

Implementing Efficient Multi-Object Auction Institutions:
An Experimental Study of the Performance of Boundedly Rational Agents*

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Abstract

We study two alternative versions of the Vickrey (1961) auction when bidders have multi-unit demands: the original, static sealed-bid Vickrey auction and a dynamic Vickrey auction with drop-out information reported during the auction (Ausubel, 1997). The Ausubel auction comes significantly closer to sincere bidding than the static Vickrey auction even though the latter has a stronger solution concept (implementation in weakly dominated strategies versus iterated deletion of weakly dominated strategies). This suggests a tradeoff between the simplicity and transparency of a mechanism and the strength of its solution concept for less than fully rational agents. The behavioral mechanism behind this result is explored through a series of experimental manipulations.

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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 single-unit demand case is well known, the multi-unit version is relatively obscure and much more complex. Thus, it's rarely advocated since many economists believe that bidders will fail to follow the dominant bidding strategy 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 do not use the dominant strategy even in the simpler single-unit demand (second-price) Vickrey auction. In contrast, the same bidders quickly adopt the dominant strategy in the strategically equivalent single-unit, ascending-bid, "English clock" auction (Kagel, Harstad and Levin, 1987).

Mainly in response to these concerns Ausubel (1997) proposed a dynamic implementation of Vickrey's multi-unit auction designed to mimic the success of the English clock auction in the single-unit case, as bidders receive information about dropout prices as they occur and items won are announced as the auction proceeds.¹ With private values and (weakly) diminishing marginal valuations, sincere bidding is a weakly-dominant strategy in the multi-unit static Vickrey auction. In contrast, and perhaps somewhat surprisingly, sincere bidding is no longer a dominant strategy *with* drop-out information provided, although it remains an

¹Also see Perry and Reny (2000) for similar developments, out of similar concerns, in this case for multi-unit demand auctions with interdependencies between units.

equilibrium in iterated deletion of (weakly-) dominated strategies (Ausubel, 1997, Theorem 2).

Two experiments are reported here comparing the static, multi-object Vickrey auction to the Ausubel auction with drop-out information. Both experiments employ *an independent-private-value* (IPV) framework in which bidders have weakly diminishing marginal valuations. In the first experiment human bidders demanding two units compete against computer rivals, each of which demand a single unit and are programmed to follow the dominant strategy of sincere bidding (a fact known to the human bidder). This is the simplest implementation of both mechanisms that still maintains their essential behavioral differences. The Ausubel auction with drop-out information generates behavior closer to sincere bidding, and significantly higher efficiency, than the static Vickrey auction. To better understand the superior performance of the Ausubel auction, we also conduct Ausubel auctions *without* drop-out information and static Vickrey auctions with information about rivals' valuations.

Critics can argue that the structure of our first experiment is biased against the static-Vickrey auctions in two ways. First, by having single-unit bidders compete against a single rival demanding multiple units, the Ausubel auction with drop-out information involves a *single* round of iterated deletion of weakly dominated strategies for the multi-unit demand bidder. Second, by replacing the single unit bidders with computers who are known to bid sincerely, we have eliminated the first step in the process of iterated deletion of dominated strategies, so that the solution concepts are essentially the same between the static Vickrey auction and the Ausubel auction with drop-out information. In addition, it has been suggested that in auctions with all humans, bidding errors are likely to cancel out, thereby restoring efficiency, the key attribute that the static Vickrey auction is designed to achieve.

Our second experiment is conducted to address these issues. In it all human bidders each demanding two units compete against each other, thereby introducing *multiple* steps of iterated deletion of (weakly) dominated strategies required to generate sincere bidding in the Ausubel auction with drop-out information, and providing clear differences in the strength of the solution concepts underlying sincere bidding between the two institutions. Here too, the Ausubel auction with drop-out information generates behavior closer to sincere bidding, and significantly higher efficiencies, with even more pronounced differences from the static Vickrey auction than in our first experiment with computer rivals.

Our results contribute directly to the debate of which type of auction performs better, static or dynamic. They also have important implications for the entire mechanism design literature. They demonstrate that focusing solely on equilibrium strength and properties of the solution concept in deciding among alternative mechanisms may well be misleading when agents are less than fully rational. 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 and transparency embedded in a dynamic mechanism, and behave closer to the predicted allocation, even if it is implemented by a mechanism with a weaker solution concept.

We are familiar with four other experimental studies of Vickrey type auctions with 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).² The fourth, Manelli, Sefton, and Wilner (1999), is closest in spirit to ours, with one treatment comparing a sealed-bid Vickrey auction with an Ausubel auction with drop-out information when bidders have private values and non-increasing demand for additional units. We employ a much finer grid of values and price increments (with valuations and prices quoted to the penny) than Manelli et al., and structure the auction so as to always insure a smooth transition from excess demand to excess supply conditions.³ Further, we have substantially more observations, and we compare different versions of the Ausubel auction (with and without price drop-out information), and different versions of the static-Vickrey auction (with and without information about rivals' valuations), in order to better understand the mechanism underlying the improvements in performance of the Ausubel auction with drop-out information.

The paper proceeds as follows: Section I briefly outlines our experimental design and the alternative auction mechanisms. Section II reports the results for auctions with computerized rivals. Section III gives results for auctions with all human bidders. We end with a brief discussion and summary of our results as they apply to auctions and to other experiments investigating mechanism design issues.

I: Experimental Design

Theoretical Considerations: We investigate bidding in IPV auctions with n bidders and m

²In the same vein Kagel and Levin (2001a) compare the Ausubel auction with drop-out information with a uniform-price auction when bidders have multiple-unit demands. investigating mechanism design issues

³Private values were drawn with replacement from a set of six values discrete values in Manelli et al. In addition bidders quote amounts demanded as prices increase discretely so that in a number of cases more than one bidder drops out following a price increment, so that the market goes from excess demand to excess supply. In these cases unassigned units are not allocated and the auction ends.

indivisible identical objects for sale, where $n \geq m$. Each bidder i ($i = 1, \dots, n$) demands up to two units of the good, placing value v_{ij} on good j . Bidders' values are drawn *iid* from a *uniform* distribution on the interval $[0, V]$.

In the Vickrey auction each bidder simultaneously submits a separate sealed-bid for each unit demanded. These are ranked from highest to lowest, with the m highest bids each winning an item and paying the amount of the k th highest rejected bid other than her own for the k th object won. Thus, in cases where a bidder wins only one item she pays the $m + 1$ highest bid *provided this is not her bid* (in which case she pays the $m + 2$ highest bid). And in cases where a bidder wins both items the total payment is the sum of the $m + 1$ and the $m + 2$ highest bids.

The Ausubel auction employs a price “clock” which starts at zero and increases 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_0 , bidder i 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 i has clinched winning an item no matter how the auction proceeds. As such bidder i is awarded one item at the clinching price, p_0 . This process repeats itself with the supply reduced from m to $m - 1$ and with i 's demand reduced by one unit. In this way the auction sequentially implements the Vickrey rule that each bidder pays the amount of the k th highest rejected bid, other than his own, for the k th object won.

With drop-out information, all drop-out prices are publicly reported as they occur, along with units clinched and the price at which they were clinched. No such information is provided

in the Ausubel auction without drop-out information. Sincere bidding is a weakly dominant strategy absent drop-out information since bidders have the same information set at their disposal as in the sealed-bid auctions. In contrast, in the Ausubel auction with drop-out information, sincere bidding is the unique equilibrium surviving *iterated elimination* of (weakly-) dominated strategies (Ausubel, 1997).⁴

Experimental Procedures: Valuations were drawn iid from a uniform distribution with support $[0, \$7.50]$ with new, random draws in each auction. In auctions with computerized rivals a single human, 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 that the computers were bidding their randomly drawn valuations (but not the logic underlying this strategy). In all of these auctions, supply, m , was set at two, with h having flat demand for two units. The number of computer rivals was either 3 or 5. This environment preserves the essential elements underlying the multi-unit demand Vickrey auction in a highly simplified setting. It also permits direct comparisons with a companion series of uniform-price multi-unit demand private value auctions both with and without synergies (Kagel and Levin, 2001 a, b).

Auctions with all human bidders employed four bidders in each market, with each bidder demanding two units. Two or more markets operated simultaneously, with subjects randomly reassigned to markets between auctions. Demands were weakly decreasing, employing two

⁴ The Ausubel auction with drop-out information has a number of theoretical advantages over the static Vickrey auction or the Ausubel auction without drop-out information when valuations have a common value component.

independent draws from the uniform distribution $[0, \$7.50]$. Supply, m , was either 2 or 3 units.⁵

All of the Ausubel auctions employed a “digital” price clock with a price increment of \$0.01 each 0.1 second in auctions with computer rivals and increments of \$0.25 each 3 seconds with all human bidders.⁶ In the Ausubel auctions with drop-out 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 bidders could tell at exactly what price a rival has dropped out. In the auctions with computerized rivals and drop-out information there was a 0.3 second pause in the price clock following a dropout, during which time h could drop out. These dropouts are recorded as dropping at the same price, but are indexed as dropping later than the dropout that initiated the pause.⁷ When bidders clinched an item the clinching price was automatically recorded on her computer screen just below the value of the item, with the profits earned for that item reported just below this. This occurred on the section of the computer screen just above the price clock so that a bidder would have to be totally preoccupied to fail to take account of this information.⁸ Following completion of an auction all dropout prices and

⁵Once we decided to go with all human bidders *each* demanding two units there were bound to be differences with the auctions with computerized rivals. We used weakly decreasing demands to increase the number of decisions bidders had to make. We varied supply both to keep things interesting and to see if there were any noticeable differences given the reduced level of competition associated with the increased supply.

⁶The larger increments and increased tick times were necessary to keep the clocks synchronized while simultaneously recording dropouts and reporting these results to bidders.

⁷The 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 drops out. This requires allowing “moves that occur consecutively at the same moment in time” (Simon and Stinchcombe, 1989; also see Ausubel, 1997). Given the increased time between price increments in the auctions with all human bidders, there was no need to introduce an additional pause following dropouts since these could be reported to all bidders within the tick time.

⁸Clock auctions with no drop-out information maintained the pause in the price increases following h dropping out on a single unit, thereby keeping procedures as close as possible to auctions with drop-out information, but eliminated the pause or any information regarding single-unit bidders drop-out prices, own

valuations were reported back to subjects, with dropout prices ranked from highest to lowest, and with own bids clearly distinguished from rivals.⁹

In the sealed-bid auctions subjects submitted bids on both units simultaneously. All bids and corresponding valuations were reported back to subjects, with bids ranked from highest to lowest, and with own bids clearly distinguished from ones rivals. 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 (Kagel and Levin, 2001a).

Finally, one sealed-bid session with computer rivals was conducted in which the value of the second-highest computer was posted on bidder's screens prior to bidding. This treatment effectively provides most of the essential information available to bidders in the Ausubel auction with drop-out information provided. We conduct this totally synthetic auction to demonstrate the potential for the drop-out information to induce sincere bidding, absent any understanding of the Vickrey logic.¹⁰

Instructions were read out loud to subjects, with copies for them to follow along with as well. The instructions included examples of how the pricing rules worked. The examples included hypothetical bids for auctions with computerized rivals, but provided essentially the

earnings, or anything else prior to the price having reached its maximum value.

⁹The clock auctions with drop-out information reported xxx in place of the winning (censored) bids.

¹⁰There was no discussion of how bidders might use c_2 to ease the logical difficulties in determining how to bid. It was implied for them to figure out how to use.

same information regarding the pricing rules without any examples for the auctions with all human bidders. This last change was designed to minimize any possible inadvertent guidance we might have been providing subjects on how to bid.¹¹

All sessions began with several dry runs followed by a number of “wet” runs (see Table 1). Auctions with computerized rivals employed a broad cross section of students from the University of Pittsburgh and Carnegie Mellon University. Bidders were given starting capital balances of \$5 with profits and losses added to this as they occurred. Auctions with all human bidders employed a broad cross section of students from Ohio State University. Bidders were given starting cash balances of \$8. In both experiments balances were paid in cash at the end of the session and expected profits were sufficiently high that no participation fee was provided.¹² Sessions lasted between 1.5 and 2 hours. There are a number of small differences between the auctions with computerized rivals and those with all human bidders, yet, we believe that comparing the two is useful. In any event, since the static Vickrey auction and the Ausubel auctions *within* each experiment employ exactly the same procedures (except for the different auction institutions), and the same subject population, comparing them is without any confounds potentially exists in comparing between experiments.

¹¹A complete set of instructions are maintained at the web site <http://www.econ.ohio-state.edu/kagel/MultunitVick.instructions.pdf>.

¹²The larger starting cash balances were designed to avoid negative cash balances which might induce bidders to bid strangely, or worse yet, to leave early which would compromise the experimental design. Cash balances for all bidders remained non-negative throughout except for a few bidders in the auctions with computerized rivals. Note that the presence or absence of negative cash balances has no impact on bidding strategies in this design given the role of dominance. Further, in using Mann-Whitney tests to analyze the data, our results are robust to the inclusion or exclusion of these few bidders in the analysis.

II. Results for auctions with computerized rivals.

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

Conclusion 1: There is considerably more bidding above value in sealed-bid compared to Ausubel auctions so that there is 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 drop-out information.¹³ 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.¹⁴ Statistical tests are all non-parametric Mann-Whitney tests, with average subject data as the unit of observation. For unit 1 bids with $n = 3$, a little more than 15% of the time bidders win and lose money in the Vickrey 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.¹⁵ (The row labeled “bid $> v_h$ with possible negative profit.”) Finally there is somewhat more underbidding relative to v_h in the Ausubel auctions, but these differences are only marginally significant for unit 1 bids with $n = 3$.

Conclusion 2: Bidders earnings and auction efficiency are significantly lower in the Vickrey auctions compared to the Ausubel auctions. However, the greater overbidding in

¹³Winning bids are censored in the Ausubel auction but not in the Vickrey auction. By treating winning bids separately, and simply determining whether they were profitable or not, we are employing information that is available for both treatments and nothing more. All remaining bids are not censored and hence on the same footing.

¹⁴All data reported are averages computed over subject averages for the last 12 auctions. Thus, individual subject behavior serves as the unit of observation avoiding possible repeated measure problems.

¹⁵Potentially harmful overbids are defined as drop outs on unit 2 bids that occurred before or exactly when the number of computers went down to three; for unit 1 bids before or exactly when the number of computers went down to two. We applied a like definition for the Vickrey auctions.

the Vickrey auctions results in significantly higher revenue.

Table 3 reports bidder earnings (profits), efficiency, and revenue. All outcomes are reported in terms of deviations from sincere bidding. For example, with $n = 3$, in the 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 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. Further, it should be kept in mind that since the computers follow the dominant bidding strategy, there is not much room for efficiency losses using this measure.¹⁶

Alternatively, we can compare efficiencies here to efficiencies in a companion series of multi-unit demand uniform-price clock auctions with exactly the same experimental structure (Kagel and Levin, 2001a). These auctions call for limit prices to be equal to value for unit 1 and for unit 2 bids to never affect the market price (effectively zero bids) for h . Efficiencies in the uniform-price auctions, which were quite close to predicted levels, averaged 97.4% and 98.3% with $n = 3$ and 5, respectively. Thus, at best, the static Vickrey auction yields only a modest

¹⁶An alternative efficiency measure sometimes used in auctions is the percentage of times the highest valued units are the winning units. Using this 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.

improvement in efficiency relative to these uniform-price auctions. In contrast, the Ausubel auction with drop-out 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. Given the overbidding relative to value, actual revenue is substantially *higher* than with sincere bidding in the 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 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.

The overbidding reported in the sealed-bid auctions raises the question of why don't the losses force subjects to reduce their bids? 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 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). Thus bidders rarely end up with negative average profits as a result of bidding above v_i . This occurred for 2 out of 37 bidders, with losses averaging less than 8¢ per auction in both cases. Given that the Vickrey payment rules are sufficiently complicated that the dominance argument against bidding above value is not immediately transparent, the feedback for this overbidding (provided it does not get too far out of hand) is, apparently, not sharp

enough to eliminate the behavior.¹⁷

Ausubel Auctions with No Drop-out information:

Conclusion 3: The Ausubel auction with no drop-out information has the same curative effect on overbidding compared to the Vickrey auction as the Ausubel auction with drop-out information. However, there is significantly less sincere bidding than in the Ausubel auction with drop-out information as there is substantially more underbidding relative to valuations.

Table 4 reports bid patterns for the clock auctions without drop-out information and the differences in these patterns compared to the auctions with drop-out information provided. First, there is roughly the same (low) frequency of clinching units and losing money.¹⁸ Further, there is roughly the same overall frequency of bidding above v_h and possibly earning negative profits. However, there is substantially more *underbidding* relative to v_h for both units compared to the Ausubel auctions with drop-out information, with the frequency of bidding below v_h being at least double that reported for auctions with drop-out information (compare Table 2 with Table 4; these differences are statistically significant at the 10% level or better in all cases). This results in a small, but statistically significant reduction in efficiency compared to the auctions with drop-out information for the case of $n = 3$.

The differences in the pattern of deviations from sincere bidding between the Vickrey auction and the Ausubel auction with no drop-out information are quite striking and raise the obvious question of what accounts for them? These results also provide clues regarding the behavioral mechanism underlying the superior performance of the Ausubel auction with drop-out

¹⁷Recall that our experimental design - competing against computer rivals - permits us to rule out rivalrous behavior as the explanation for bidding above value.

¹⁸To account for censoring in comparing the two action institutions we make the same adjustments to the data as noted in footnote 11 comparing the Ausubel auction with drop-out information to the Vickrey auction.

information. First, the characterization of the auction mechanism in terms of the clinching rules appears to play a critical role in alerting bidders to the fact that it is not in their best interest to bid above their value. We know this because we have implemented an Ausubel auction with no drop-out information but one in which we described the auction mechanism using the same terminology as in the sealed-bid auctions. Results from this treatment showed essentially the same frequency of winning and earning negative profits for unit 1 bids, as well as bidding above v_h and not losing money, as the static Vickrey auction.¹⁹

This still leaves open the question of why there is underbidding in the Ausubel auction without drop-out information but not in the Ausubel auction with drop-out information. Here we offer the following conjecture: First, it is clear that most, if not all, of our bidders do not recognize the dominant bidding strategy. The clinching instructions, in conjunction with the clock induce them not to bid above v_h , but they still do not know exactly when to drop out. With the clock and the drop-out information there is often no decision to be made as they are likely to clinch an item well before they must seriously consider dropping out. Further, being rewarded in these cases can only encourage them to remain active longer. At the same time clinching an item with profits computed on the spot provides immediate feedback that bidding above value in order to win an item is patently silly, which serves to largely eliminate such bids. Finally, with higher values, when they should win an item, seeing their rivals drop out at lower prices should encourage bidders to remain active, as the chances of winning and making a positive profit

¹⁹See our working paper (Kagel, Kinross, and Levin, 2001) for these results. Note, however, that unit 2 bids do not show this same pattern but rather underbidding relative to v_h as in the Ausubel auctions without drop-out information and the clinching instructions. Although we do not know exactly what role the clinching instructions play independent of the clock implementation, it would seem to require a clock or some other dynamic framework for the clinching rules to be described naturally and most transparently.

grows (provided they don't bid above their value) as the number of rivals decreases. In short, bidders are encouraged to follow the simple strategy of remaining active until the price reaches their value.

In contrast, without the drop-out information bidders must always decide when to drop out. That is, they get no "effortless" wins: clinching an item well before thinking about dropping out. And they get no encouragement with high valuations to remain active as they see their rivals dropping out. Given that the dominant bidding strategy is not transparent, and that the clinching rules induce them not to bid above value, they are essentially left with only one type of mistake to make, bid below value. This type of mistake involves opportunity costs, as opposed to out of pocket costs, which requires somewhat deeper reasoning to identify as a mistake (e.g., you must first look at what you bid, look at what the winning computer(s) bid, determine that their bids were below your value, and then calculate your forgone profits had you topped the computer's bid). Apparently, such depth of reasoning is not transparent to most people (see, for example, Nagel, 1995, Stahl, 1993).²⁰

Sealed-Bid Auctions with the Second-Highest Computer Bid Announced:

In conducting static-Vickrey auctions with the second-highest computer value/bid announced (c_2) we provide bidders with most of the critical information provided in the dynamic auction with drop-out information. At the same time we have greatly simplified the decision

²⁰We also investigated whether our instructions had, perhaps, inadvertently emphasized the prospect of losing money too strongly and this interacted with the clinching instructions and the absence of drop-out information to promote bidding below value, or perhaps we had simply drawn an odd sample of subjects. Thus, we ran two additional sessions removing the potentially biased elements from the instructions for Ausubel auctions both with and without drop-out information. We replicated the results reported in the text. These sessions also employed a crossover design to determine if bidders provided with the drop-out information would internalize the bidding rules and apply them correctly to the auctions without the drop-out information. The results clearly suggest some carryover effects of this sort (Kagel, Kinross, and Levin, 2001).

process for the human bidders, since providing c_2 immediately informs h whether she ought to win a unit or not: Clearly when $v_h < c_2$, winning (any unit) assures losses and when $v_h \geq c_2$ winning, at least, one unit is profitable. It is only when it comes to bidding on her second unit that h must apply the Vickrey logic.

Indeed, the data shows that with c_2 announced bidders fully capitalize on the simplification: There are only a handful of winning bids when $v_h < c_2$ (11 out of 287 such bids; 3.8%). And bidders almost never miss the opportunity to earn non-negative profits on at least one unit when $v_h \geq c_2$ (in only 2 out of 193 such cases; 1.0%). It is only when these same bidders get to the point of needing to apply the Vickrey logic with respect to their second unit that there are any sizable deviations from “rational” bidding, with some 62.2% (120/193) of all such bids deviating from sincere bidding by more than 5ϕ .

Results from this synthetic auction highlight and confirm that it is indeed the simplification of the decision task provided by the drop-out information in the Ausubel auction that is responsible for its superior performance over the static-Vickrey auction. Further, in the Ausubel auction, when $v_h \geq c_2$ the multi-unit bidder has the opportunity to see the relationship between the highest computer value and her value, which even obviates the need to apply the Vickrey logic to her second unit. Clearly, not everyone will take advantage of these opportunities (there are always trembles and mistakes), but they are present when the drop-out information is provided.

III. Results for auctions with all human rivals.

Conclusion 4: Results from auctions with all human bidders are qualitatively similar to auctions with computer rivals: There is substantially more sincere bidding, higher efficiency, and less revenue in the dynamic Ausubel auctions than in the static Vickrey auctions. Further, quantitatively, these differences are more pronounced in auctions with

all human bidders.

Table 5 reports bid patterns in the auctions with all human bidders.²¹ There is significantly more bidding above value, both when winning units and losing money, and when not winning in the static Vickrey auctions at both supply levels and for both units. Further, a quick look at Table 2 compared to Table 5 shows that, if anything, the overbidding is more pronounced in the static Vickrey auctions with all human bidders than against computerized rivals, whereas the pattern for the Ausubel auctions is mixed. The overbidding in the all human Vickrey auctions is much more likely to result in large losses conditional on winning since others are also overbidding. One would think that this would produce a stronger learning/adjustment effect but none is apparent in the data. The fact that it does not occur may well represent misguided imitation of rivals' bids and/or imitation of the computers' bids in the earlier auctions.²² As for bids below v_h there are no significant differences between the two auction formats.

Table 6 reports market outcomes. Profits (relative to optimal bidding) are significantly and substantially lower in the static Vickrey auctions than in the Ausubel auctions - differences in the neighborhood of \$1.50 or more per auction. These are substantially larger differences than in auctions with computer rivals, consistent with the fact that overbidding here typically results in substantially larger losses due to others' overbidding. Efficiencies are significantly higher in the Ausubel auction than in the static Vickrey auctions, with these differences also larger than in

²¹Comparisons here and in Table 6 are based on the first 12 period cycle with $m = 2$ as there are substantially more subjects present in the clock auctions (recall Table 1). Results are qualitatively similar if we were to use the last $m = 2$ cycle. Given the 25¢ increments in the clock we counted as dropping out at value as dropping immediately before or after the closest 25¢ increment to bidders' values. For the sealed-bid auctions we counted as bidding equal to value any bid within $\pm 12.5\%$ of value.

²²Recall that bidders get to see all bids and valuations ranked from highest to lowest following each auction under both formats.

the auctions with computer rivals.²³ Finally, consistent with the overbidding in the static Vickrey auctions, seller revenue is substantially higher than in the Ausubel auctions, and substantially higher than in the auctions with computer rivals.

Our results on greater overbidding in the Vickrey auction compared to the Ausubel auction with drop-out information are similar to those reported in Manelli et al. (1999). This overbidding results in significantly higher revenue for the sealed-bid auctions in both our experiment and in theirs. However, Manelli et al. find no differences in efficiency between the two auctions. This may well be the result of the far fewer observations in Manelli et al. and/or the coarseness of bidder valuations in their auctions, so that bidding errors comparable to those reported here will tend to produce fewer inefficient allocations.²⁴

IV Discussion and Concluding Remarks

The closer conformity to equilibrium bidding strategies reported here for a dynamic auction with rivals drop-out information provided versus a sealed-bid auction replicates results reported for 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 drop-out information provide a transparency that is lacking in static sealed-bid

²³These differences are even more dramatic using the alternative efficiency measure - the frequency with which high value holders win units - with minimum average efficiency differences of 14.5%. Further, back of the envelope calculations for uniform price auctions (which call for truthful revelation on the higher valued unit and complete demand reduction on the lower valued unit) yield average efficiencies of 99.1% with $m = 2$ and 96.5% with $m = 3$.

²⁴Manelli 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. Supply was 3 units and each bidder had flat demand for 2 units.

auctions. However, in contrast to these other auction environments, where *the same* solution concepts underlie both the dynamic and static auctions, here the strength of the solution concept differs between auction formats: The Vickrey auction generates sincere bidding as a dominant strategy. The equilibrium solution for the Ausubel auction with drop-out information is weaker, namely iterated deletion of weakly-dominated bidding strategies. The ascending prices in the dynamic auction in conjunction with the provision of drop-out information underlie *both* the greater transparency of the auction rules and the weakening of the solution concept.²⁵

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 constituting the most preferred solution concept (see, for example, Kreps, 1990). However, 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, and/or that makes optimal behavior more transparent, versus one that relies on a stronger solution concept. This insight is codified in the following conclusion:

Conclusion 5: 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 drop-out information compared to the sealed-bid Vickrey auction provides one example of such an effect.

Ours is not the first experiment suggesting that standard considerations in mechanism design such as incentive compatibility and individual rationality are not enough to assure

²⁵The ascending prices along with the drop-out information enriches the strategy space, allowing strategies that are contingent on other agents' previous moves. Hence, the weakening of the solution concept.

behavior that is in line with designer objectives. Chen and Tang (1998) report *systematic* differences between two incentive-compatible mechanisms for public goods provision that have the same Nash equilibrium outcome. They even report systematic differences within the same mechanism between a low and high punishment parameter when the Nash equilibrium should not be affected by this punishment parameter. And, of course, there are the *systematic* differences between the single-unit Vickrey auction and the strategically equivalent ascending-price English auction reported earlier.

In both of these cases (and all other cases that we are aware of) the strength of the solution concept has been the same. In contrast, here the strength of the solution concept is not the same for the two mechanisms. Both the static Vickrey auction and the Ausubel auctions without drop-out information generate sincere bidding as a dominant strategy. The equilibrium solution for the Ausubel auction with drop-out information is weaker, iterated deletion of weakly-dominated bidding strategies. Yet, behavior is exactly the opposite to the pattern one would expect from reading the standard mechanism design literature.

Implementation by a dominant strategy mechanism is extremely valuable because it is robust: It does not depend on common-knowledge of rationality, and assumptions on preferences and/or distributions of signals which weaker solution concepts do. However, even a dominant strategy implementation requires full individual rationality. But what if agents are less than fully rational? In this case a possible tradeoff emerges as the richer strategy space that underlies the weaker solution concept although introducing all kinds of possible “misbehavior” may, at the same time, provide aids that help ease the agents decision problem. When the simplifications help more than the additional strategic ambiguity hurts, as we believe to be the case here, we

might expect the surprising result of improved performance with the weaker solution concept.

The potential tradeoffs identified here between strength of the solution concept versus simplicity is not just relevant to the multi-unit Vickrey auction, but to the applied mechanism design literature in general. From this perspective a number of important questions remain to be answered. First, will the tradeoff generalize beyond the present situation? Will it extend to situations when the more transparent mechanism is substantially weaker than the one employed here, i.e., one with a Nash equilibrium not supported in dominated strategies? Second, can we establish quantifiable measures for simplicity in relationship to human behavior that enable us to predict *in advance* what kind of simplifications will improve mechanism performance even at the expense of strength of solution concept? These and related questions provide the agenda for future research.

References

- Ausubel, L. M., "An Efficient Ascending-Bid Auction for Multiple Objects," mimeographed, Un. Maryland, 1997.
- _____ and Cramton, P. C., "Demand Revelation and Inefficiency in Multi-Unit Auctions," mimeographed, Un. Maryland, 1996.
- Brenner, D. and Morgan, J., "The Vickrey-Clarke-Groves versus the Simultaneous Ascending Auction: An Experimental Approach," Princeton University, 1997.
- Chen, Yan and Fang-Fang, Tang, "Learning and Incentive-Compatible Mechanisms for Public Goods Provision: An Experimental Study," Journal of Political Economy, 106, 1998, 633-62.
- Isaac, R. M. and James, D., "Robustness of the Incentive Compatible Combinatorial Auction," Experimental Economics, 3, 2000, 31-54.
- Kagel, J. H., Kinross, S, and Levin, D., "Comparing Efficient Multi-Object Auction Institutions," mimeographed, Ohio State University, 2001.
- Kagel, J. H., Harstad, R. M. and Levin, D., "Information Impact and Allocation Rules in Auctions with Affiliated Private Values: A Laboratory Study," Econometrica 55, 1987, 1275-1304.
- Kagel, John H. and Levin, Dan, "Behavior in Multi-Unit Demand Auctions: Experiments with Uniform Price and Dynamic Vickrey Auctions," Econometrica, 69, 2001 (a), 413-454.
- _____ and _____, "Multi-Unit Demand Auctions with Synergies: Behavior in Sealed-Bid versus Ascending-Bid Uniform-price Auctions," mimeographed, Ohio State University, 2001 (b).
- Kreps, David M., A Course in Microeconomic Theory, Princeton, Princeton University Press, 1990.
- Levin, D., Kagel, J. H., and Richard, J-F, "Revenue Effects and Information Processing in English Common Value Auctions," American Economic Review, 86, 1996, 442-460.
- List, John A. and David Lucking-Reiley, "Demand Reduction in Multi-Unit Auctions: Evidence from a Sportscard Field Experiment," American Economic Review, 90, 2000, 961-72.
- Manelli, Alejandro M., Sefton, Martin, and Wilner, Benjamin S., "Multi-unit auctions: A Comparison of Static and Dynamic Mechanisms," mimeographed, Arizona State University, 1999.

Nagle, Rosemary, "Unraveling in Guessing Games: An Experimental Study," American Economic Review, 85 (5), 1995, 1313-1326.

Nalebuff, Barry J. and Bulow, Jeremy I., "Designing the PCS Auction," Comment to the FCC on behalf of Bell Atlantic, 1993.

Perry, Motty and Reny, Philip, "An Efficient Ascending Multi-Unit Auction," mimeographed, Un. of Chicago, 2000.

Simon, L. K. and Stinchcombe, M. B., "Extensive Form Games in Continuous Time: Pure Strategies," Econometrica, 57, 1989, 1171-1214.

Stahl, D., "Evolution of Smart_n Players," Games and Economic Behavior, 5, 1993, 604-17.

Vickrey, William. 1961. "Counterspeculation, Auctions, and Competitive Sealed Tenders," Journal of Finance, 16: 8-37.

Table 1
Experimental Treatments

Institution	Auctions with Computer Rivals ^a			Auctions with All Human Bidders ^b		
	Session	Number of Computers	Number of Subjects	Session	Units Supplied	Number of Subjects
Sealed-bid	1	3 per 1-13 5 per 14-27	19	7	2 per 1-12 3 per 13-24 2 per 25-36	8
	2	5 per 1-13 3 per 14-27	18	8	2 per 1-12 3 per 13-24 2 per 25-36	12
Ausubel with drop-out information	3	3 per 1-13 5 per 14-27	14	9	2 per 1-12 3 per 13-24 2 per 25-36	16 ^c
	4	5 per 1-13 3 per 14-27	13			
Ausubel no drop-out information	5	3 per 1-13 5 per 14-27	20			
Sealed-bid with C_2 announced	6	3 per 1-13 5 per 14-27	20			

a Preceded by three dry runs

b Preceded by two dry runs

c Eight subjects in periods 25-36 as time constraint required several subjects to leave after completing period 24

C_2 = second highest computer value.

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						
Won and earned 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

	Bidder Earnings			Efficiency			Revenue		
	Sealed Bid	Ausubel	Difference: SB less Ausubel	Sealed Bid	Ausubel	Difference: SB less Ausubel	Sealed Bid	Ausubel	Difference: SB less Ausubel
s = 2	-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**
s = 3	-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**

^a Differences from sincere bidding: Actual bids less sincere bids
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 and Without Drop-out Information

n=3	Unit 1		Unit 2			No Drop-out Information (S _m)	Difference: With Drop-out Information less Without
	No Drop-out Information (S _m)	Difference: With Drop-out Information less Without	No Drop-out Information (S _m)	Difference: With Drop-out Information less Without			
Won and earned negative profit ^a	0.074 (0.030)	-0.006	0.095 (0.055)	-0.047	Bidder Earnings ^b	-0.132 (0.034)	0.038
Bid > v _h with possible negative profit ^a	0.167 (0.054)	0.046	0.039 (0.025)	0.002	Efficiency ^c	98.6% (0.39)	0.46*
Bid < v _h ^a	0.449 (.096)	-0.289*	0.566 (0.087)	-0.312**	Revenue ^b	-0.178 (0.140)	0.151
n=5					n=5		
Won and earned negative profit ^a	0.051 (0.025)	0.009	0.080 (0.050)	-0.007	Bidder Earnings ^b	-0.065 (0.021)	-0.026
Bid > v _h with possible negative profit ^a	0.111 (0.043)	-0.026	0.050 (0.027)	-0.027	Efficiency ^c	99.5% (0.18)	-0.180
Bid < v _h ^a	0.353 (0.090)	-0.222+	0.528 (0.099)	-0.309*	Revenue ^b	-0.074 (0.084)	0.049

^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

+ 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 5

Sealed-Bid Vickrey Auctions versus Ausubel Auctions
with Drop-Out Information: Bid Patterns for Auctions with All Human Bidders

(Frequencies with standard error of the mean in parentheses)

<i>m</i> = 3	Higher valued unit			Lower valued unit		
	Sealed-Bid	Ausubel	Difference: SB less Ausubel	Sealed-Bid	Ausubel	Difference: SB less Ausubel
Won and earned negative profits	0.290 (0.103)	0.009 (0.047)	0.281**	0.611 (0.232)	0.125 (0.210)	0.486*
Bid > v_h and not win	0.575 (0.137)	0.050 (0.112)	0.525**	0.642 (0.128)	0.180 (0.134)	0.462**
Bid < v_h	0.250 (0.127)	0.122 (0.089)	0.128	0.192 (0.108)	0.060 (0.079)	0.132*
<i>m</i> = 5						
Won and earned negative profit	0.175 (0.093)	0.000 (0.000)	0.175**	0.474 (0.192)	0.103 (0.148)	0.371*
Bid > v_h and not win	0.710 (0.143)	0.069 (0.101)	0.641**	0.643 (0.134)	0.294 (0.142)	0.349**
Bid < v_h	0.156 (0.126)	0.098 (0.094)	0.058	0.135 (0.108)	0.031 (0.055)	0.104

SB sealed-bid

* 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 6

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

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

	Profits			Efficiency			Revenue		
	Sealed Bid	Ausubel	Difference: SB less Ausubel	Sealed Bid	Ausubel	Difference: SB less Ausubel	Sealed Bid	Ausubel	Difference: SB less Ausubel
<i>m</i> = 2	-1.465 (0.254)	0.018 (0.138)	-1.483**	95.0% (0.15)	98.3% (0.11)	-3.31%**	0.856 (0.198)	-0.211 (0.101)	1.067**
<i>m</i> = 3	-2.712 (0.369)	-0.061 (0.114)	-2.651**	95.2% (0.12)	98.8% (0.09)	-3.56%**	1.964 (0.341)	-0.134 (0.089)	2.098**

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