As predicted the auction-ultimatum game mechanism generates more revenue than the sequential English auction.

Multi-unit Demand Auctions: Most of the work on multi-unit demand auctions has been devoted to mechanism design issues, in particular dealing with problems created by

complementarities, or synergies, between items. Absent package bidding the latter can create an "exposure" problem whereby efficient outcomes require submitting bids above the standalone values for individual units since the value of the package is more than the sum of the individual values. Correcting for this problem by permitting package bids increases the complexity of the auction significantly and creates a "threshold" problem whereby "small" bidders (e.g., those with only local markets) could, in combination, potentially outbid a large competitor who can internalize the complementarities. But the small bidders have no means to coordinate their bids. Leading examples of this line of research are Porter et al. (2003) and Kwasnika et al. (2005). Much more work remains to be done in this area.

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