Comparing Efficient Multi-Object Auction Institutions*

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Abstract

We study three alternative versions of the Vickrey (1961) auction in cases where bidders have multi-unit demands**:** the original, static sealed-bid Vickrey auction and dynamic Vickrey auctions with and without drop out information reported (Ausubel, 1997). The auction with drop out information comes significantly closer to sincere bidding than the other two, although all three mechanisms are designed to produce this outcome. Of the three studied, the dynamic auction with drop out information is clearly the most transparent to boundedly rational bidders**,** but is based on a weaker solution concept than the other two. This suggests a tradeoff between the simplicity and transparency of a mechanism and the strength of its solution concept.

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In a seminal paper, Vickrey (1961) characterized procedures that provide bidders with incentives to truthfully reveal their values for commodities in both single and multi-unit demand auctions. While the case where bidders demand a single unit each is well known, the multi-unit version of the Vickrey auction is relatively obscure and rarely advocated for application in field settings. The main reason for this is that many economists believe it to be too complicated for most people to understand, so that bidders will fail to follow the dominant bidding strategy that the mechanism is designed to elicit and which assures efficient allocation. For example, in their comments to the Federal Communications Commission describing the multi-unit Vickrey auction Nalebuff and Bulow (1993) write (p. 29): "However, experience has shown that even Ph. D. students have trouble understanding the above description. ... The problem is that if people do not understand the payment rules of the auction then we do not have confidence that the end result will be efficient." Indeed, experiments show that bidders often deviate from the dominant strategy in the far simpler single-unit demand Vickrey auction; i.e., in second-price sealed bid auctions. In contrast, the same bidders quickly learn to play the dominant strategy in an ascending-bid, "English clock" auction that is strategically equivalent to the second-price Vickrey auction (Kagel, Harstad and Levin, 1987).

Partly in response to the potential difficulties in implementing the multi-unit version of the Vickrey auction Ausubel (1997) has proposed a dynamic version of the auction designed to mimic the success of the English clock auction in the single-unit case. The Ausubel mechanism is best characterized in the vernacular of team sports. As the price clock ticks up and people drop out of the bidding, quantity demanded falls. At the moment an active bidder is assured of winning an item no matter what other bidders do, that bidder is said to have "clinched" an item and pays the clinching price.[1]

Ausubel proposes two forms for the ascending-bid auction. In the first form, all bidders receive information about drop out prices and clinching is announced as the auction proceeds. In the second form, bidders receive no information about dropout prices or units clinched until the auction ends. Ausubel demonstrates that with private values and (weakly) diminishing marginal valuations, sincere bidding is a weakly-dominant strategy in his dynamic version of the Vickrey auction with no bid information, just as in the static, sealed-bid Vickrey auction (Ausubel, 1997, Theorem 1). In contrast, and perhaps somewhat surprisingly, sincere bidding is no longer a dominant strategy in the dynamic Ausubel auction *with* dropout information, although it remains an equilibrium in iterated deletion of (weakly-) dominated strategies (Ausubel, 1997, Theorem 2).

The experiments reported here compare the static, multi-object Vickrey auction to the Ausubel auction both with and without bid information. The auctions take place in a pure private value framework in which a single bidder with flat demand for two units competes against different numbers of rivals demanding a single unit of the commodity. Single unit buyers have a dominant strategy to bid sincerely. Their role is played by computers which are programmed to follow this strategy.[2] Two units are offered for sale in each auction. This environment preserves the essential elements underlying the multi-unit demand Vickrey auction in a highly simplified setting. It also permits direct comparisons with

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[1]The characterization here is for the case of homogeneous goods where bidders have non-increasing demands.

[2]Bidders are told that the computers will always bid their value, but not that this is a dominant bidding strategy. Bidding sincerely means submitting bids equal to one values in the static auction and dropping out when price equals value in the dynamic auctions.

a companion series of uniform-price multi-unit demand private value auctions both with and without synergies (Kagel and Levin, 2001 a, b).

Results are reported from three experiments. The first experiment compares the Ausubel auction *with* dropout information to the static sealed-bid Vickrey auction. The Ausubel auction generates outcomes closer to sincere bidding, higher efficiency, and greater earnings for bidders. However, it generates lower seller revenue since bids in the static Vickrey auction consistently exceed values.

A second experiment compares the Ausubel auction *without* dropout information to the first two auction institutions. Two different sets of instructions are used to implement the auction. In one, the clinching metaphor is used to characterize who will earn units and how much they will pay. In the other, who will earn units and how much they will pay is described using language and instructions borrowed from the static Vickrey auction. Sincere bidding is more prevalent in the Ausubel auction with dropout information than in both versions of the Ausubel auction without dropout information. However, the pattern of deviations from sincere bidding is clearly influenced by the instructions employed, with behavior somewhat closer to sincere bidding with the clinching indicating instructions. This is indicative of a clear framing effect in the data, and serves to reinforce the idea that the instructions which accompany a mechanism are an integral a part of the mechanism design.[3]

The last experiment shifts between Ausubel auctions with and without dropout information (using the clinching instructions) within an experimental session to see if, perhaps, bidders can internalize

[3]We distinguish here between a pure framing effect and a procedural effect. By pure framing effect we mean using different language or metaphors to implement identical mechanisms. By the latter we mean using different procedures to elicit bids (e.g., static Vickrey versus the Ausubel auction).

bidding rules from auctions with dropout information and apply them to auctions without dropout information. The data show that bidders can learn to do quite well without the dropout information, in part because of lessons learned from experience in auctions with dropout information.

We are familiar with four other experimental studies of Vickrey type auctions with multiple units for sale and bidders demanding multiple units. In three of these - Brenner and Morgan (1997), Isaac and Duncan (2000), and List and Lucking-Reiley (2000) - comparisons are made between the sealed-bid Vickrey auction and some other auction mechanism (e.g., a uniform-price auction).[4] The fourth, Manelli, Sefton, and Wilner (1999), is closest in spirit to ours, with one series of auctions comparing a sealed-bid Vickrey auction with an Ausubel auction with dropout information. (Bidders have private values and non-increasing demand for additional units.) Manelli et al. employ a handful of discrete private values, with bidders quoting amounts demanded as prices increase discretely.[5] In cases where more than one bidder drops out following a price increment, so that the market goes from excess demand to excess supply, unassigned units are not allocated and the auction ends. We employ a much finer grid of values and price increments (to the penny), structure the auction in such a way that any potential excess supply problem is eliminated, and compare different versions of the Ausubel auction (with and without price dropout information) with the static Vickrey auction. We compare their results to ours in section II below.

Beyond being of interest to issues in multi-unit demand auctions, our study provides a broader

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[4]In the same vein Kagel and Levin (2001a) compare the Ausubel auction with dropout information with a uniform-price auction when bidders have multiple-unit demands.

[5]Private values were drawn with replacement from a set of six values.

message of relevance to the applied mechanism design literature. Our experiment demonstrates that because of agents bounded rationality limiting attention to equilibrium properties and strength of the solution concept in deciding between alternative mechanisms may well be misleading. Thus, even though, other things equal, implementing an allocation by a dominant strategy is very appealing, less than fully rational agents may benefit from the additional information imbedded in a dynamic mechanism, and behave closer to the predicted allocation even if it is implemented by a mechanism with a weaker solution concept, such as iterated deletion of dominated strategies.

The paper proceeds as follows: Section I briefly outlines our experimental design and the alternative auction mechanisms. We report our experimental results in Section II. We end with a brief summary and conclusions section.

I: Experimental Design

Theoretical Considerations: We investigate bidding in independent-private-values (IPV) auctions with $(n+1)$ bidders and m *indivisible* identical objects for sale, where $n \$ m$. Each bidder i (i = 1, ... , n) demands a single unit of the good, placing a value v_i on the good. These bidders are indexed by their values so that $v_1 \$ v_2 \$, ..., \$ v_n$. Bidder h, the $(n+1)^{th}$ bidder, demands two units of the good, placing the same value v_h on both units. Bidders' values are drawn *iid* from a *uniform* distribution on the interval [0,V].

In the static Vickrey auction each bidder simultaneously submits a sealed bid for each of the units demanded. These are ranked from highest to lowest, with the m highest bids each winning an item. Each bidder pays the amount of the kth highest rejected bid other than her own for the kth object he/she wins. Thus, in cases where bidder h wins only one item he pays the $m + 1$ highest bid *provided* *this is not his bid* (in which case he pays the $m + 2$ highest bid). And in cases where h wins both items the total payment is the sum of the $m + 1$ and the $m + 2$ highest bids.[6]

In the Ausubel auction each auction begins with a price of zero with the price increasing continuously thereafter. Bidders start out actively bidding on all units demanded, choosing what price to drop out of the bidding. Dropping out is irrevocable so a bidder can no longer bid on a unit he has dropped out on. Winning bidders pay the price at which they have "clinched" an item. Clinching works as follows: With m objects for sale, suppose at a given price, p_o, bidder h still demands two units, but the aggregate demand of all *other* bidders just dropped from m to m-1. Then, in the language of team sports, bidder h has just clinched winning an item no matter how the auction proceeds. As such bidder h is awarded one item at the price, p_o, the clinching price. This process repeats itself with the supply reduced from m to m-1 and with h's demand reduced by one unit. In this way the auction sequentially implements the rule that each bidder pays the amount of the kth highest rejected bid, other than his own, for the kth object won, as the Vickrey mechanism requires.

In the Ausubel auction with bid information, posted on each bidder's screen at all times is the current price of the item, the number of items for sale, and the number of units actively bid on, so that h can tell at exactly what price a rival has dropped out of the bidding. Further, there is a brief pause in the price increments following a dropout, during which time h can drop out. These dropouts are recorded as dropping at the same price, but are indexed as dropping later than the dropout that initiated

[6] The complete set of instructions for the static Vickrey auction and the other auctions is provided in the appendix to the paper.

the pause[7]

In auctions with no bid information bidders are only informed if they have clinched an item and what other bidders' dropout prices are *after* the auction is over. As such there is no way to tell at what price rivals have dropped out of the bidding, or how many rivals are still active, until the auction is over. Like the sealed-bid Vickrey auction, sincere bidding is a weakly dominant strategy since bidders have the same information set at their disposal as in the sealed-bid auction. In contrast, in the Ausubel auction with dropout information, flat demand and private values, sincere bidding is the unique equilibrium surviving *iterated elimination* of (weakly-) dominated strategies (Ausubel, 1997).[8]

Experimental Procedures: Valuations were drawn iid from a uniform distribution with support [0, $7.50]. Bidders with single unit demands were represented by computers programmed to submit bids equal to their valuation. Bidder *h* was played by human subjects drawn from a wide cross-section of undergraduate and graduate students at the University of Pittsburgh and Carnegie-Mellon University.[9]

Each *h* operated in her own market with her own set of computer rivals. *h*s knew they were bidding against computers, the number of computers, and the computers' bidding strategy (but not the logic underlying this strategy). Supply, *m*, was set at two in all auctions. The number of computer

[7]The auction is formally modeled as a continuous-time game. However, we want to take into account the possibility that bidder *j*'s strategy is to reduce his quantity at the soonest possible instant after bidder *i* dropout. This requires allowing "moves that occur consecutively at the same moment in time" (Simon and Stinchcombe, 1989; also see Ausubel, 1997).

[8] The Ausubel auction with dropout information has a number of theoretical advantages over the static Vickrey auction or the Ausubel auction without dropout information when valuations have a common value component. This case is not considered here.

[9]Students were recruited through fliers posted throughout both campuses, advertisements in student newspapers, and electronic bulletin board postings.

rivals was either three or five.

All of the Ausubel auctions employed a “digital” price clock with price increments of $0.01 per second. In auctions with dropout information there was a 3-second pause following each drop out. *h*’s were informed of having clinched an item(and the price paid) following dropouts.[10]

In the sealed-bid auctions subjects submitted bids on both units simultaneously. All bids and corresponding valuations (including the computers’) were reported back to subjects, with bids ranked from highest to lowest, and with *h*’s bids clearly distinguished from the computers. Pricing rules were explained to subjects in terms of having earned zero, one or both units, along with the general pricing principle underlying the payoffs. Subjects were required to submit bids on unit 1 followed by unit 2. Any non-negative bid was accepted for unit 1, with the unit 2 bid required to be the same or lower than the unit 1 bid. Earlier multi-unit demand auctions demonstrate that this restriction on unit 2 bids has no effect on bidding behavior (Kagel and Levin, 2001a).

Ausubel auctions with no bid information maintained the pause in the price increases following *h* dropping out on a single unit, thereby keeping procedures as close as possible to the Ausubel auctions with bid information, but eliminated the pause or any dropout information prior to the price having reached its maximum value of $7.50. There are two natural, but different, ways to explain the auctions’ rules: (1) Using the clinching rules via an example or two, just as in the Ausubel auction with dropout information, or (2) Using the sealed-bid auction rules via an example or two, just as in the static Vickrey auction. Theoretically, both methods induce the same outcomes, so that *a priori* there is no

[10] *h* could drop out on a single unit by hitting any key other than the number 2 key. The first stroke of the key pad dropped out unit 2. Hitting the number 2 key, or hitting a second key during the price pause, permitted *h* to drop out on both units at the same price.

basis for preferring one explanation to the other. However, given that agents are boundedly rational (which is, after all, an important motivation behind the development of dynamic versions of the Vickrey auction) the way instructions are framed may matter.[11] As such we decided to conduct two separate sessions, one employing the clinching instructions and one employing the sealed-bid instructions.

In all sessions instructions were read out loud to subjects, with copies for them to follow along with as well. The instructions included examples of how the auctions worked both in cases where it produced positive profits and in cases where bidding above value produced negative profits.

All sessions began with 3 dry runs to familiarize bidders with the procedures. In sessions 1-6 (see Table 1) these dry runs were followed by 27 auctions played for cash. Further, the number of computer rivals was changed from 3 to 5 (or vice versa) mid-way through the "wet" runs.[12] Following these sessions, two additional sessions (7 and 8) were conducted in which subjects were systematically crossed back and forth between Ausubel auctions with and without dropout information, using the clinching instructions throughout. In these two sessions the number of computer rivals was fixed at 5, and there were between 45-46 wet runs. The additional wet runs were included to see if experience in auctions with dropout prices reported might result in closer conformity to sincere bidding following elimination of the dropout information. The number of computer rivals was fixed so that we could investigate this (potential) learning process absent any potential confounding effect, no matter how

[11]See Perry and Reny (2000) for the development of dynamic versions of the Vickrey auction for the case of multi-unit demands with interdependcies between commodities.

[12]We varied the sequencing of computer rivals in the sealed-bid Vickrey auctions and in the Ausubel auction with dropout information, the treatments of primary interest. Given the absence of obvious sequencing effects in these treatments, the secondary nature of our interest in the Ausubel auctions without dropout information, and the fact that this treatment already involved variation in the instructions employed, we chose not vary the sequencing of computer rivals in this treatment.

small, due to changing numbers of bidders.

At the start of each auction both *h* and the computers received new valuations. At the conclusion of each auction bids were ranked from highest to lowest along with the corresponding valuations. Winning bids were identified, prices were posted, profits were calculated, and cash balances were updated on bidders' computer screens.

Bidders were given starting capital balances of $5. Positive profits were added to this balance and negative profits subtracted from it. End of experiment balances were paid in cash. Expected profits were sufficiently high that we did not provide any participation fee.[13] Inexperienced subject sessions lasted between 1.5 and 2 hours.

II. Experimental results

Sealed-Bid Vickrey Auctions verus Ausubel Auctions with Dropout Information: Figures 1 and 2 report data for the last 12 auctions with n = 3 from the sealed-bid auctions and the Ausubel auctions respectively.[14] Data are reported for all subjects, so that there are repeated measures for the same subject. Note that there is massive overbidding with respect to unit 1 values in the sealed-bid auctions. Bidding above value is moderated somewhat for unit 2 bids, but there is still substantial bidding above value.

In the Ausubel auctions the potential maximum dropout price for clinched items is unknown (*h*'s

[13]In those few cases where end of experiment earnings were below $2.00, a token $2.00 payment was provided.

[14]Data from the last 12 auctions under each treatment condition will serve as the norm in all of the empirical analysis that follows, unless otherwise stated. Bids are truncated at $7.50 for the sealed-bid auctions to preserve comparability with the other auction formats.

were informed immediately after clinching an item, with the price fixed at the dropout price that clinched the item). As such bids on items clinched are reported as prices paid and represented by open circles. These bids are censored. Dropouts at prices at or below value are represented by open squares. For dropouts above value, we distinguish between potentially harmful dropouts, when the next, unknown, computer dropout would have resulted in negative profits (triangles) and dropouts that occurred before there was any chance to lose money (diamonds).[15] For both unit 1 and unit 2 bids, the predominant pattern is for dropouts to occur very close to value (along the 45 degree line). There are much fewer bids above value than in the sealed-bid auctions, and these are often harmless, with dropouts occurring before there is any chance to lose money (diamonds). Bids below value are mostly represented by open circles, indicating clinched items. Scatter plots of data from auctions with $n = 5$ show similar results to Figures 1 and 2.

> *Conclusion 1:* There is considerably more bidding above value in sealed-bid compared to Ausubel auctions resulting in much closer conformity to sincere bidding in the Ausubel auctions.

Table 2 compares bid patterns between the two auctions, putting the data on the same footing as the Ausubel auctions with dropout information. The first row of data reports the frequency with which bidders won an item and lost money as a consequence, with data from the sealed-bid auctions reported first, followed by the Ausubel auctions, and then the difference between the two.[16] Statistical tests are all non-parametric Mann-Whitney tests, with average subject data as the unit of observation.

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[15]For unit 2 bids this would be before or exactly when the number of computer bidders went down to three, for unit 1 bids before or exactly when the number of computer bidders went down to two.

[16]All data reported are averages computed over subject averages for the last 12 auctions. Thus, individual subject behavior serves as our basic unit of observation we avoid any repeated measurement problems.

For unit 1 bids with $n = 3$, a little more than 15% of the time bidders win and lose money in the sealed-bid auctions versus less than half that often in the Ausubel auctions. These differences are even more extreme with unit 2 bids, and when $n = 5$. There are similar differences in the frequency of potentially harmful bids above value between the two auction institutions.[17] (The row labeled bid > v_h with possible negative profit.) Finally there is somewhat more underbidding, relative to value in the Ausubel auctions, but these differences are only marginally significant for unit 1 bids with $n = 3$.

> *Conclusion 2:* Bidder earnings and auction efficiency is significantly lower in the sealed-bid Vickrey auction compared to the Ausubel auction. However, the greater overbidding in the sealed-bid auctions results in significantly higher revenue.

Table 3 reports the impact of these bids on bidder earnings (profits), efficiency, and revenue. All outcomes are reported in terms of deviations from sincere bidding. For example, with $n = 3$, in the sealed-bid Vickrey auctions *h*'s earn 24.1¢ less per auction compared to sincere bidding. This compares to 9.4¢ less per auction in the Ausubel auctions, so that bidders earned 14.7¢ less per auction (compared to maximum possible earnings) in the static Vickrey auctions. This difference is statistically significant at the 5% level using a two-tailed Mann-Whitney test in which average subject values serve as the unit of observation. Comparable differences in earnings are reported for $n = 5$.

Efficiency is measured in the usual way - the sum of the values of the two winning units as a percentage of the sum of the values of the two highest units. The sealed bid auctions yield efficiencies of 97.5% and 97.9%, on average, with $n = 3$ and 5 respectively, compared to 99.1% and 99.3% in the Ausubel auctions. Although these differences are small, they are statistically significant in both cases.

[17] These are bids above value that had one of the computers dropped out, would have resulted in negative profits, but *h* dropped out prior to this happening.

Further, it should be kept in mind that since the single unit bidders (the computers) always follow the dominant bidding strategy, there is not much room for efficiency losses using this measure.[18] For example, we can compare efficiencies here to efficiencies in a companion series of multi-unit demand uniform-price auctions with exactly the same experimental structure (Kagel and Levin, 2001a).[19] Efficiencies in the uniform-price auctions averaged 96.8% and 97.3% in sealed-bid auctions with n = 3 and 5 respectively, and 97.4% and 98.3% with n = 3 and 5 in dynamic auctions using a price "clock" procedure similar to the one employed here. (Note that efficiencies in these uniform-price auctions are quite close to predicted efficiency in both cases.) Thus, at best, the sealed-bid Vickrey auction yields only a modest improvement in efficiency relative to these uniform-price auctions. In contrast, the Ausubel auction with dropout information consistently yields higher efficiency than the uniform-price auctions, just as the auction is designed to do.

Revenue in Table 3 is also measured relative to sincere bidding. As would be expected given the overbidding relative to value, actual revenue is substantially higher than with sincere bidding in the static Vickrey auctions, averaging 44.3¢ and 37.7¢ higher per auction with n = 3 and 5, respectively. This compares to actual revenue which is within 3¢ of sincere bidding revenue in the Ausubel auctions. These revenue differences (reported in the last column of Table 3) are statistically significant at better than the 1% level for both n = 3 and 5.

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[18]An alternative efficiency measure sometimes used in auctions is the percentage of times the highest valued units are the winning units. Using this alternative measure the sealed bid auctions yield efficiencies of 90.3% and 88.4% with n = 3 and 5 versus 95.8% and 96.8% in the Ausubel auctions.

[19]These auctions call for bids (or limit prices) equal to value for unit 1 and complete demand reduction (zero bids) on unit 2 for h, with single unit bidders (also played by computers) following the dominant strategy of bidding equal to value.

The overbidding reported in the sealed-bid auctions raises the question of why don't the monetary losses force these subjects to adjust their bidding as a consequence? The answer is that bidders do not suffer much in the way of obvious losses. Bidders in the static Vickrey auctions earn positive profits, on average, and more often than not observe positive profits associated with their overbidding. For example, taking all sealed-bid auctions with bids above value, slightly less than 25% resulted in winning and losing money for both n = 3 and 5. In contrast, 60.6% and 32.7% resulted in winning and making a positive profit with n = 3 and 5, respectively (with the remaining cases resulting in not winning any items). The net effect is that bidders rarely end up making negative average profits as a result of bidding above v_h. This occurred for only 2 out of 37 bidders, with losses averaging less than 8¢ per auction in both cases. Given that the static Vickrey payment rules are sufficiently complicated that the dominance argument against bidding above value is not immediately transparent, the feed back for this overbidding (provided it does not get too far out of hand) is, apparently, not sharp enough to eliminate the behavior.[20]

Our results on greater overbidding in the sealed-bid Vickrey auction compared to the Ausubel auction with dropout information are similar to those reported in Manelli et al. (1999) in auctions with all human bidders. This overbidding results in significantly higher revenue for the sealed-bid auctions in both our experiment and theirs as well. Although we find significant efficiency improvements associated with the Ausubel auctions compared to the static Vickrey auctions, Manelli et al. find no differences. This may well be the result of the far fewer observations in Manelli et al. and/or the coarseness of

[20]Recall that our experimental design - competing against computer rivals - permits us to rule out rivalrous behavior as the explanation for bidding above value.

bidder valuations in their auctions, so that bidding errors comparable to those reported here will tend to produce fewer inefficient allocations.[21]

The closer conformity to equilibrium bidding strategies reported here for an ascending-price auction with rivals dropout information provided, versus a static sealed-bid auction, replicates results reported under a variety of auction institutions and demand structures: uniform-price multi-unit demand auctions with and without synergies (Kagel and Levin, 2001a, b), single-unit, private-value auctions (Kagel, Harstad, and Levin, 1987), and single-unit common value auctions (Levin, Kagel, and Richard, 1996). It is consistent with our earlier arguments that dynamic auctions with dropout information provide a transparency that is lacking in static sealed-bid auctions. However, in contrast to these other auction environments where the strength of the solution concept is the same for dynamic and static auctions, the strength of the solution concept differs between auction formats here: The sealed-bid Vickrey auction generates sincere bidding as a dominant strategy. The equilibrium solution for the Ausubel auction with dropout information is weaker, namely iterated deletion of weakly-dominated bidding strategies. The ascending prices in the dynamic auction in conjunction with the provision of dropout information underlie *both* the greater transparency of the auction rules and the weakening of the solution concept.[22]

In the mechanism design literature, it is taken for granted that the stronger the solution concept, the more likely the mechanism is to achieve its desired outcome, with a dominant strategy mechanism

[21]Manelli et al's analysis is based on average session values for the last 10 auctions (out of 20) for 12 groups of 3 bidders each. There was supply of 3 units and each bidder had flat demand for 2 units.

[22]The ascending prices along with the dropout information enriches the strategy space, allowing strategies that are contingent on other agents' previous moves. Hence, the weakening of the solution concept.

constituting the most preferred solution concept (see, for example, Kreps, 1990).[23] However, it seems that when players are less than fully rational (or when the search for optimal behavior is costly but is abstracted away in the model) the intuition that implementation via a stronger solution concept necessarily implies closer conformity of behavior to predictions needs to be reevaluated. That is, there may well be a tradeoff between a mechanism that simplifies agents decision task versus one that relies on a stronger solution concept. This insight is codified in the following conclusion:

> *Conclusion 3:* Implementation by a mechanism that has a weaker solution concept but that is more transparent may result in closer conformity to the planner's desired outcome. The closer conformity to sincere bidding in the Ausubel auction with dropout information compared to the sealed-bid Vickrey auction provides one example of such an effect.

The tradeoff lies in the fact that transparency is valued by bounded rational agents, so that it may more than offset the additional strategic ambiguity that may arise due to the weaker solution concept. This is particularly relevant when (as in our study) the incremental information simplifies a great deal while the incremental ambiguity is minimal, as it takes two rounds of iterated elimination of (weakly-) dominated strategies to arrive at the equilibrium in our experimental design. We also simplify things by having the role of single unit bidders played by computers who are know to bid their value (their dominant strategy) which, at least on a behavioral level, might be expected to further reduce the ambiguity associated with the weaker solution concept.[24] Nevertheless, we do demonstrate a tradeoff,

[23] "These worries (about achieving the desired outcome) are ameliorated if the desired behavior constitutes a dominant strategy for all the players in the mechanism that has been designed. ... In cases where it may be unreasonable to expect players to find their way to a Nash equilibrium, it may be reasonable to expect them to recognize (and play) a dominant strategy. Even if the strategies are not strictly dominant (so there may be other equilibria in weakly dominated strategies), the mechanism designer may feel relatively secure in a prediction that players will settle on strategies that are dominant." (Kreps, 1990, p. 698).

[24] The fact that computers play the role of single-unit bidders and are known to bid their value does not alter the fact that it still takes two rounds of deletion of (weakly-) dominated strategies to arrive at sincere bidding, since

one that has not previously been recognized in the literature. Further, as the work of Manelli et al. suggest, in this context at least, the results are likely to generalize to situations with greater ambiguity both theoretically (more rounds of deletion of dominated strategies) and behaviorally (all human bidders).

Ausubel Auctions with No Dropout Information: Figures 3 and 4 report bids for the Ausubel auctions with no dropout information with n = 3 for, respectively, auctions employing the sealed-bid instructions and those employing the clinching instructions. Bids of $7.50 (at the upper bound of the vertical axis) are censored since they represent bidders remaining active until the price reaches its maximum possible value, at which point the item is won. All other bids represent observed dropout prices.

In auctions employing the sealed-bid instructions there is a relatively high frequency of unit 1 bids above value, similar to the static sealed-bid auctions themselves. However, unlike the sealed-bid auctions, there is a relatively high frequency of bidding below value as well, particularly with respect to unit 2 bids. With the clinching instructions unit 1 bids at lower values are predominantly at or above the 45-degree line, but at higher values they are almost evenly split in frequency above and below the 45-degree line. In contrast, unit 2 bids are often below the 45-degree line, almost independent of the bidder's value.

> *Conclusion 4:* The pattern of deviations from sincere bidding, particularly with respect to unit 1 bids, differs substantially between the two Ausubel auctions with no dropout information: Overbidding is prevalent with the sealed bid instructions and underbidding with the clinching instructions. More important, for both cases, there is less conformity to the sincere bidding than

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in equilibrium single-unit bidders will be doing the same with all human bidders. The fact that computers play the role of single-unit bidders does, however, reduce ambiguity for h at the behavioral level.

in the Ausubel auctions with dropout information.

Table 4 reports the data for the Ausubel auctions with no dropout information. There are clear and statistically significant differences in the pattern of deviations from sincere bidding with respect to unit 1 bids. For example, with $n = 3$, there is only limited winning and losing money under the clinching instructions, 7.4% of all unit 1 bids, but substantially more wins with losses under the sealed-bid instructions, 21.7%. In contrast bidding below value occurs 44.9% of the time with the clinching instructions, compared to 22.8% with the sealed-bid instructions. This compares with a frequency of winning and losing money in the Ausubel auctions with dropout information of 6.8% and bidding below value of 16.0%. The former is significantly below the frequency in auctions in sealed-bid instructions, the latter significantly below the frequency in auctions with clinching instructions.[25] Further, absent dropout information, there is relatively massive underbidding with respect to unit 2 bids in both cases without dropout information, averaging more than 50% with $n = 3$, and more than 40% with $n = 5$. This is nearly twice the rate, or more, of unit 2 underbids when dropout information is provided, with the frequency of underbidding significantly less, at the 5% level or better, in all cases. These differences translate into significantly higher efficiency and bidder earnings in auctions with dropout information compared to no dropout information with $n = 3$ for both sealed-bid and clinching instructions, and for $n = 5$ for the sealed-bid instructions ($p < .05$ in all cases).

Thus, the Ausubel auction with dropout information moves bidders closer to sincere bidding than the Ausubel auction without dropout information, regardless of the instructions employed. This

[25] $P < .05$ in both cases, Mann-Whitney test with average subject frequency as the unit of observation. Results are similar for $n = 5$.

serves to provided further support to Conclusion 3 that transparency in design can outweigh the strength of the solution concept in mechanism design. What the different instructions do is produce a different pattern of deviations from sincere bidding with respect to unit 1 bids. This is indicative of a pure framing effect. What is surprising in these results are the frequent deviations to underbidding, as compared to overbidding, for unit 1 bids with the clinching instructions. The results are surprising as there is a general pattern of overbidding for unit 1 bids in a companion series of multi-unit demand, uniform-price, "clock" auctions with no dropout information (Kagel and Levin, 2001a). It is a dominant strategy to bid sincerely on unit 1 in both cases.

An Additional Experiment: The last experiment in this series was motivated by two things. First, given the unanticipated underbidding on unit 1 bids in the Ausubel auction without dropout information (with clinching instructions), we wanted to replicate these results to make sure we had not drawn an odd sample of subjects. Second, we wanted to determine if providing subjects with dropout information in the Ausubel auction might lead them to internalize bidding rules from auctions with dropout information and apply them to auctions without this added information. Two additional auction sessions were conducted in which the presence or absence of dropout information was varied using an ABA design. One session began with a series of auctions with no dropout information, switched to dropout information, and then back to no dropout information. The other session employed the opposite order - dropout information, no dropout information, dropout information. Both sessions employed the clinching instructions and n = 5. Further, the number of auctions was increased, as this was necessary to determine if experience with the dropout information helped develop the understanding needed to generate sincere bidding (recall Table 1).[26]

> *Conclusion 5:* Initial behavior largely replicates the differences reported earlier between Ausubel auctions with and without dropout information. Further, there appear to be some clear carry-over effects in going from auctions without dropout information to auctions with dropout information, as well as some generalized learning, as there are statistically significant increases in sincere bidding in both sessions compared to initial bids.

The top panel of data in Table 5 reports data for the last 12 auctions under the initial dropout information conditions, so that subjects would have had approximately the same experience as under the initial treatment conditions reported earlier. Both auctions show approximately the same degree of bidding above value, with no statistically or economically significant differences. However, there is half as much bidding below value on both units 1 and 2 in auctions with the dropout information compared to without it (p = .077, unit 1; p = .011, unit 2, two-tailed Mann-Whitney tests). This replicates the earlier results reported.[27] Note that, as before with $n = 5$, the underbidding has minimal effect on bidder earnings or efficiency between the two treatments.[28] Data for the last 12 auctions following the first change in dropout information conditions are reported in the middle panel of Table 5.[29] Comparing

[26]Two small changes were made in the instructions in sessions 6-8 to see if perhaps this was influencing the underbidding (see the Appendix). These small changes had no effect as witnessed by the replication of the earlier results for Ausubel auctions with the results reported here (compare top panel, Table 5 below).

[27]Further evidence to this effect is provided by Mann-Whitney tests comparing bidding here with the results reported earlier. These shows no significant differences from the earlier data reported except for a somewhat higher frequency of bidding above value and losing money on unit 2 bids with the dropout information here (p = .071), and higher revenue with the dropout information here (p = .01).

[28]These minimal effects are partly a consequence of employing 5 rather than 3 computer rivals as the probability of winning is lower than with $n = 5$, so that impact of underbidding on both these measures is reduced. There is, however, significantly higher revenue with the dropout information provided, largely as a result of excess revenues (relative to the sincere bidding benchmark) resulting from greater overbidding, when overbidding occurs, compared to the no dropout information auctions.

[29]This permits a number of replications for subjects to familiarize themselves with the new information conditions (recall Table 1).

bidding before and after the change in dropout information there is a dramatic reduction in the frequency of underbidding associated with the provision of dropout information as it is cut by more than 50% for both unit 1 and unit 2 bids.[30] Thus, the provision of dropout information has the predicted effect, sharply reducing bidding below value. In contrast, there is only a modest increase in the frequency of bidding below value in changing between dropout information and no dropout information, with this difference marginally significant ($p = .102$) for unit 2 bids. The fact that underbidding increases only modestly once dropout information is withdrawn for this group, suggests that subjects are able to internalize bidding rules from auctions with dropout information and apply them to auctions without this added information

The bottom panel of Table 5 reports the data for the final crossover back to the original dropout information conditions. The group with dropout information withdrawn largely maintains the increase in sincere bidding as there are only modest, statistically insignificant increases in underbidding on both units 1 and 2. Further, there are larger reductions in underbidding on both units for the group with dropout information restored, with the reductions statistically significant at better than the 5% level for both units. This last result is indicative of overall learning effects in the data, as the group that began with dropout information shows increases in sincere bidding on almost all dimensions: Statistically significant reductions in the frequency of winning and losing money as a consequence on both units 1 and 2 ($p < .01$ unit 1, $p < .05$ unit 2), marked reductions in underbidding on both units, with the change most prominent on unit 2 bids ($p < .01$), and marked improvements in both economic efficiency ($p < .01$) and in profits (p <

[30]These differences are statistically significant at better than the 5% level for unit 1 bids and at better than the 1% level for unit 2 bids, using a Wilcoxin signed-rank test with individual subject data as the unit of observation. Two-tailed tests are reported throughout.

.01).[31] These learning effects are observable here compared to earlier sessions as there are (i) many more auctions in each session giving subjects substantially more opportunities to learn and (ii) no changes in *n* to confound our observations and/or subjects' behavior.[32]

We can summarize the results of this section as follows: We confirm the importance of dropout information in helping to generate sincere bidding in dynamic Vickrey auctions when bidders have multi-unit demands. Providing experience with dropout information improves performance even after the dropout information is removed. This is not too surprising since rules-of-thumb and/or learning experiences in the presence of dropout information, which improve earnings, are unlikely to be discarded once the dropout information is removed. Finally, there is some evidence for experience alone improving performance since there is more sincere bidding over time, and significantly higher subject earnings and efficiency, in auctions that started and ended with the dropout information provided.

III Summary and Conclusions

We compare various forms of the Vickrey auction when bidders demand multiple units of a commodity - a sealed-bid Vickrey auction and dynamic Vickrey/Ausubel (1997) auctions with and without dropout information provided. With private values and non-increasing demand, all three auctions predict the same outcome, sincere bidding, although the strength of the solution concept varies between auction formats. Our main finding is that behavior in the Ausubel auction with dropout

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[31]We are comparing the data in the top panel of Table 6 with data form the bottom panel here.

[32]We might also speculate that the change in treatment conditions for this group promotes learning, as the withdrawal of dropout information and its reintroduction is bound to disrupt whatever routines bidders might have developed, setting off a new round of adjustments in bidding strategies. Evidence to this effect is also reported in Kagel and Levin (2001a; session 13).

information comes closer to sincere bidding than behavior in either the sealed-bid Vickrey auction or the Ausubel auction without dropout information, even though the auction with dropout information involves a weaker solution concept than the other two. Secondary results reported are (1) the differential effects of the language used to describe outcomes in the Ausubel auction without dropout information, which provides clear evidence of a framing effect, and (2) experience with the Ausubel auction with dropout information seems to improve performance even when the dropout information is eliminated.

Our main finding suggests a tradeoff between a mechanism that simplifies agents decision task versus one that relies on a stronger solution concept when the two do no coincide. The tradeoff seems to lie in the fact that transparency is valued by boundedly rational agents, so that it may more than offset the additional strategic ambiguity that may arise due to a weaker solution concept. This is particularly relevant when (as in our study) the incremental information simplifies a great deal while the incremental ambiguity is minimal. The question that remains is whether or not, and to what extent, this tradeoff will generalize beyond the present situation. Will it extend to situations where there is more behavioral ambiguity (as in competing against all human bidders)? Will it extend to situations when the more transparent mechanism is substantially weaker than the one employed here, i.e., a mechanism that requires several steps of iterated deletion of dominated strategies or one with a Nash equilibrium not supported in dominated strategies?

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Figure Captions

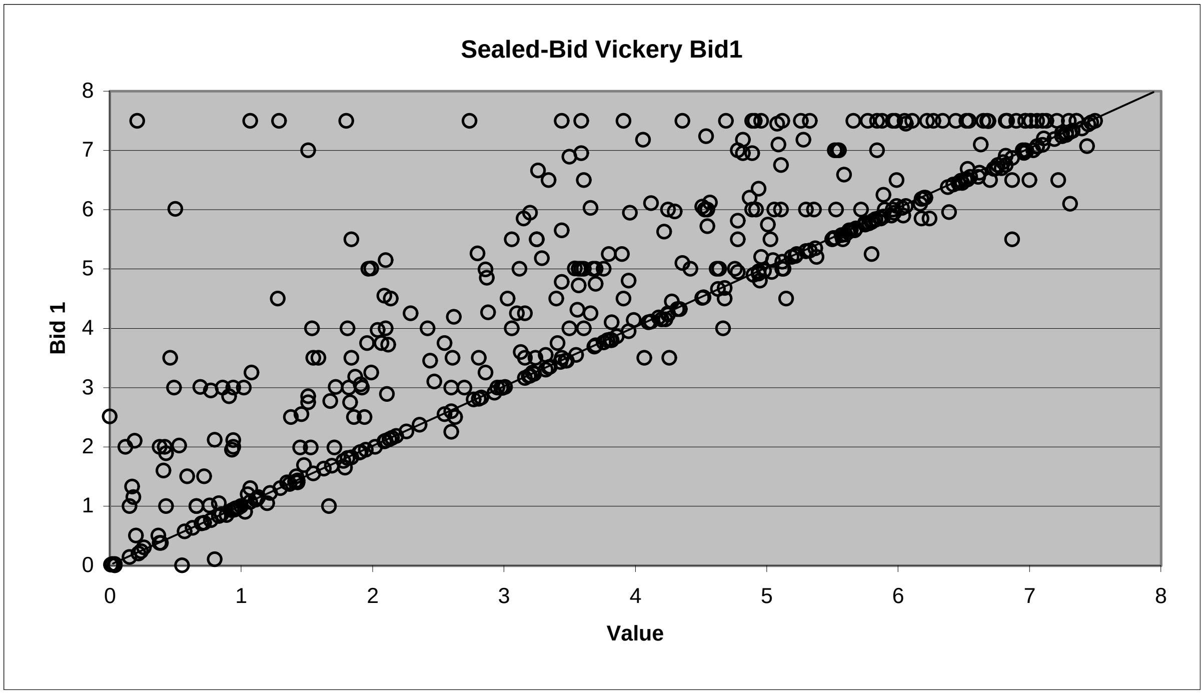
Figure 1: Bids in sealed-bid Vickrey auctions. Last 12 auctions with 3 computer rivals.

Figure 2: Bids in Ausubel auctions with drop-out information reported to bidders. Last 12 auctions with 3 computer rivals. " - items won (price paid); 9- drop outs at or below value; —, • - drop outs above value (see text).

Figure 3: Bids in Ausubel auctions with no drop-out information and sealed-bid instructions. Last 12 auctions with 3 computer rivals.

Figure 4: Bids in Ausubel auctions with no drop-out information and clinching instructions. Last 12 auctions with 3 computer rivals.

Figure 1
Sealed-Bid Vickery Auctions



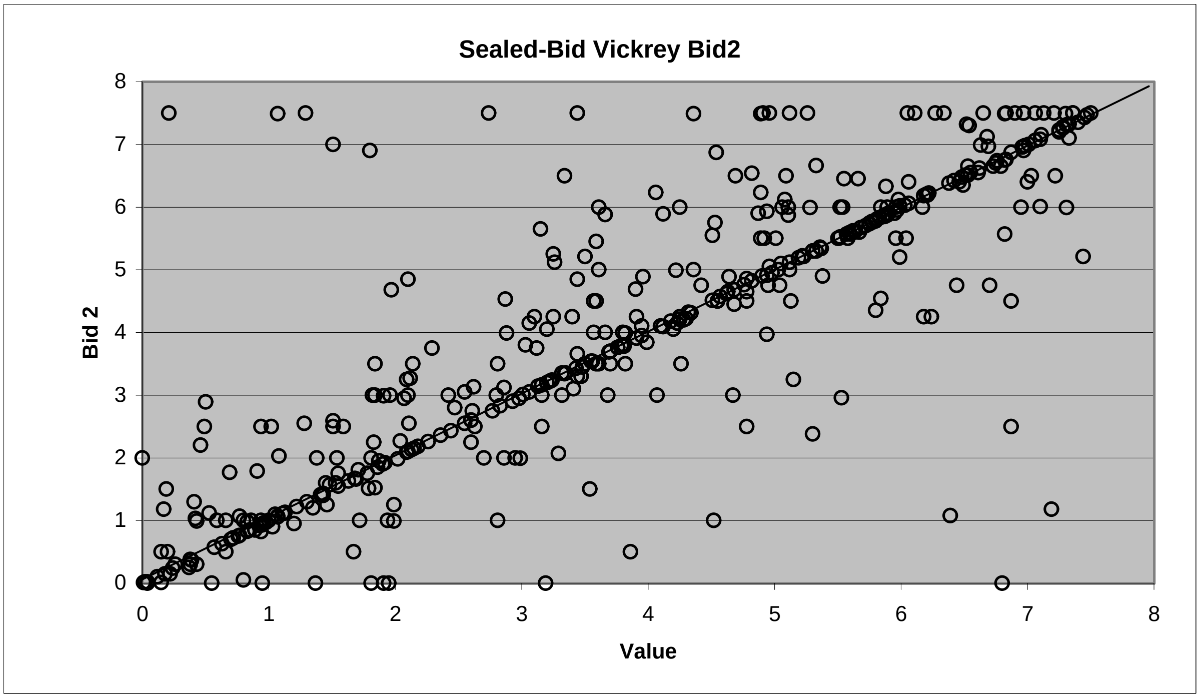
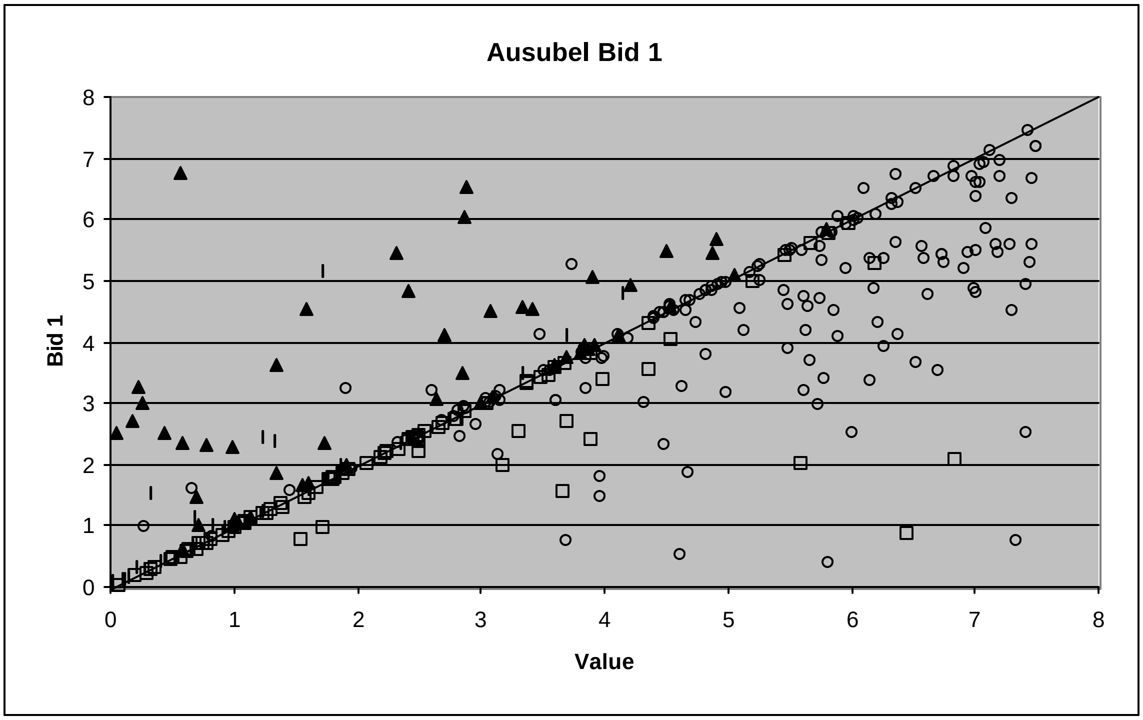


Figure 2
Ausubel



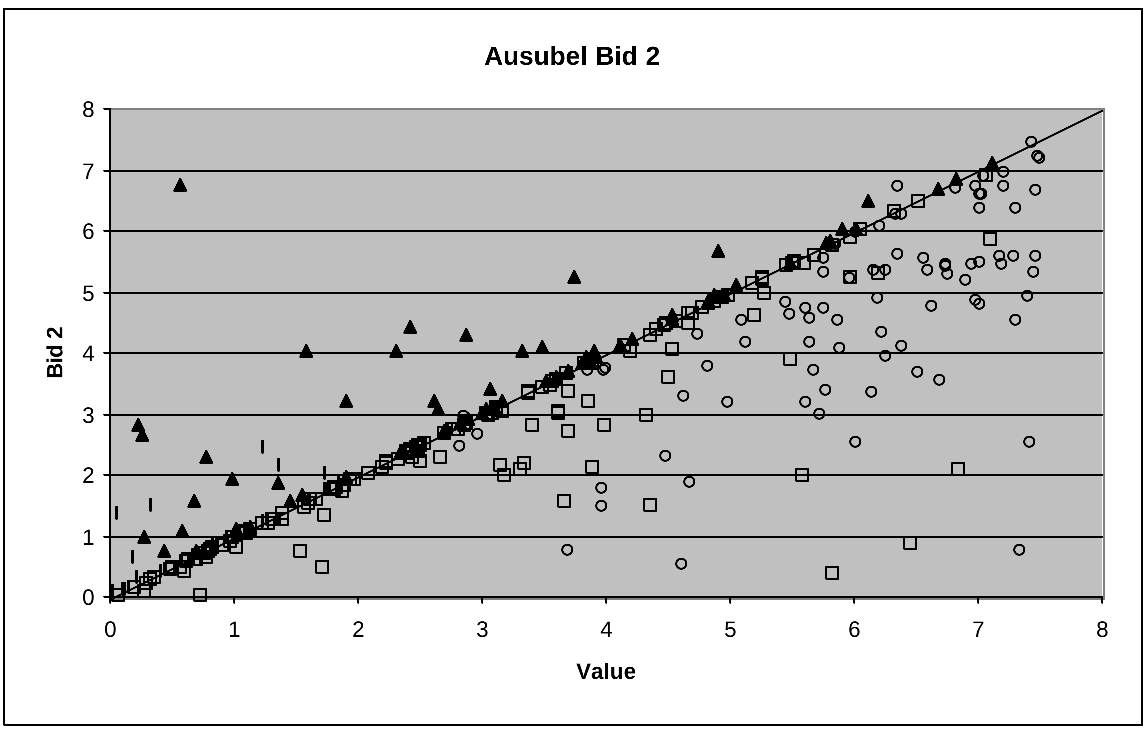
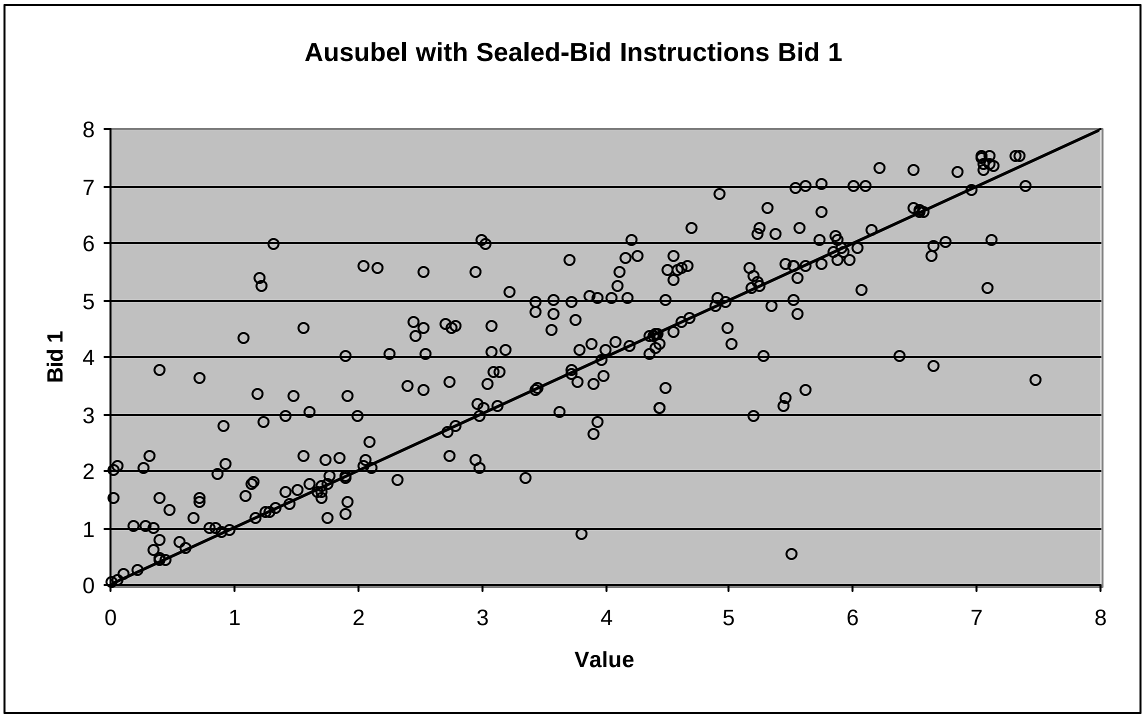


Figure 3
Ausuble with Sealed-Bid Instructions



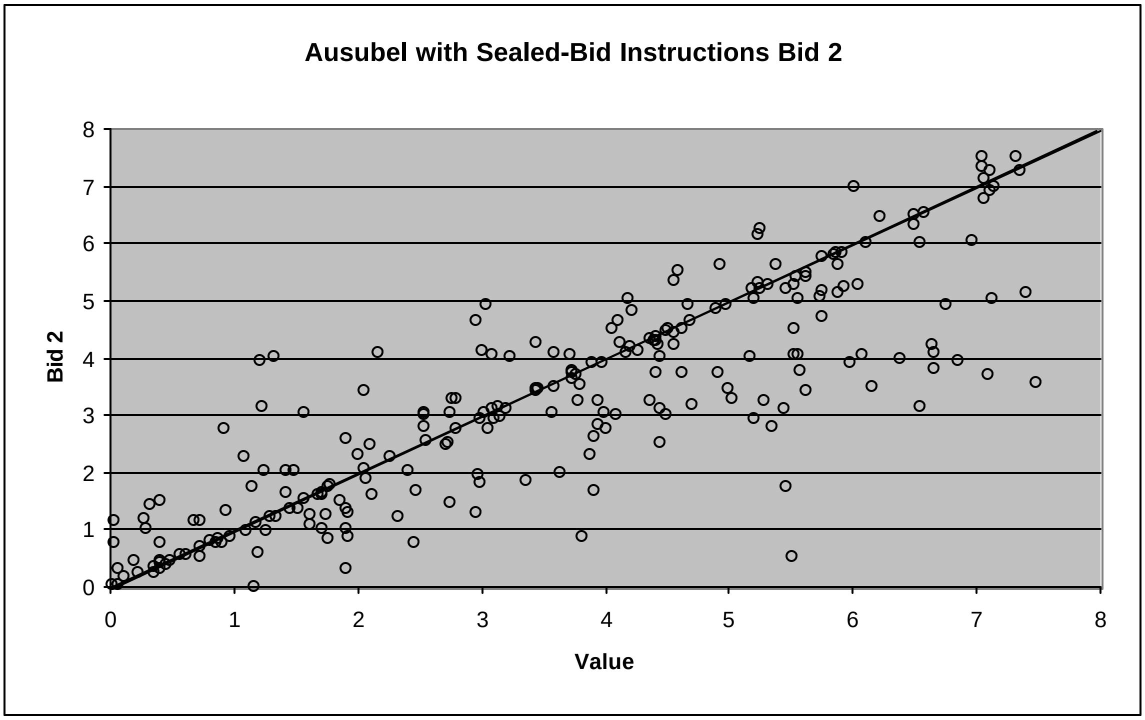
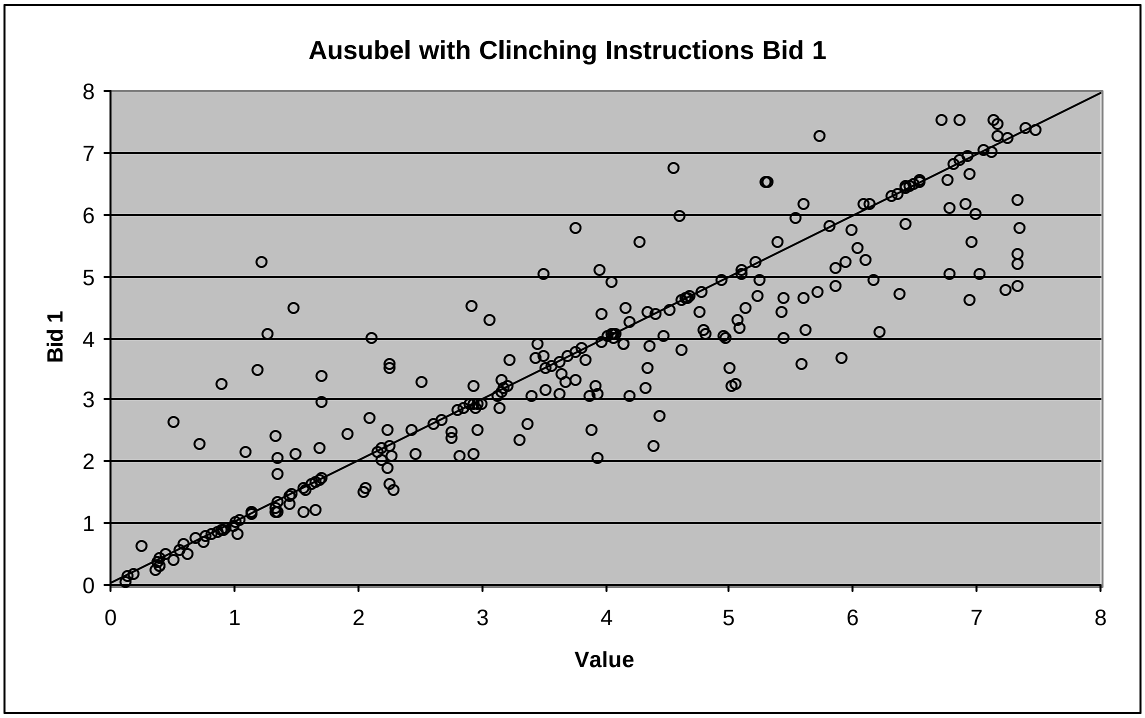


Figure 4
Ausubel with Clinching Instructions



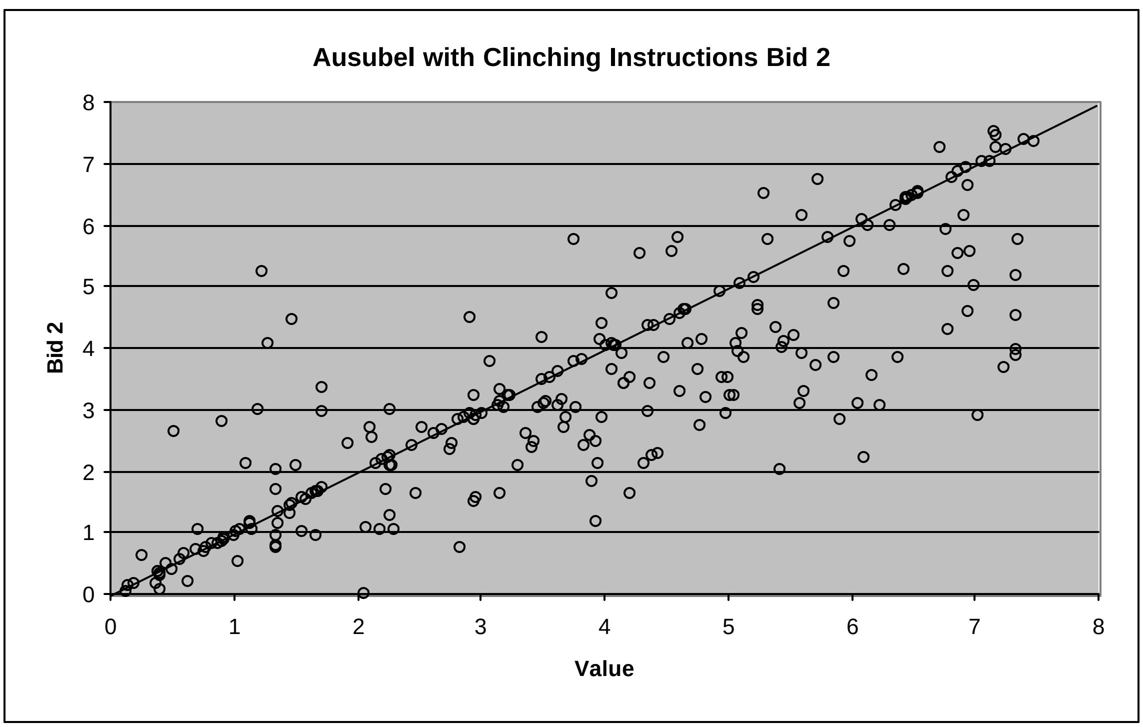


TABLE 1

	Experimental Sessions		
Institution	Session	Number of Computers	Number of Subjects
Sealed-bid	1	3 per 1-13 5 per 14-27	19
	2	5 per 1-13 3 per 14-27	18
Ausubel with drop-out information	3	3 per 1-13 5 per 14-27	14
	4	5 per 1-13 3 per 14-27	13
Ausubel, no drop-out information, clinching instructions	5	3 per 1-13 5 per 14-27	20
Ausubel, no drop-out information, sealed-bid instructions	6	3 per 1-13 5 per 14-27	20
Ausubel, with and without drop-out information	7[a]	5 per 1-46	20
	8[b]	5 per 1-45	18

a No bid information periods 1-14, bid information periods 15-31, no bid information periods 32-46

b Bid information periods 1-15, no bid information periods 16-30, bid information periods 31-45.

Table 2

Sealed-Bid Vickrey Auctions versus Ausubel Auctions
with Drop-Out Information: Bid Patterns

(Frequencies with standard error of the mean in parentheses)

n=3	Unit 1			Unit 2		
	Sealed-Bid	Ausubel	Difference: SB less Ausubel	Sealed-Bid	Ausubel	Difference: SB less Ausubel
Won and earned negative profits	0.155 (0.028)	0.068 (0.033)	0.087**	0.158 (0.041)	0.047 (0.039)	0.111*
Bid $> v_h$ with possible negative profits	0.364 (0.057)	0.214 (0.060)	0.150+	0.143 (0.034)	0.042 (0.015)	0.101+
Bid $< v_h$	0.061 (0.024)	0.160 (0.052)	-0.099+	0.248 (0.053)	0.255 (0.054)	-0.007
n=5						
Clinch with negative profit	0.238 (0.035)	0.061 (0.031)	0.177**	0.253 (0.055)	0.073 (0.046)	0.180**
Bid $> v_h$ with possible negative profit	0.243 (0.041)	0.085 (0.027	0.158**	0.086 (0.021)	0.023 (0.012)	0.063*
Bid $< v_h$	0.085 (0.031)	0.131 (0.037)	-0.046	0.208 (0.049)	0.219 (0.048)	-0.011

SB sealed-bid
+ Significantly different from 0 at the 10% level, two-tailed Mann-Whitney test
* Significantly different from 0 at the 5% level, two-tailed Mann-Whitney test
** Significantly different from 0 at the 1% level, two tailed Mann-Whitney test

Table 3

Sealed-Bid Vickrey Auctions versus Ausubel Auctions
with Drop-Out Information: Profits, Efficiency and Revenue

(differences from sincere bidding: sincere bidding less actual bids)

	Bidder Earnings			Efficency			Revenue		
	Sealed Bid	Ausubel	Difference: SB less Ausubel	Sealed Bid	Ausubel	Difference: SB less Ausubel	Sealed Bid	Ausubel	Difference: SB less Ausubel
n = 3	-0.241 (0.055)	-0.094 (0.043)	-0.147*	97.5% (0.56)	99.1% (0.38)	-1.55%*	0.443 (0.093)	-0.027 (0.134)	0.470**
n = 5	-0.229 (0.046)	-0.091 (0.043)	-0.138**	97.9% (0.45)	99.3% (0.35)	-1.42%**	0.377 (0.077)	-0.025 (0.040)	.0.407**

SB = sealed-bid.

* Significantly different from zero at the 5% level two-tailed Mann-Whitney Test

** Significantly different from zero at the 1% level two-tailed Mann-Whitney Test

Table 4
Ausubel Auction with No Drop-Out Information

	Unit 1		Unit 2				
n=3	Sealed-Bid Instructions (S_m)	Clinching Instructions (S_m)	Sealed-Bid Instructions (S_m)	Clinching Instructions (S_m)		Sealed-Bid Instructions (S_m)	Clinching Instructions (S_m)
Won and earned negative profit[a]	0.217 (0.055)	0.074 (0.030)	0.046 (0.026)	0.095 (0.055)	Bidder Earnings[b]	-0.191 (0.046)	-0.132 (0.034)
Bid $> v_h$ with possible negative profit[a]	0.301 (0.056)	0.167 (0.054)	0.087 (0.024)	0.039 (0.025)	Efficiency[c]	98.0% (0.51)	98.6% (0.39)
Bid $< v_h$ [a]	0.228 (.058)	0.449 (0.096)	0.527 (0.081)	0.566 (0.087)	Revenue[b]	0.166 (0.125)	-0.178 (0.140)
n=5					n=5		
Won and earned negative profit[a]	0.223 (0.063)	0.051 (0.025)	0.141 (0.070)	0.080 (0.050)	Bidder Earnings[b]	0.159 (0.054)	-0.065 (0.021)
Bid $> v_h$ with possible negative profit[a]	0.187 (0.041)	0.111 (0.043)	0.049 (0.016)	0.050 (0.027)	Efficiency[c]	98.6% (0.48)	99.5% (0.18)
Bid $< v_h$ [a]	0.134 (0.039)	0.353 (0.090)	0.426 (0.073)	0.528 (0.099)	Revenue[b]	0.247 (0.110)	-0.074 (0.084)

[a] Frequencies
[b] Difference from sincere bidding: sincere bidding less actual bids
[c] As a percentage of sincere bidding
S_m = standard error of the mean

Table 5

Ausubel Auctions With and Without Drop-Out Information

	Unit 1			Unit 2						
A	With Information (S_m)	Without Information (S_m)	Difference[b] (| p | = 0)	With Information (S_m)	Without Information (S_m)	Difference[b] (| p | = 0)	A	With Information (S_m)	Without Information (S_m)	Difference[b] (| p | = 0)
Won and earned negative profit[a]	0.164 (0.059)	0.152 (0.050)	0.012 (p=.947)	0.190 (0.074)	0.250 (0.115)	-0.06 (p=.903)	Bidder Earnings[c]	-0.246 (0.113)	-0.222 (0.067)	0.024 (p=.294)
Bid > v_h with possible negative profits[a]	0.102 (0.032)	0.120 (0.060)	-0.018 (p=.512)	0.020 (0.011)	0.046 (0.026)	-0.026 (p=.945)	Efficiency[d]	97.8% (0.98)	98.2% (0.60)	-0.4% (p=.32)
Bid < v_h [a]	0.144 (0.054)	0.331 (0.072)	-0.187+ (p=.077)	0.230 (0.057)	0.497 (0.071)	-0.267+ (p=.011)	Revenue[c]	0.276 (0.131)	0.025 (0.140)	0.251** (p = .008)
B	Without Information	With Information	Difference	Without Information	With Information	Difference	B	Without Information	With Information	Difference
Won and earned negative profit[a]	0.121 (0.051)	0.114 (0.040)	-0.007 (p=.859)	0.151 (0.070)	0.128 (0.052)	-0.023 (p=.806)	Bidder Earnings[c]	-0.201 (0.076)	-0.146 (0.084)	-0.055 (p=.259)
Bid > v_h with possible negative profit[a]	0.080 (0.036)	0.156 (0.060)	0.076 (p=.427)	0.017 (0.012)	0.046 (0.036)	0.029 (p=.765)	Efficiency[d]	98.2% (0.71)	98.8% (0.69)	0.6% (p=..36)
Bid < v_h [a]	0.190 (0.060)	0.121 (0.039)	-0.069 (p=.382)	0.365 (0.075)	0.233 (0.051)	-0.132 (p=.150)	Revenue[c]	-0.009 (0.081)	0.166 (0.101)	0.175 (p = .144)
A	With Information	Without Information	Difference	With Information	Without Information	Difference	A	With Information	Without Information	Difference
Won and earned negative profit[a]	0.044 (0.024)	0.028 (0.019)	0.016 (p=.609)	0.103 (0.057)	0.054 (0.032)	0.049 (p=.751)	Bidder Earnings[c]	-0.045 (0.026)	-0.015 (0.010)	0.030 (p=.581)
Bid > v_h with possible negative profit[a]	0.065 (0.027)	0.088 (0.040)	-0.023 (p=.954)	0.006 (0.006)	0.059 (0.033)	-0.053 (p=.160)	Efficiency[d]	99.6% (0.24)	99.9% (0.08)	0.3% (p=.581)
Bid < v_h [a]	0.074 (0.034)	0.198 (0.060)	-0.124+ (p=.062)	0.182 (0.049)	0.274 (0.066)	-0.092 (p=.381)	Revenue[c]	0.039 (0.294)	0.014 (0.044)	0.025 (p = .370)

[a] Frequencies

[b] With information less without information

[c] Difference from sincere bidding: sincere bidding less actual bids.

[d] As a percentage of sincere bidding.

S_m = standard error of the mean.

\+ Significantly different from 0 at the 10% level, two-tailed Mann-Whitney test

* Significantly different from 0 at the 5% level, two-tailed Mann-Whitney test

** Significantly different from 0 at the 1% level, two-tailed Mann-Whitney test