Ascending Prices and Package Bidding: Further Experimental Analysis*

John H. Kagel
Ohio State University

Yuanchuan Lien
Hong Kong University of Science and Technology

Paul Milgrom
Stanford University

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Abstract

We explore the performance of multi-round, price-guided combinatorial auctions for a previously untested class of auction profiles; one with synergies resulting from shared fixed costs. These new profiles indicate the importance of prior information in the form of bidders' "names" (corresponding to packages holding positive value for them) in influencing auction efficiency. The experiments also reveal a new and surprising finding about aggressive bidding tactics by local bidders who bid on valueless items driving up another bidder's payments, thereby mitigating the "threshold" problem. Comparisons between a combinatorial clock auction (CCA) and a simultaneous ascending auction (SAA) are reported.

Key words: Package auctions, SAA auctions, CCA auctions, threshold problem.
JEL classification: D44

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In a previous paper we compared the properties of two price-guided auction mechanisms when bidders demand multiple units of a commodity with synergies among items (Kagel, Lien, and Milgrom, 2010). The two mechanisms were a combinatorial clock auction (CCA) and a closely matched version of the simultaneous ascending auction (SAA), which is a non-package auction that has been widely used in radio spectrum sales. In that paper, we found that, within a certain class of environments exhibiting synergies due to geographic adjacency, we could use simulations to predict under which conditions the CCA would, in the lab, achieve higher efficiency than the SAA and in which the efficiency comparison would be reversed. The present paper expands the comparative exploration of these two price-guided mechanisms by adding another important type of environment for combinatorial auctions with a very different synergy structure – one in which synergies among items arise as a consequence of lumpy shipping costs or large fixed costs. Such a structure has been used to explain the use of a combinatorial auction for London bus routes, in which a bus company servicing multiple routes uses a common hub for maintaining and storing equipment (Cantillon and Pesendorfer, 2006).

One of the daunting tasks facing participants in combinatorial auction mechanisms is deciding which of the many potential packages to bid on, even under the relatively simple demand structure employed in the earlier paper.[1] Real human bidders bid on only a small number of packages in an auction, and we hypothesized that the implications of that behavior could be captured by simulations in which bidders were programmed to bid in each round *only* for a single bundle – their most profitable one at prevailing prices, and to bid on no bundle when they were holding a provisionally winning bid. It was this *straightforward* simulation that, as reported above, was reasonably successful overall in predicting the demand structures in which, with human bidders, the CCA mechanism achieved substantially higher efficiency than the SAA mechanism from those in which the SAA mechanism achieved higher efficiency. However, the simulator's predictions failed in at least one systematic way. When the simulator predicted relatively low efficiency for the CCA but the efficient outcome required that all items be split between the local bidders, or all go to the global bidder, the CCA auctions continued to provide significantly higher efficiency in the lab than in the corresponding SAA auctions, contrary to the predictions of the simulator. Bidders in the experiment were given names ("regional" or "global"), which corresponded to the items that held positive value for them. We hypothesized that those names could have provided an additional cue to human bidders, while the simulated bidders were guided only by prices.

The fixed-costs environment introduces a new possible pattern for efficient assignments that did not arise in our previous experiment with geographic synergies environments, namely that of profiles in which the efficient assignment splits the items between the large bidder and at least one of the smaller bidders and in which the straightforward bidding simulator results in CCA outcomes that are fully efficient, or nearly so. On

[1] An auction with three bidders and six items, with two local/regional bidders with non-overlapping demand for the six items, and one global bidder with demand for all six items.

average, in our new experiment, these auction profiles resulted in substantially lower efficiency in the CCA auctions compared to the SAA auctions, contradicting the simulator predictions. Thus, taken as whole, the data from both the present experiment and the earlier one support an increased role for named packages in explaining the performance of the CCA auction design in our experiments. Specifically, when the efficient outcome corresponds to bidders' "named" packages (the package of all items for the global bidder and the package of all positively valued items for the local bidder), CCA auctions are more likely to achieve high efficiency compared to SAA auctions. But when the named packages do not correspond to the efficient outcome for the large bidder, with full efficiency requiring that items be split between the large bidder and at least one of the smaller bidders, the SAA auction is likely to achieve higher efficiency than the CCA.

In addition to this comparative efficiency result, we have two other novel findings. The first concerns a behavior that we call "strategic bidding": local bidders sometimes place bids on packages containing items with zero value to them, but they do not often continue bidding on those packages for so long that such bids become winning and they are forced to buy those items. In combinatorial auctions like the CCA, such bids on zero value items can be part of an undominated strategy.[2] The rationale for these bids is that they may drive up the price eventually paid by the another bidder, thus serving as a partial antidote to what is know as the "threshold problem," according to which some ("local") bidders fail to bid sufficiently high for their total bid to exceed the bid of the another ("global") bidder.

Second, we found that a simple change to our simulator markedly improves its predictive accuracy. Because bidders in our experiment often bid on multiple profitable packages, we tested a variation of the straightforward simulator in which, with probability 0.4, the simulator places bids for the two most profitable packages, rather than for just the single most profitable package. This change leads to a general improvement in the forecasts and sharply improves the simulator's ability to predict high CCA efficiency in those cases where named packages do not correspond to the efficient allocation.

The paper proceeds as follows: Section I reviews some of the theoretical results reported in our earlier paper (KLM) that guide the analysis of the experimental outcomes. The experimental design and procedures are reviewed in Section II, with the experimental results reported in Section III. Concluding remarks are offered in Section IV.

I. Theoretical Considerations: Blumrosen and Nisan (2005) provide a number of striking examples where price guided auction procedures fail to achieve even a fraction of the maximum possible (efficient) allocation of resources. Nevertheless a number of pioneering theoretical and experimental studies have explored various price guided auction mechanisms designed to overcome these worst case outcomes (Kwasnica et al., 2005;

[2] See Beck and Ott (2012) for an analysis of equilibrium bids exceeding value in core-selecting combinatorial auctions.

Porter et al., 2003; Brunner et al., 2010; Goeree and Holt, 2010). KLM address the question of "under what conditions do a series of bids in a *combinatorial* auction produce allocations that are efficient and/or in the core?" In doing so they prove two theorems which, stated informally, show that if bidders bid sufficiently *aggressively* in an auction for the right packages (their "efficiency-relevant" or "core-relevant" packages, respectively), then the outcome of the auction will necessarily be efficient or in the core..[3] These theorems offer a possible theoretical explanation for how various auctions can lead to good outcomes even in combinatorial environments.

However, the sheer number of possible packages available to bid on even with a very limited number of items up for auction ensures that a bidder can bid on only a subset of its profitable packages.[4] So the question becomes: what might guide bidders even to identify, let alone to bid sufficiently aggressively, on these efficiency-relevant or core-relevant packages? One obvious answer is that if bidders focus exclusively on their most profitable package, and these packages correspond to the efficiency-relevant or core-relevant packages in an ascending price package auction, this will lead to (near) efficient or core outcomes.[5] Alternatively, bidders might focus on a package that corresponds to their role in the experiment as either a global bidder with value for all items, or as a local bidder with value for only a limited set of items, and bid on these "named" packages, which in most cases will correspond to their most profitable package when bidding starts. Once bidders' named packages no longer correspond to their most profitable package, they might continue to bid on them out of habit or because of potential strategic advantages given the complicated fitting issues inherent in package bidding. If the named packages actually are the efficiency-relevant or core-relevant packages in the auction and if bidders bid mostly on those packages, then the KLM theorem implies that one can expect (near) efficient or core outcomes.

The named packages can be further understood as follows. In many practical auctions, bidders have some idea about how other bidders value different packages. When it is also commonly observed that bidders bid on only a few packages, it is more important for bidders to coordinate on certain combinations. From a single bidder's point of view, if he knows what packages other bidders would bid on, then to increase the chance of winning and keeping prices low, he would bid on the packages that fit well in the sense that they can win when other bidders' package bids are also winning. If the named packages fit together in this way, then they may become a focal point for bidders. Consistent with that, our experimental results suggest that bidders are able to bid on the relevant packages the relevant packages correspond to the named packages.

[3] The reader should consult KLM for a formal statement and proof of these two theorems.

[4] One way to compensate for this is for the auctioneer to put some structure on the packages. However, this will typically still leave a large numbers of packages to bid on and, as will be shown below, care must be taken as to how packages are structured in relationship to bidder preferences and bid patterns, in order to achieve high efficiency.

[5] Near because with minimum reasonable size price increments one can expect to miss the maximum that can be achieved with sufficiently small price increments.

In our experiment, the items of potential interest to any bidder are known to all bidders: There are two local (or regional) bidders, one with value for items ABC only and the other with value for DEF only, and a global bidder with value for all six items. As revealed by the results reported on below, the packages ABC and DEF become focal points that can successfully coordinate bidding, even when price signals alone would be ineffective. The global bidder, in addition to bidding on the global package, can sometimes also strategically bid on subsets of items to promote an early end to the auction, or to insure getting some items that it values particularly highly.

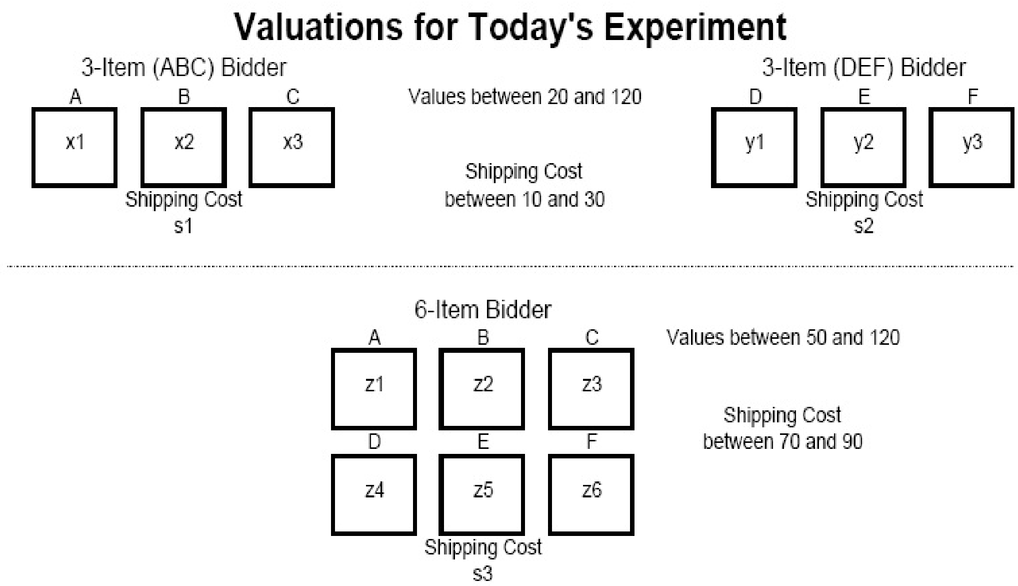
In addition to exploring when, how and why bidders achieve high or low efficiency outcomes in CCA package auctions, we compare the performance of the CCA to a closely matched version of the simultaneous ascending price auction (SAA), which is a suitable benchmark because it is a non-package auction that is widely used for radio spectrum sales. We also investigate individual bidder behavior in the CCA auctions and compare revenue and profit outcomes between the CCA and SAA auctions.

II. Simulation Outcomes and Experimental Design and Procedures*:* Auctions were conducted with either four or six items for sale. Since similar value structures and procedures were used in both cases, we only provide a detailed description of the six-item case, as illustrated in Figure 1.

There were three bidders in each auction: Two “local” bidders, one with positive value only for items A, B and C, and a second one with positive value only for items D, E and F. Both local bidders had synergies between all three items as a result of lumpy shipping costs, which were fixed and independent of the number of items purchased for up to three items.[6] Local bidders wanting to purchase additional items incurred a second fixed shipping cost equal to the shipping cost of the initial three items purchased. The third bidder was a “global” bidder with positive value for all six items, along with a fixed shipping cost for up to six items. As noted, this valuation structure is representative of synergies resulting from lumpy shipping costs or large fixed costs that would result from a common hub servicing a number of trucking or bus routes (e.g., as in the London bus route system; Cantillon and Pesendorfer, 2006).

[6] In KLM there were pairwise synergies between items with positive value as opposed to between all items with positive value for a bidder.

Figure 1



Before any laboratory experiments were run, we first ran a set of simulations in an effort to identify valuation structures for which the CCA auction would be likely to achieve high efficiency, as well as valuation structures that would be likely to achieve low efficiency. For these, the stand-alone values for local bidders were integer values drawn from the interval [20, 120] and the fixed shipping costs integer values drawn from the interval [10, 30]. Global bidders' stand-alone values were integers drawn from the interval [50, 120], and the shipping costs were integer draws from the interval [70, 90].[7] The four-item auctions were the same as the six-item auctions but with standalone items C and F dropped.

The simulations employed three sets of 100 random draws based on this valuation structure, with 100 simulations for each random draw.[8] All of the simulations were for CCA auctions, with simulated bidders bidding on the single package in each round yielding the highest positive profit, except that provisional winners from the previous round did not bid in the current round. Based on the simulation results, the following four types of valuation profiles were selected for employment in auctions with human agents:[9]

1. *Easy/Named:* Valuations for which the CCA simulations achieved 100% efficiency and the efficient allocation called for allocating items according to named packages (either splitting the items between the two local bidders or assigning all the items to the global bidder). In the KLM experiment these valuation

[7] The full set of instructions along with a number of screen shots can be found at http://www.econ.ohio-state.edu/kagel/KLM_trucking_insts.pdf.

[8] Repeated simulations are needed as different outcomes may result due to ties for the provisionally winning bidders in each round, which were resolved randomly in the simulations and in the auction software.

[9] The full set of profiles used and the simulation results are contained in the online data appendix.

profiles achieved very high efficiency in CCA auctions and had significantly higher efficiency compared to SAA auctions.[10]

2. *Hard/Named:* Valuations for which the CCA simulations achieved relatively low efficiency but the efficient allocation called for items to be allocated according to named packages. In KLM, these profiles achieved somewhat lower efficiency in the CCA auctions compared to the Easy/Named valuations, but still had substantially higher efficiency than in corresponding SAA auctions.[11]
3. *Hard/Unnamed:* Valuations for which the CCA simulations achieved relatively low efficiency and the efficient allocation did *not* call for items to be allocated according to named packages (items to be split between all three bidders or the between one of the local bidders and the global bidder). In KLM, these profiles achieved relatively low efficiency in CCA auctions and significantly lower efficiency compared to SAA auctions.[12]
4. *Easy/Unnamed:* Valuations for which the straightforward CCA simulator achieved 100% efficiency and the efficient allocation did *not* call for items to be allocated according to named packages. There were no profiles of this sort in KLM as they did not show up in the simulations with any consistency given the synergy structure and parameter values employed there.

Subjects in the laboratory experiments were provided with copies of Figure 1 as well as a detailed description of the possible synergy relationships and stand-alone values. In any particular auction, they got to see only their own valuations. Regarding the other participants, subjects were told that "Item values and shipping costs will be selected so that we can explore what happens under a number of different valuation profiles, while providing you with what we anticipate will be respectable earnings when *averaged* over all the auctions within a given experimental session."

The auctions' rules were essentially the same as those reported in KLM and are briefly summarized below.

A. CCA Auctions: The CCA auctions used a variant of the package auction rules in Porter et al. (2003). Players could bid on as many packages as they wanted to under XOR bid rules so that only one of the bids was a provisional winner in any given round, and players got *all* the items in that package. Package bids eliminate the *exposure problem*, thereby allowing a bidder to bid nearly up to its values for a set of items without the risk of getting stuck winning only a low-value subset.

In each round, bidders observed the prices for each item and decided which packages to bid on. Each package bid consists of a set of items along with a single package price equal to the sum of the current round prices of the included items. At the end of each round, provisionally winning bids were determined from among

[10] These valuation profiles were simply referred to as "Easy" in KLM.
[11] These valuation profiles were referred to as "Medium Hard" in KLM.
[12] In KLM these profiles were simply referred to as "Hard".

all current and past bids by finding the feasible combination that maximized seller revenue. Ties among multiple sets of packages that maximized seller revenue were broken randomly. Prices associated with past bids were based on prices in the round in which the bids were originally placed.

Prices for all items started at 5 ECUs (experimental currency units), and were raised according to the following rules: From the set of provisionally winning bids in the previous round and the set of new bids in the current round, if an item attracts two or more bids, or if it is included in a provisionally winning bid and a new bid, then its price increased by 5 ECUs. Otherwise the item price remained the same.[13] Thus, those items with price increases in the current round were easily identifiable as items which two or more bidders were actively competing for.[14]

Following each round, bidders were privately informed about which, if any, of their bids was a provisionally winning bid.[15] This was done so that subjects would not wind up competing against themselves.

Subjects were encouraged to place bids on multiple potentially profitable packages, particularly early on as "… the opportunity to make profitable bids on individual items or packages with low synergies, which may become provisional winners later in the auction, will only be present early in the auction."[16] There were no activity rules restricting the items subjects could bid on.

An auction ended after two consecutive rounds of no new bids or, what amounts to the same thing, no price increases. Two rounds were used to give everyone a chance to determine whether they were satisfied, given current prices, with their provisionally winning allocations.

B. SAA Auctions: The SAA screen was designed to look the same as the CCA screen, so that differences in comparative performance could not be attributed to differences in presentation. The rules were also designed to be as similar as possible, with the auction proceeding in a series of rounds with automatic 5 ECU increases in prices for items with excess demand. Like the CCA, a subject only had to click "set" next to any set of items to place a bid on those items (see below). However, unlike the CCA, an SAA bidder could only make one bid in each round, and that bid was interpreted and processed as a collection of independent item bids rather than as a package bid.

The auction ended once there was no longer excess demand for any item, with each item sold at the current price. Thus, a bidder who bid more than his or her standalone value for an individual item in order to capture the synergy payoff was exposed to a possible loss from winning only a subset of those items and paying

[13] Prices were thus weakly increasing from round to round unlike RAD (Kwasnica et al. (2005)) or the FCC's Modified Package Bidding.

[14] If a provisional winner bids on a new package with overlap with any item previously bid on the price of that item will increase.

[15] Tentative winning bids were *not* announced in either Porter et al. (2003) or in Brunner et al. (2010).

[16] In a mechanism design experiment, the instructions are an important part of the treatment as bidders are informed of the favorable properties and operation of what will typically be a novel institution.

more than its standalone value. Our version of the SAA also had a number of rules and features not present in the CCA.

1. *Activity requirement:* Each auction started with bidders eligible to bid on all items. In subsequent rounds the total number of items a bidder was eligible to bid on could not exceed the number bid on in the previous round. This *activity rule,* which resembles the rule used in spectrum auctions, was explained to bidders as necessary to have the auction close in a timely manner.
2. *Default bids:* Each round of the auction started with a default bid labeled "currently demanded bid" which was the previous round's bid (or a bid on all items in the first round of bidding). Any time a new bid was entered that reduced eligibility, the bidder was notified and required to reconfirm the bid.[17]
3. *Minimum bid requirement:* Once there was no longer any excess demand for an item, the current high bidder for each item could not withdraw its provisionally winning bid and remained committed to that bid until someone else topped it.
4. *Price rollback rule:* Near the end of an auction, it was possible to go from excess demand for an item to zero demand as all those bidding on that item dropped their demand at the same time. This could result in unsold items with a potentially large, negative impact on efficiency. The price rollback rule deals with this situation.[18] In the event that demand for an item falls to zero, the round outcome is cancelled and the price of the item with zero demand is rolled back to the level of the preceding round. In addition, one of the bidders with positive demand for that item in the previous round is selected at random and a minimum bid requirement is imposed on that bidder for those items at the previous round's price. The round is then rebid with the revised prices and constraints binding.

C. Computer Interface and Aids for Subjects: Auctions with multiple items and synergies among them are quite complicated so that the nature of the bidder interface and any analytic tools it includes can affect bidder behavior. Since the experiment was intended to be representative of a high-quality field implementation, subjects were provided with computational aids they might expect to have from support staff in a field setting. These consisted of a table listing *all* possible bids, with corresponding analytic information, so that subjects could bid on items by simply clicking on the "add" or "set" space next to packages they were interested in (see Figure 2 for a sample screen shot). To make it easy for bidders to compare alternative packages, the table could be sorted using a number of potentially relevant criteria; e.g., current cost, current profit, etc.[19] A *double-criterion sort* routine was employed so that a bidder interested in comparing a particular group of bids could easily do so based on applying a check in the box designated for that purpose next to each package. Checked

[17] KLM report that in a previous set of SAA auctions without default bids a number of subjects let their eligibility lapse well before it was profitable to do so. These procedures were implemented to prevent this from happening inadvertently.
[18] The minimum bid requirement would not apply in this case, as there would be no current high bidder for the item in question.
[19] See the online instructions for complete details regarding this and the rest of the bidder aids provided.

packages were sorted first followed by unchecked packages. Check marks were automatically put in place for packages containing only those items with positive values for local bidders so as to minimize any potential confusion. Check marks were automatically placed next to any package bid on following round 1, as presumably these were packages of interest. Bidders could easily uncheck any packages they were no longer interested in. The same set of sort routines and calculations were provided for both SAA and CCA auctions. Based on the training sessions it was reasonably clear that we had provided bidders with too many sort options, so that we emphasized the need to use the current profit sort to help in deciding which items to bid on, after which they might find one of the other sort options useful.

[Insert figure 2 here]

D. Experimental Procedures: Subjects were recruited to participate in a series of three sessions taking place within a two-week period, with each session lasting for approximately two and a half hours. Within each series, all of the auctions had the same auction mechanism – SAA or CCA – and the same number of items (four or six). The first meeting was a training session where subjects were introduced to the experimental procedures and computer interface, followed by several dry runs, which were all that could be completed in the allotted time period. To insure a high return rate, subjects were offered a $30 participation fee, to be paid after the completion of all three sessions, with half of session two's auction profits withheld until completion of all three sessions. In addition, subjects were paid a flat $15 at the end of the initial training session in lieu of any earnings from the dry runs. Given the complicated nature of the auctions, subjects were provided with summary instructions which they could take home to study. Sessions 2 and 3 began with asking if subjects had any questions, answering the questions posed, and then proceeding directly to play for cash.

Earnings in sessions 2 and 3 were advertised to range between $10 and $60 or more per person with average earnings of $30-$50 per person. Payoffs were denominated in experimental currency units (ECUs), with a minimum conversion rate of 1 ECU = $0.10.[20] Subjects were provided with starting capital balances of 150 ECUs. Any profits earned in an auction were added to these starting capital balances, and losses subtracted from it, with total earnings for a session consisting of a subject's end-of-session balance, less 130 ECUs, but not less than zero.

Subjects' roles as a local or global bidder were randomly assigned prior to each auction, with bidders in each auction group randomly re-assigned following each auction. Each experimental session was designed to have five or more auctions (all with the same valuations) running at the same time. In case the number of subjects was not a multiple of three, the extras became bystanders for that auction, and were guaranteed to be active in the next auction.[21] Subjects' computer screens reported only their own outcome until the end of the

[20] In sessions where average earnings were lower than advertised the conversion rate was increased at the end of the session. The instructions explicitly stated that these were *minimum* conversion rates (emphasis in the instructions).

[21] Bystanders had the final payoff screen from their last auction they participated in frozen on their screen.

auction, when the full allocation of units to all bidders in their auction was reported along with a final analytics screen that they could manipulate. The latter was designed to give bidders a chance to see what profitable packages they might have missed out on.

Each auction began with subjects given a couple of minutes to look at their valuations, to sort packages and to check any items/packages they might be particularly interested in. All auctions started with each auction round lasting 25 seconds. After round 6 or 7, the round time was reduced to 20 seconds, and was reduced to 15 seconds after round 12 or so, to speed things up.[22] Once these shorter round times went into effect, the auctioneer announced "round ending" a second or two prior to the round actually ending.

[Insert Table 1 here]

Table 1 lists the auction sessions conducted, along with the number of subjects, and the number of auction profiles employed in each session. With minor exceptions the same auction profiles were employed in the CCA4 and SAA4 auctions, as well as in the six item auctions.[23] Two sets of six item CCA auctions were conducted as in many ways these where the most informative of outcomes under the different CCA auction profiles, and we were unable to complete the full set of profiles planned in CCA6-Series 1 within the 2.5 hour time frame sessions were scheduled for.

Subjects were recruited through e-mail lists of students taking economics classes at Ohio State University in the current and previous quarters during which the sessions took place. No subject participated in more than one auction series. For subjects completing all three sessions, average earnings for the six-item auctions were $119, with minimum earnings of $59 and maximum earnings of $196, including the $30 show-up fee and the $15 payment for the first session. Average earnings for the four-item auctions were $108, with minimum earnings of $64 and maximum earnings of $171, including the $30 show-up fee and the $15 payment for the first session.

II Experimental Results

A. Early Ending/ Collusive-Like Auctions: Before discussing bidding in detail we briefly report on a number of auctions which ended much sooner than the vast majority of auctions. These early ending auctions typically ended with bidders earning substantially greater profits than in the reaming auctions and with all bidders earning positive profits (or with two of the three bidders earning positive profits with the remaining bidder typically priced out of the market). As such we consider them to be "collusive-like" auctions, involving tacit collusion of one sort or another.

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[22] Times for round completion were determined based on the training sessions during which we asked subjects if they had enough time or not. The only complaints we had, which were few, were requests for shorter round times.

[23] These exceptions resulted from differences in the number of auctions we were able to complete within the time frame sessions were scheduled for, along with one incorrectly programmed profile in one of the sessions.

We define auctions as collusive-like if the bidding lasted for 10 rounds or less. Although this is a somewhat arbitrary cut off, 10 rounds for the CCA auctions includes 2 rounds with no price changes at the end, with a number of the auctions in question ending well before 10 rounds. Table 2 reports the mean number of rounds to auction completion for all CCA and SAA auctions, along with the mean number of rounds to completion for the early ending auctions. The frequency of early ending/collusive-like auctions is also reported. The early ending auctions were typically ones in which all three bidders made substantial profits, or with two out of the three bidders earning substantial profits with one of the local bidders priced out of the market, with the remaining local bidder and the global bidder no longer competing.

[Insert Table 2 here]

One might be tempted to argue that collusive like outcomes in the CCA auctions were a result of providing bidders with information about provisional winners following each round of bidding. While this may be a facilitating factor, the fact that collusive-like outcomes are also reported in the SAA auctions, where provisional winners are not announced, indicates it is not a necessary condition for collusive-like results to occur.[24]

CCA6-Series 1 had an unusually large number of auctions (18 out of 96) that ended early with bidders earning very large profits. In six out of the first eight of these, the global bidder dropped out and earned zero profits, but global bidders in the other auction groups with the same profiles competed for a large number of rounds and earned reasonably high profits (between 30 and 77 ECUs per auction profile). So these auctions did not end early because of unusually low value draws for global bidders. In eight out of the ten remaining early-ending auctions, either all three bidders earned substantial profits or two earned substantial profits and one of the local bidders was priced out of the market.

The unusually large number of auctions that ended early in this series was, we believe, the result of one subject near the end of the training period announcing (to paraphrase) "If a bidder has low valuations they cannot make much money and might as well drop out early to help the others." That the initial auctions that ended early were largely the result of early drops by global bidders suggests that this subject's statement precipitated these early global drop-outs. This, in turn, established a paradigm for the more sustainable collusive pattern observed in later auctions in which all three bidders held back from stiff competition, or the two remaining bidders held back once one of the local bidders was priced out of the market.[25]

[24] Within the SAA the closest thing to a provisional winner being announced is when the minimum bid requirement kicks in which would indicate that no one else is bidding on that item. However, Brusco and Lopomo (2002) identify the existence of low revenue, tacit collusive equilibria in SAA type auctions and Cramton and Schwartz (2002) report evidence to this effect in some of the FCC radio spectrum auctions. Beside setting reserve prices, ways to mitigate collusive type outcomes within the CCA would be, in the case of ties for provisional winners, to allocate items to the smallest number of bidders (as opposed to the random allocation employed in the experimental design) so as to keep the maximum number of bidders "out of the money."

[25] An interesting side note here: The subject making the announcement was the first global bidder to drop out early, but did not do so later as either a global or a local bidder. This suggests that either his announcement was designed to get others to do so or that after

The analysis that follows includes all the early ending/collusive-like auctions. The results show that early-ending auctions have a large negative impact on efficiency and revenue, while substantially increasing bidder profits.

B. Patterns of Individual Bidding: Subjects' bidding behavior in the CCA auctions exhibit a number of consistent characteristics that are consequential to auction outcomes. First, consistent with previous results, subjects bid on only a small number of profitable packages, with the most profitable package attracting the most attention. This is of considerable importance since a sufficient condition for the auction outcomes to be fully efficient is that subjects bid sufficiently aggressively on the relevant packages (KLM, 2010).[26] If bidders bid on only a small number of packages, they may miss the relevant packages or not bid sufficiently aggressively on them.[27]

Table 3, columns 2 and 5, report the percentage of profitable packages subjects bid on in each round for global and local bidders, respectively, with the average number of profitable packages available to bid on reported in parentheses. The columns following these show where the bids were directed in terms of the percentage of times bids were placed on the most profitable and the second-most profitable packages.[28] Data are excluded for the last two rounds of each auction where, by definition, there are no new bids, as well as rounds in which the bidder is a provisional winner. For example, in rounds 1-5 in the CCA6 auctions, global players bid on 11.9% of the profitable packages available to bid on (7.2 out of 59.5 profitable packages), with bidders bidding on their most profitable package 63.5% of the time, and their second most profitable package 49.0% of the time. Bidding on only a small number of profitable packages occurred even in later rounds where there were relatively few profitable packages available to bid on; e.g., local bidders in rounds 11-15 in the CCA6 auctions bid on less than half of the profitable packages available to bid, with the average number of profitable packages as little as 4.8.[29] With the exception of global bidders in the 6 item auctions, there was very limited bidding on lower valued packages to the exclusion of the first and second highest valued packages.[30]

[Insert table 3 here]

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his first experience he recognized that there was actually little personal gain to this strategy as a global bidder given that the group composition changed randomly between auctions.

[26] If the efficient outcome is unique, this condition is also necessary for full efficiency. By sufficiently aggressively, we mean bidding to the point that bidders had exhausted all potential profit opportunities before the auction ended.

[27] Scheffel et al. (2012) also make this point. They find that limited number of packages bidders evaluate is the biggest barrier to full efficiency in combinatorial auctions. They find that on average bidders select the same number of packages to bid on independent from the number of packages a bidder is interested in. While we do not have the any measure of the number of packages bidders are interested in, we do find that the number bid on increases with increases in the number of profitable packages available to bid on.

[28] These percentages are independent of each other in that a bid on the second most profitable package is counted regardless of whether or not a bid was placed on the most profitable package. With the exception of global bidders in the 6 item auctions, there was very limited bidding on lower valued packages to the exclusion of the first and second highest valued packages:

[29] Subjects reported that they had more than enough time to bid on all the packages they wanted, so the limited bidding is not driven by round duration times.

[30] For auctions in rounds 11 and higher these percentages ranged from 2%-6% (1% or less) for global (local) bidders in the 4 item auctions; and between 23-26% (8-11%) for global (local) bidders in the 6 item auctions.

If CCA prices fail to guide bidders to the relevant packages in each round, the theoretical conditions required to achieve (near) fully efficient and core outcomes could still be satisfied if bidders vary the packages they bid on during the auction, and bid sufficiently aggressively on these packages at appropriate times. But this was quite unlikely to happen, particularly in cases where unnamed packages constitute the efficient or core allocation, since bidders typically failed to place any bid on a number of packages. For example, in the CCA4 auctions a global bidder on average bids at least once on only 6.3 distinct packages out of the 15 packages they could bid on, so that on average over 8 packages never receive any bid at all from the global bidder during the auction. Local bidders come closer to bidding on all packages at least once during the auction; e.g., on average in the CCA4 auctions they bid at least once on 2.4 out of the 3 packages containing only positively valued items they could bid on. For CCA6 auctions, global bidders bid on average on 11.7 out of the 63 possible (profitable) packages they could bid on, with local bidders bidding on 4.9 out of the 7 possible (profitable) packages containing only positively valued items.

To summarize: (i) bidders bid on only a small percentage of the profitable packages in each round and omit some packages entirely from their bidding during the auction and (ii) the most profitable packages were consistently bid on most often.

While the fact that bidders tend to bid much more often on their most profitable package than on their less profitable packages is consistent with the possibility that bidders' package choices are guided primarily by prices and profits, it is also possible that these same packages might be selected by other criteria. In many cases, particularly early in each auction, the most profitable packages and the "named" packages – the ones consisting of all items for the global bidder and all positively valued items for the regional bidders – coincide. Later in the auction, if a named package is not the most profitable one, it will often be the second most profitable package and might be expected to attract considerable attention from bidders. To establish the degree to which prices and profits guide bidding, Table 4 reports data for those auction rounds in which the most profitable packages did *not* coincide with the named packages. As shown, when the named package did not coincide with the most profitable package, and bidders chose to bid on only one of the two, the most profitable package attracted substantially more attention. Note, however, that the named package alone, or the named package *and* the most profitable package, attracted a fairly large percentage of all bids, which helps to explain some of the differences between bidding by human subjects and the straightforward simulator in the data reported on below.

[Insert Table 4 here]

Subjects typically did *not* place bids in rounds in which they were provisional winners. This effect was most pronounced in later rounds when the auction had a greater chance of ending. In auction rounds 11 and above, global (local) bidders failed to submit new bids in 86.9% (77.0%) of all rounds in which they were provisional winners in CCA4 auctions, and in 79.2% (75.6%) for the CCA6 auctions.[31] The reasons for these high frequencies are threefold: (i) subjects do not bid in every round even when they are *not* provisional winners (see below), (ii) bidding on packages as a provisional winner can extend the auction and/or raise prices on provisionally winning bids with unknown consequences, so that provisional winners were willing to settle for what they already had, and (iii) more often than not the profit on the provisionally winning package was greater than or equal to the potential profit from any other package.

In cases where a provisional winner's profits were greater than or equal to their highest potential profit, new bids were not submitted in 88.9% (84.3%) of all cases for global (local) bidders in CCA4 auctions and in 84.3% (85.8%) of all cases for global (local) bidders in CCA6 auctions. Provisional winners were much less likely to stand pat when their provisional profits were lower than their highest potential profits, with no new bids submitted in 58.5% (28.6%) of all such cases for global (local) bidders in the CCA4 auctions, and 56.2% (53.2%) of all such cases in the CCA6 auctions. Bidders were substantially more likely to bid following a round in which they had not secured a provisionally winning bid (and there were positive profits to be had), bidding on at least one package 75.3% (67.2%) of all such cases for global (local) bidders in the CCA4 auctions and in 78.1% (74.4%) of all cases for global (local) bidders for CCA6 auctions. Finally, looking at those cases in which a provisionally winning bidder did not bid and was not winning on her most profitable package, the profit difference compared to their best alternative averaged 20.6 (16.3) ECUs for global (local) bidders in the CCA4 auctions, and 61.1 (34.0) ECUs for global (local) bidders in the CCA6 auctions.

[Insert Table 5 here]

Table 5 reports the scope for potential profits available at the end of the auction, distinguishing between losing and winning bidders. Most losing bidders had fully exhausted any potential profit opportunities by the last bidding round. This behavior is part of the theoretical sufficient conditions for achieving close to efficient and/or core outcomes in package auctions. However, what is particularly striking is the large size of the forgone profit opportunities for losing global bidders in the CCA6 auctions.[32] The standard error of the mean is quite large here (23.4), which given the small number of observations in this category indicates that these large forgone profit opportunities are largely driven by a few outliers.[33] Relatively large forgone profit opportunities for winning bidders are much easier to understand, as the complicated nature of the auction is such that with reasonable profits in hand, a potential winner might well not want to extend the auction, as these profits might well be jeopardized by setting off new rounds of competition.

[31] For rounds 1-10, the corresponding percentages are 81.1% and 88.0% for global and regional bidders in CCA4 auctions and 63.6% and 71.1% for global and regional bidders in CCA6 auctions, respectively.
[32] All calculations here are conditional on bidders not having exhausted their profit opportunities.
[33] The standard error, as opposed to the standard error of the mean here is 84.2, almost the same as the average foregone profits.

The *threshold problem* is an inefficiency that arises when local bidders withhold profitable bids on their packages, hoping that the other local bidder will raise its bid sufficiently for the combination to defeat the global bidder. If this effect were significant in our experiment, then we should find that local bidders when *losing* the auction would have greater scope for increased profit opportunities compared to global bidders. There is no evidence of a threshold problem in Table 5 for either the four- or six-item CCA auctions, as the frequency with which higher profits were available for losing local bidders is smaller, in both cases, compared to global bidders.

The traditional analysis of the threshold problem omits the possibility that local bidders might adopt alternative strategies to encourage higher bids by the other local bidder. What helps to mitigate the threshold problem here is that in a number of cases local bidders bid on packages containing items with *zero value* to them; i.e., a local bidder with positive values for A, B and C, bids on a package containing one or more items D, E and F. This is especially common in early auction rounds: Overall, in the CCA auctions, 37.0% of all local bids consisted of packages with one or more zero value items. This decreased to 8.6% of all local bids in rounds 11 and higher, when the auction had a decent chance of ending. In a number of cases this resulted in local bidders being provisional winners on packages containing one or more of these zero value items (10.5% of local bidders provisionally winning bids). But they rarely got caught winning packages of this sort as in only 3 out of 572 cases did a local bidders' winning package contain one or more zero value items. Bidders varied a lot in terms of strategic bidding of this sort: 25.9% (15 out of 58) made these bids 40% of the time or more versus 32.8% who made these bids 5% of the time or less (with 11 out of these 19 never making a bid of this sort).

We discuss the impact of this zero value item bidding strategy in some detail in Section G below. For the moment, we simply point out that biding on zero value items results in a significant reduction in early ending auctions, which in turn plays a big role in improving economic efficiency. It also results in a modest increase in profits for the local bidder doing the zero value bidding, primarily as a result of obtaining positive items that they would not have otherwise won.

C. Efficiency: Efficiency is calculated as $\left(S_{actual} - S_{random}\right) / \left(S_{max} - S_{random}\right)$ x 100, where S_{actual} is the realized surplus from the auction, S_{random} is the mean surplus resulting from a random allocation of items, and S_{max} is the maximum possible surplus.[34] This normalized efficiency measure yields a mean efficiency of 0% with random assignment of the items versus 100% for the surplus-maximizing assignment.

To analyze efficiency, we ran one-sided Tobit regressions, accounting for the corner solution at 100% efficiency, where the dependent variable is our normalized efficiency measure. We also ran probits where the dependent variable is 1, in cases where 100% efficiency is achieved, and 0 otherwise. The regressions pool the

[34] The value of the random allocation is computed by taking the average of the surplus over all possible allocations – 3^4 and 3^6 respectively – assuming all items are sold in each auction.

data for all CCA and SAA auctions. In both regressions the omitted variable consisted of the Easy/Named auction profiles along with the following dummy variables: Early = 1 in case the auction ended in 10 rounds or less, 0 otherwise; 4Item = 1 for the 4 item auctions, 0 otherwise; SAA = 1 if SAA auctions, 0 otherwise, Hard/Named = 1 for Hard/Named auction profiles, 0 otherwise; Easy/Unnamed = 1 for Easy/Unnamed auction profiles, 0 otherwise; Hard/Unnamed = 1 for Hard/Unnamed auction profiles, 0 otherwise, and three dummies, one each to account for interaction effects between the SAA auctions and the Hard/Named, Hard/Unnamed and Easy/Unnamed auctions.[35] We employed two different error specifications, one with errors clustered by auction profile, and one with clustering at the session level, both of which yield essentially the same results. Results reported here are with errors clustered by auction profile, as there are many more of these than there are sessions (40 versus 10), and the cluster-robust standard error estimator is sensitive to having a sufficiently large numbers of clusters.

Average overall efficiency calculated from the Tobit index function is 91.8%. Auctions that end early, in 10 rounds or less, *reduce* average efficiency by 9.9% to 81.9%, while four-item auctions average 5.3% higher efficiency. Table 6 reports mean differences in efficiency between the different CCA auctions based on the Tobit index function, along with mean efficiency differences from the corresponding SAA auctions. The statistical significance of the efficiency differences is also reported. Looking at the first column of numbers in Table 6, the Hard/Named CCA auction profiles have 3.2% lower average efficiency than the Easy/Named CCA profiles, with this difference statistically significant at the 5% level. Efficiency drops even further for the Easy and Hard Unnamed CCA auctions compared to the Easy/Named CCA auctions. There are no significant differences in efficiency between the Easy and Hard Unnamed auctions. The bottom row of Table 6 compares efficiency in the SAA auctions to the corresponding CCA auctions at the top of the table. The important thing to note here is that whereas the CCA versions of both the Easy/ and Hard/Named auction profiles achieved significantly higher efficiency than their SAA counterparts, whereas both the Easy/ and Hard/Unnamed CCA profiles has lower efficiency than their SAA counterparts.

[Insert Tables 6 and 7 here]

Table 7 reports the marginal effects from the probit regressions for the different auction profiles. That is, it reports dE(y)/dx, the change in the probability of achieving 100% efficiency between the different auction profiles, along with the statistical significance of the differences reported. The format is the same as Table 6, with the results mirroring those reported in Table 6. The only major change is that the difference between the Hard/Unnamed CCA auction profiles and their SAA counterparts is statistically significant by this measure, whereas it is not statistically significant by the earlier measure.

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[35] We also ran a specification checking for interaction effects between the 4-item auction dummy and the SAA dummy. This interaction effect was not significant at conventional levels ($p > 0.10$) in both cases, so that it was dropped from the regressions reported here.

Tables 6 and 7 indicate that in terms of comparing CCA with SAA auctions, which is a prime purpose of the present paper, we don't miss much by collapsing the four auction profiles into the two main categories - Named versus Unnamed auctions. Running probits and Tobits similar to those underlying Tables 6 and 7, but collapsing the four different auction profiles into these two categories shows that for Named auctions the CCA achieves significantly higher efficiency than the SAA, whereas for Unnamed auctions the SAA achieves significantly higher efficiency than the CCA (see Table 8).

[Insert Table 8 here]

The mechanism behind the fact that named packages and their relationship to the efficient outcome serve as a better predictor of efficiency in the CCA auctions than the straightforward simulator is reasonably straightforward: First, as Table 4 showed, for both local and global bidders, when the named package no longer corresponds to the most profitable package, named packages still attract a considerable amount of attention either in terms of bidding on the named package only, or more often, bidding on *both* the named package and the most profitable package. Further, when the named package is no longer the most profitable package, the amount bid on the named package must be greater than the bid on the most profitable package, since the latter contains fewer items. This, in conjunction with the CCA auction assigning packages so as to maximize seller revenue, means that other things equal the CCA algorithm would pick a bidder's named package over the bidder's most profitable package to include as the winning package when both are bid on, and in general would tend to pick named packages over more profitable packages as provisional winners.[36] The net result is that in the CCA auctions, for the Hard/Named profiles bidding on Named packages in addition to, or in favor of, the most profitable package helps to promote auction efficiency. In contrast, in the Easy/Unnamed CCA auctions bidding on Named packages tends to reduce auction efficiency compared to bidding exclusively on the most profitable packages.

Closely related to this is the fact that the four item CCA auctions achieve higher efficiency than the six item CCA auctions (5.3% higher according to the Tobit index function, with a 0.428 greater probability of achieving 100% efficiency according to the probit regression). This reflects the fact that although both global and local bidders are bidding on more packages in the six item auctions (recall Table 3), they are bidding on a substantially smaller percentage of the profitable packages in each stage of the auction process, so that it would be that much less likely that they will be bidding on those packages that constitute the efficient outcome compared to the CCA4 auctions.

D. Revenue Effects: Following Milgrom (2007) we use the minimum revenue in the core as the standard against which to judge revenue from the package auctions. The core for package allocation problems has a competitive-

[36] One important reservation to this conclusion could result from sufficiently thick competition so that smaller (unnamed) packages are aggressively bid on in later auction rounds. However, with strong complementarities between individual items this is not very likely, even with reasonably strong competition.

revenue interpretation: An individually rational allocation is in the core if there is no group of bidders who could all do better for themselves and for the seller by raising some of their losing bids. Hence our analysis focuses on revenue as a percentage of the minimum revenue in the core. Note that the selection of auction profiles paid little if any attention to revenue or profits, being mainly concerned with auction efficiency. However, as a practical matter revenue and bidders' profits are important factors to take into account in choosing between auction mechanisms.

To investigate revenue effects we run regression similar to those used to analyze efficiency. In these regressions the dependent variable is revenue as a percentage of minimum revenue in the core. For treatment effects we focus on the collapsed categories reported in Table 8, based on the clear and striking differences between auctions in which the efficient outcome corresponds to Named versus Unnamed packages. More precisely, we run linear regressions for the pooled CCA and SAA auction data with the following right hand side dummy variables: Early = 1 in case the auction ended in 10 rounds or less, 0 otherwise; 4Item = 1 in case of 4-item auctions, 0 otherwise; SAA = 1 if SAA auctions, 0 otherwise, Unnamed = 1 for the Unnamed auction profiles, 0 otherwise; and the interaction effect between the SAA auctions and the Unnamed auction profiles. Consistent with the efficiency regressions, errors are clustered by auction profile. An unrestricted linear regression is employed since revenue as a percentage of minimum revenue in the core can exceed 100%.

[Insert Table 9 here]

Revenue as a percentage of minimum revenue in the core is predicted to be 93.8% based on the revenue regression run. The most striking impact on revenue results from early ending auctions where the marginal effect is a 52.1% reduction in revenue. Table 9 shows that within the CCA auctions, at the margin revenue increased 4.8% in Unnamed compared to Named auction profiles ($p < 0.10$). So although efficiency is higher in the CCA auctions when the efficient outcome corresponds to Named versus Unnamed packages, revenue is lower.

E. Bidder Profits: Table 9 also reports profits based on a regression specification that is identical to the one used for revenue, except for the dependent variable which is total bidder profits measure as a percentage of the efficient allocation. Total profits predicted from the regression average 21.0% of the efficient allocation. As with revenue, the biggest impact on profits comes from early ending auctions, as profits there have essentially doubled (41.0% of the efficient allocation) compared to the overall average.

Profit patterns between treatments are the mirror image of those reported with respect to revenue. Total profits are 7.6% lower in SAA compared to CCA auctions when Named packages correspond to the efficient outcome ($p < 0.01$), with no significant differences between the two when Unnamed packages correspond to the efficient outcome. Within the CCA auctions, total profits are a bit lower when Unnamed packages correspond to the efficient allocation compared to when Named packages do.

F. Distance from the Core: Distance from the core is measured in terms of the scaled distance from the core, with the latter defined as the maximum violation of one of the inequalities defining the core, divided by the difference between full efficiency and efficiency resulting from randomly allocating items to bidders.[37] Here too we pool all the data from SAA and CCA auctions and run one-sided Tobits (with the corner solution zero distance from the core), along with probits where the dependent variable is equal to 1 in the case of zero distance from the core (0 otherwise). The regression specifications employ the collapsed auction profile categories, Named versus Unnamed packages, with errors clustered by auction profile. In this one case the interaction effect between the 4-item auctions and the SAA dummy is significant at conventional levels ($p < 0.10$ for both the Tobits and probits), so that results are reported accounting for this interaction effect.

The Tobit index function measures the overall scaled distance from the core as 22.0%. Early ending auctions have a large impact here as well, with the marginal impact being 51.0% increase in the scaled distance from the core, with *none* of the early ending auctions having zero distance from the core. The Tobits show that the marginal effect for the CCA4 auctions compared the CCA6 auctions is to reduce the scaled distance from the core by 11.7% ($p< 0.01$), while the probits report that the change in the probability of achieving zero distance from the core increases by 0.232 for four-item CCA auctions compared to six-item CCA auctions ($p < 0.01$).

[Insert Table 10]

Table 10 reports the results of the Tobits and probits with respect to Named versus Unnamed CCA auctions and their SAA counterparts. The Tobits show no significant differences between Named and Unnamed CCA auctions with respect to distance from the core, with the probits showing that Named CCA auctions

[37] This is $D_{max}/(S_{max} - S_{random})$ where D_{max} is the maximum violation of one of the inequalities defining the core and S_{max} and S_{random} are the same as were used to define efficiency. The normalization is based on the fact that in calculating the core, efficiency is used as one of the core constraints, the one for the grand coalition involving all bidders and the auctioneer. This normalization enables us to compare the distance from the core across different auction profiles and to compare it to normalized efficiency as well.

achieve zero distance from the core substantially more often than do the Unnamed CCA auctions. Named CCA auctions come closer to core outcomes than their SAA counterparts for four-item auctions, with Unnamed CCA auctions tending in the opposite direction for six-item auctions.

To sum up, outcomes are closer to the core (the core embeds both efficiency and competitive pricing) under CCA than SAA auctions when Named packages correspond to the efficient outcome, with the reverse pattern holding when Unnamed packages correspond to the efficient outcome.

G. Impact of Bidding on Zero Value Items: Local bidders' bidding on zero value items strongly impacts the auction process. First, early ending auctions have a substantially lower frequency of zero value bidding than later ending auctions – 46.4% of early ending auctions had at least one zero value bid in the first ten auction rounds compared to 76.4% of non-early ending auctions. Further, a probit shows that the marginal effect of a zero value bid in the first ten rounds reduces the probability of an auction ending early by 0.10 ($p < 0.01$).[38] Given the large negative impact of early ending auctions on revenue and efficiency, zero value bidding indirectly promotes increased auction revenue and improved efficiency.

To investigate the impact of zero value bidding on profits we ran separate Tobits for global and local bidders, employing the same specification as the regressions profits as a whole, but adding a BidZero dummy (value = 1 if either local bidder bids on a package containing zero value items; 0 otherwise) for the global bidder Tobit, and separate BidZero dummies for each of the local bidders for the local bidder Tobit.[39] There is a negative effect on global bidders' profits from zero value bidding which just misses being statistically significant at the 10% level ($p = 0.11$). A local bidder who bids on zero value items generates a positive increase in own profits of 1.4% ($p < 0.05$) which, although modest in absolute value, is substantial compared to average normalized local bidder profit of 5.7%. Zero value bidding by one local bidder has no significant effect on the other local bidder's profits ($p = 0.67$). Running a probit on the frequency of winning suggests that much of the increase in a local bidder's profits resulting from own zero value bidding can be attributed to an increase in the probability of winning ($p < 0.01$).[40] Taken together with the negative impact on the global bidders profits from zero value bidding indicates that local bidders' zero value bidding helps to overcome the threshold problem.

[38] Right hand side variables in this case consisted of dummy variables for the CCA4 auctions, the Unnamed auctions, and a BidZero dummy set equal to 1 if any zero value items were bid on in the first 10 auctions (and zero otherwise), with the omitted treatment variable consisting of Named CCA6 auctions. Note, there clearly are alternative ways to characterize bidding on zero value items than the one employed here. We adopt this parameterization because it is straight forward to implement and, as noted earlier, the bidding n zero value items tends to be concentrated in a subset of the bidders.

[39] Tobits need to be employed here since there are many cases where no local bidder gets an item as well as many cases where the global bidder gets no items. The BidZero dummies in these regressions take on a value of 1 if zero value items were bid in any auction period.

[40] The increased probability of winning is equal to 0.11. Employing Heckman's (1979) two stage estimator to correct for sample selection bias confirms these results as it shows no significant impact on a local bidder's profits conditional on winning, from own zero value bidding, but own zero value bidding results in a statistically significant increase in the probability of winning ($p < 0.01$).

H. Predictive Power of an Alternative Simulator: Results from the initial CCA4 auctions showed that predictions for the straightforward bidding simulator failed rather dramatically for the Easy/Unnamed CCA auctions where the simulator predicted 100% (or near 100%) efficiency. At the same time it was clear from the individual bid data that subjects consistently bid on more than their most profitable package in the CCA auctions (recall Tables 3 and 4). In response to this we looked for a simple alternative that might better track the four item data, settling on one in which subjects always bid on their most profitable package, while also randomly bidding on their second most profitable package 40% of the time.[41] While this alternative simulator is still just a rough approximation to bidder behavior, looking at its predictions relative to the straightforward simulator indicates it is a significant step in the right direction, without being so detailed as to not be applicable to other settings.

In an effort to test this alternative simulator, the CCA6 profiles were selected so that in about half of all cases predicted efficiency was essentially the same under the two simulators, with the other half selected so that the two simulators gave very different predictions (e.g., about half of the Easy/Unnamed auctions profiles were chosen so that the second simulator predicted relatively low efficiency in contrast to the high efficiency predicted with straightforward bidding, with the other half chosen so that both simulators predicted relatively high efficiency). This strategy was employed for all four categories, and was reasonably successful in all but the Easy/Named category where both simulators came back with very high efficiency for all of the 300 randomly drawn profiles used to determine which auction profiles to explore in the experiment.

[Insert Table 11 here]

Table 11 reports mean absolute differences between predicted and actual efficiency under the two simulators for all the auction profiles implemented, distinguishing between Named and Unnamed auction profiles. For both the four- and six-item CCA auctions, the alternative simulator is significantly more accurate. If we break out the early ending CCA auctions, there are no significant differences between the predictive accuracy of the two simulators ($p = 0.31$), which is not surprising given the low and essentially arbitrary nature of efficiency in these auctions. Further, focusing on the Easy/Named auctions, there are no significant differences in accuracy between the two simulators as well ($p = 0.30$). This indicates that even though there was bidding on multiple packages, it failed to disrupt the efficiency predictions of the straightforward simulator in this case, given the high frequency with which subjects bid on their most profitable package.

The question remains as to what the alternative simulator is picking up on in terms of bidding behavior? One key factor is that the alternative simulator predicts more possible realized allocations than the straightforward simulator, with these predictions coming closer to realized outcomes. For example, looking at one of the Hard/Unnamed CCA4 auction profiles, full efficiency calls for the following allocation (A, D, BC),

[41] Consistent with the data, neither simulator placed a new bid when it was a provisional winner in the previous auction round.

where A and D represent allocations to the two local bidders, with the global bidder's items listed last. In this case the straightforward simulator predicts the allocation (0, D, ABC) in all 100 replications, with a normalized efficiency value of 84%. In contrast, the alternative simulator predicts the following allocations: (0, D, ABC; 51), (A, D, BC; 41), (A, 0, BCD; 6) and (0, 0, ABCD; 2) (where the numbers following the semi-colon indicate the predicted number of times for each allocation) resulting in an average efficiency of 91%. Of the six actions involving this particular profile four achieved the fully efficient outcome (A, D, BC), with one each achieving (0, 0, ABCD) and (0, D, ABC) for an average realized efficiency of 94%.

Alternatively, take the following Hard/Named CCA6 auction profile where full efficiency calls for the global bidder to get all six items. In this case the straightforward simulator predicts the fully efficient outcome 45 times, along with the inefficient outcome (0, 0, ABD) for the remaining times, for an average efficiency of 78%. The alternative simulator on the other hand predicts the fully efficiency outcome 33 times along with the close to fully efficient outcome (C, 0, ABD) for the remaining times for a predicted efficiency of 97%. This compares with the experimental outcomes which yield the fully efficient outcome 4 times and the (C, 0, ABD) outcome the remaining 2 times, for an average efficiency of 99.1%.

In short, what the alternative simulator does by having subjects bid on their second-most profitable package 40% of the time (in addition to bidding on their most profitable package) is to (i) come closer to bidder's actual behavior and (ii) open up allocations that the alternative simulator misses. As such the relatively simple alternative simulator predicts auction efficiency more accurately.

IV Conclusions

According to the theory articulated in KLM, combinatorial auctions lead to good (efficient or core) allocations when bidders, during the auction, bid sufficiently aggressively on certain "relevant" packages that can be hard for bidders to identify in advance of the auction. Compounding the difficulty is that, in experiments, bidders bid on relatively few packages, even when the number of items is so small that bidding on all packages would at least be conceivable.

To achieve good outcomes, combinatorial auctions must somehow help bidders to identify the relevant packages to bid on, and there is no easy, general way for a bidder or an analyst with limited information to do that: this is the *package identification problem*. In contrast, for auctions like the SAA in which bids are made on each item individually, the item bids define an implicit bid on every package. So while bids in the SAA generally cannot be perfectly aligned with values, the relevant packages are never entirely omitted.

In the presence of strong complementarities between individual items, auctions like the SAA that force separate bid competition for each individual item create a different problem: the *exposure problem*. That is the risk that a bidder who bids nearly up to its values, but not beyond, in an effort to buy a particular package may get stuck with a low-value subset of that package. Even when a global bidder has the highest value for the complete package of all items, if that bidder's values exhibit complementarities, straightforward bidding by other bidders who have values only for small packages may result in a total price that is higher than the global bidder's value.

Our experiment suggests that the relative magnitudes of the package identification problem and the exposure problem can determine the relative performance of the SAA and the CCA. In our experiment, a surrogate for the magnitude of the first problem is the simulation outcome: our simulated bidders rely simplistically on provisional prices and profits to guide the choice of packages on which to bid. When that guidance is good, the CCA results in high efficiency, higher than that of the traditional SAA. But the guidance can be poor, and the outcomes can then be less efficient than the SAA.

In our experiment, as outside the lab, bidders may have other cues beyond prices to help them identify the relevant packages. In the laboratory, the bidders' names ("global" or "local") provided a strong clue about which packages were most likely to be relevant, even when prices and profits point the bidder toward a different package. Our straightforward simulator for predicting outcomes omitted this cue, but it seems that the subjects in experiment did not: lab outcomes were more efficient than the straightforward simulator when prices and provisional profits misled the simulator but bidder names directed lab subjects to the efficient outcomes.

The variety of experimental outcomes reported here also highlights another of our themes: that the set of possible environments is too vast to permit sweeping statements based just on experiments about the comparative performance of mechanisms. Rather, emphasis needs to be placed on understanding the behavior of individual subjects, and then supplementing experimental findings by theory and simulations to deduce how that behavior will play out in other value environments.

This paper examined the performance of these two auction mechanisms for a previously untested class of valuation profiles. In contrast to our earlier experiment, in which synergies among items were the kinds of "geographic synergies" that are commonly studied in spectrum auction experiments (Brunner et al., 2010; Goeree and Holt, 2010), the synergies in this paper arise from fixed costs shared among all items. These new valuation patterns forced us to qualify more carefully some of the findings of our previous work regarding the ability of the straightforward bid simulator to accurately predict efficient auction outcomes, along with a providing a sharp test of the role of prior information (in the form of bidder "names") in influencing auction efficiency.

The experiment also included another new and surprising finding about aggressive bidding tactics by regional bidders, who bid on valueless items to drive up their prices to other bidders, thereby mitigating the threshold problem. This opens up a potential line of study to understand why the threshold problem, which in theory can interfere with efficiency, has not been found to interfere with efficiency in many experiments.

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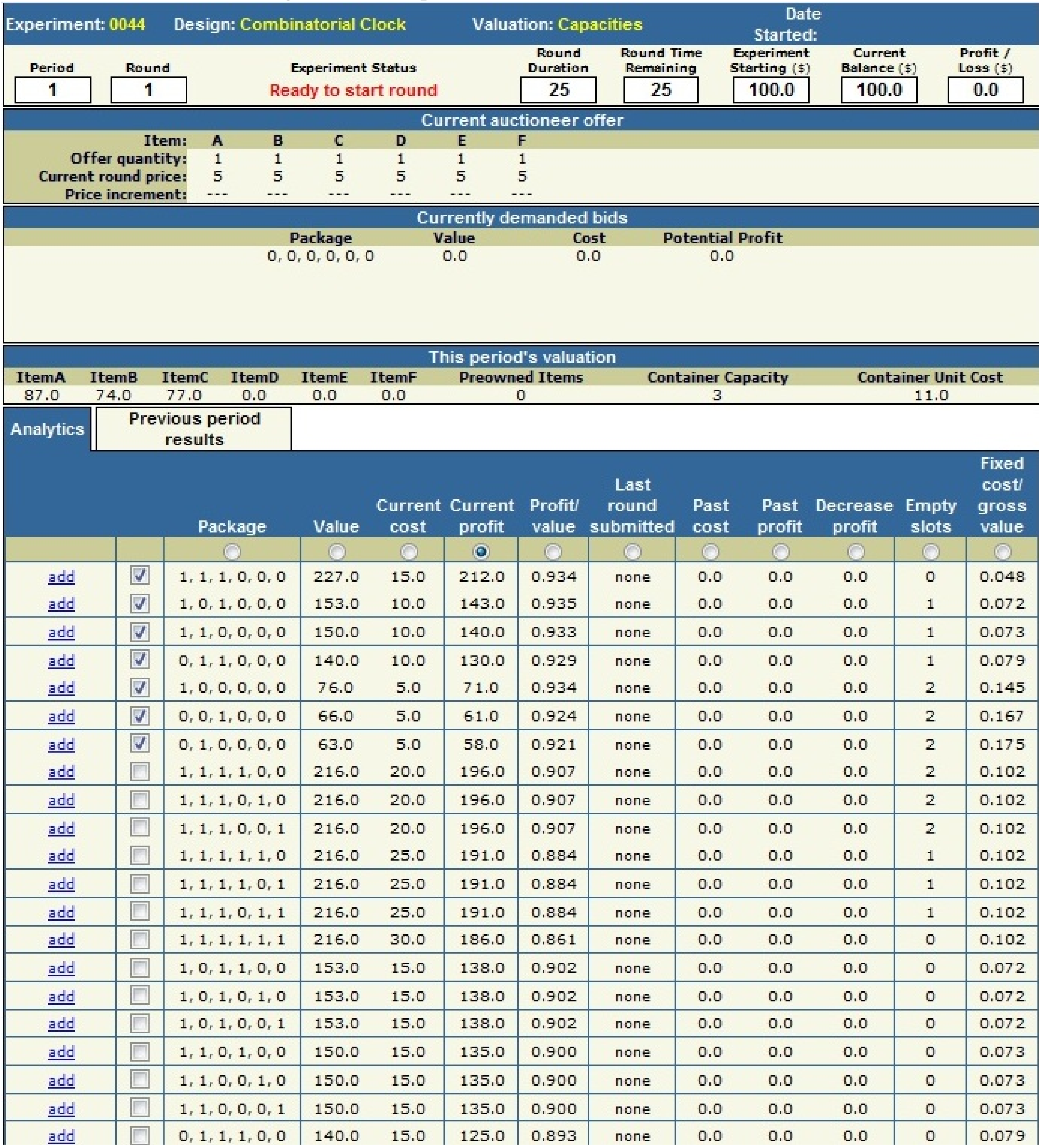
Figure 2
Layout of Computer Interface for CCA Auctions



Experiment: 0044 Design: Combinatorial Clock Valuation: Capacities Date Started:

Period	Round	Experiment Status	Round Duration	Round Time Remaining	Experiment Starting ($)	Current Balance ($)	Profit / Loss ($)
1	1	Ready to start round	25	25	100.0	100.0	0.0

Current auctioneer offer

Item:	A	B	C	D	E	F
Offer quantity:	1	1	1	1	1	1
Current round price:	5	5	5	5	5	5
Price increment:	---	---	---	---	---	---

Currently demanded bids

Package	Value	Cost	Potential Profit
0, 0, 0, 0, 0, 0	0.0	0.0	0.0

This period's valuation

ItemA	ItemB	ItemC	ItemD	ItemE	ItemF	Preowned Items	Container Capacity	Container Unit Cost
87.0	74.0	77.0	0.0	0.0	0.0	0	3	11.0

Analytics | Previous period results

		Package	Value	Current cost	Current profit	Profit/ value	Last round submitted	Past cost	Past profit	Decrease profit	Empty slots	Fixed cost/ gross value
add	☑	1, 1, 1, 0, 0, 0	227.0	15.0	212.0	0.934	none	0.0	0.0	0.0	0	0.048
add	☑	1, 0, 1, 0, 0, 0	153.0	10.0	143.0	0.935	none	0.0	0.0	0.0	1	0.072
add	☑	1, 1, 0, 0, 0, 0	150.0	10.0	140.0	0.933	none	0.0	0.0	0.0	1	0.073
add	☑	0, 1, 1, 0, 0, 0	140.0	10.0	130.0	0.929	none	0.0	0.0	0.0	1	0.079
add	☑	1, 0, 0, 0, 0, 0	76.0	5.0	71.0	0.934	none	0.0	0.0	0.0	2	0.145
add	☑	0, 0, 1, 0, 0, 0	66.0	5.0	61.0	0.924	none	0.0	0.0	0.0	2	0.167
add	☑	0, 1, 0, 0, 0, 0	63.0	5.0	58.0	0.921	none	0.0	0.0	0.0	2	0.175
add	☐	1, 1, 1, 1, 0, 0	216.0	20.0	196.0	0.907	none	0.0	0.0	0.0	2	0.102
add	☐	1, 1, 1, 0, 1, 0	216.0	20.0	196.0	0.907	none	0.0	0.0	0.0	2	0.102
add	☐	1, 1, 1, 0, 0, 1	216.0	20.0	196.0	0.907	none	0.0	0.0	0.0	2	0.102
add	☐	1, 1, 1, 1, 1, 0	216.0	25.0	191.0	0.884	none	0.0	0.0	0.0	1	0.102
add	☐	1, 1, 1, 1, 0, 1	216.0	25.0	191.0	0.884	none	0.0	0.0	0.0	1	0.102
add	☐	1, 1, 1, 0, 1, 1	216.0	25.0	191.0	0.884	none	0.0	0.0	0.0	1	0.102
add	☐	1, 1, 1, 1, 1, 1	216.0	30.0	186.0	0.861	none	0.0	0.0	0.0	0	0.102
add	☐	1, 0, 1, 1, 0, 0	153.0	15.0	138.0	0.902	none	0.0	0.0	0.0	0	0.072
add	☐	1, 0, 1, 0, 1, 0	153.0	15.0	138.0	0.902	none	0.0	0.0	0.0	0	0.072
add	☐	1, 0, 1, 0, 0, 1	153.0	15.0	138.0	0.902	none	0.0	0.0	0.0	0	0.072
add	☐	1, 1, 0, 1, 0, 0	150.0	15.0	135.0	0.900	none	0.0	0.0	0.0	0	0.073
add	☐	1, 1, 0, 0, 1, 0	150.0	15.0	135.0	0.900	none	0.0	0.0	0.0	0	0.073
add	☐	1, 1, 0, 0, 0, 1	150.0	15.0	135.0	0.900	none	0.0	0.0	0.0	0	0.073
add	☐	0, 1, 1, 1, 0, 0	140.0	15.0	125.0	0.893	none	0.0	0.0	0.0	0	0.079

Table 1
Experimental Treatments

	Number of subjects[a] (number of auction profiles in a session)		
Session	Session 1	Session 2	Session 3
Combinatorial clock auction (CCA)			
4-items	19	18 (10)	18 (12)
6-items (Series 1)	25	19 (8)	20 (8)
6-items (Series 2)	26	21 (10)	19 (10)
Simultaneous ascending auction (SAA)			
4-items	18	17 (10)	16 (11)
6-items	28	23 (10)	23 (10)

[a] Same subjects participated in a given series. Number of subjects varies due to attrition.

Table 2

Early Ending/Collusive Like Auctions

	4-Item Auctions			6-Item Auctions		
	Mean Rounds to Completion[a]		Percentage of Auctions Ending Early[b]	Mean Rounds to Completion[a]		Percentage of Auctions Ending Early[b]
	All	Early Ending		All	Early Ending	
CCA	18.1 (5.1)	7.8 (2.2)	3.0% (4/132)	20.2 (7.5)	7.2 (2.4)	10.6% (24/226)
SAA	17.1 (7.9)	9.1 (1.4)	9.5% (10/105)	23.8 (7.0)	9.5 (0.6)	2.9% (4/140)

[a] Standard deviation reported in parentheses.
[b] Number of early ending auctions divided by the total number of auctions in parentheses.

Table 3

Percent of Profitable Packages Bid on, and Package Profitability, in CCA Auctions[a]

(Average number of profitable packages available to bid on in parentheses)

	Global bidders			Local bidders[b]		
		Distribution of bids[c]			Distribution of bids[c]	
	Percent of profitable packages bid On	Percent most profitable packages bid on	Percent 2nd most profitable packages bid on	Percent of profitable packages bid On	Percent most profitable packages bid on	Percent 2nd most profitable packages bid on
CCA4 Auctions Rounds 1-5	30.8 (13.0)	73.8	64.6	64.3 (2.8)	90.8	59.8
Rounds 6-10	23.5 (9.8)	74.8	49.1	58.3 (2.4)	89.2	41.7
Rounds 11-15	23.0 (7.4)	79.6	43.0	59.1 (2.2)	90.3	31.3
Rounds > 15	28.6 (4.9)	86.7	23.9	55.0 (2.0)	95.8	14.3
CCA6 Auctions Rounds 1-5	11.9 (59.5)	63.5	49.0	50.0 (6.6)	79.1	64.1
Rounds 6-10	7.2 (54.2)	56.7	37.8	46.6 (5.8)	80.3	61.3
Rounds 11-15	7.6 (40.9)	65.4	46.1	43.8 (4.8)	81.7	52.5
Rounds > 15	6.9 (26.0)	64.5	30.6	34.1 (4.4)	77.2	39.7

[a] Rounds are dropped for provisional winners, if there were no profitable packages to bid on, and when there were no bids.
[b] Only includes packages that had positive value for all items for regional bidders.
[c] Percentages can add up to more than 100% as subjects often bid on the most profitable package as well as the second most profitable package.

Table 4

Package Bids in CCA Auctions when Named Package is No Longer the Most Profitable Package[a]

	Local bidders				Global bidders			
	Number of cases	Percent most profitable only	Percent named only	Percent most profitable and named	Number of cases	Percent most profitable only	Percent named only	Percent most profitable and named
CCA4 Auctions								
Rounds 1-5	6	50.0	0	50.0	0	--	--	--
Rounds 6-10	68	66.2	2.9	30.9	12	33.3	16.7	25.0
Rounds 11-15	68	73.5	5.9	20.6	29	65.5	17.2	13.8
Rounds 16-20	24	91.7	4.2	4.2	15	73.3	6.7	6.7
Rounds > 20	4	50.0	0	50.0	4	100	0	0
CCA6 Auctions								
Rounds 1-5	8	25.0	12.5	62.5	0	--	--	--
Rounds 6-10	240	25.8	9.2	58.8	0	--	--	--
Rounds 11-15	203	30.0	14.3	45.3	119	31.9	13.4	36.1
Rounds 16-20	157	39.5	19.1	29.9	57	40.4	17.5	12.3
Rounds > 20	67	53.7	20.9	11.9	46	52.2	21.7	8.7

[a] Observations are dropped when a named package is not profitable, a provisional winner does not bid, and in the last round of the auction when there are no bids.

Table 5

Scope for Increased Profit at End of Auction[a]

	Bidder type	Frequency higher profits available[b]	Average forgone potential profits in ECUs[c]
CCA4 Auctions Losing bidders	Global	17.7% (9/51)	32.1 (12.4)
	Local	9.7% (10/103)	25.1 (11.4)
Winning bidders	Global	4.9% (4/81)	35.0 (26.4)
	Local	1.2% (2/161)	7.0 (5.0)
CCA6 Auctions Losing bidders	Global	36.5% (19/52)	165.6 (31.4)
	Local	21.4% (46/215)	27.4 (5.2)
Winning bidders	Global	26.4% (46/174)	79.2 (10.2)
	Local	30.0% (71/237)	48.0 (6.0)

[a] Excludes handful of cases (6 in CCA6, 2 in CCA4) where bidders earned negative profits.

[b] Raw data in parentheses.

[c] Averaged over those cases with scope for increased profit. Standard error of the mean in parentheses.

Table 6
Changes in Efficiency Between Auction Profiles: Tobit Index Function

	Easy/Named	Hard/Named	Easy/Unnamed	Hard/Unnamed
Hard/Named	-3.2%**			
Easy/Unnamed	-6.5%***	-3.3%**		
Hard/Unnamed	-7.6%***	-4.4%**	-1.1%	
SAA	-5.0%***	-8.0%***	7.2%***	2.1%

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

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

Table 7
Changes in Probability of Achieving 100% Efficiency: Marginal Effects from Probit

	Easy/Named	Hard/Named	Easy/Unnamed	Hard/Unnamed
Hard/Named	-0.213***			
Easy/Unnamed	-0.426***	-0.213***		
Hard/Unnamed	-0.559***	-0.346***	-0.133	
SAA	-0.292***	-0.419***	0.381***	0.271***

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

Table 8
Efficiency when Efficient Outcome Corresponds to Named versus Unnamed Packages

	Tobits[a]		Probits[b]	
	Named	Unnamed	Named	Unnamed
Unnamed	-5.8%***		-0.402***	
SAA	-6.6%***	4.7%***	-0.366***	0.319***

[a] Mean percentage difference in efficiency calculated from Tobit index function.

[b] Mean change in probability of achieving 100% efficiency from the probit regressions.

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

Table 9

Marginal Effects on Revenue and Profits in CCA and SAA Auctions

	Revenue[a]		Total Profit[b]	
	Named	Unnamed	Named	Unnamed
Unnamed	4.8%*		-2.8%*	
SAA	5.3%**	-0.1%	-7.6%***	1.5%

[a] Measured as a percentage of minimum revenue in the core.

[b] Measured as a percentage of the efficient allocation.

[c] Average of the two local bidders' profits.

*Significantly different from zero at the 10% level, two-tailed test.

**Significantly different from zero at the 5% level, two-tailed test.

***Significantly different from zero at the 1% level, two-tailed test.

Table 10

Scaled Distance from the Core when the Efficient Outcome Corresponds to Named versus Unnamed Packages

	Tobits[a]		Probits[b]	
	Named	Unnamed	Named	Unnamed
Unnamed	2.5%		-0.148***	
4-Item SAA	6.2%*	0.9%	-0.167***	0.00
6-Item SAA	0.1%	-5.5%***	-0.081*	0.081

[a] Mean percentage difference in efficiency calculated from Tobit index function.

[b] Mean change in probability of achieving 100% efficiency from the probit regressions.

* Significantly different from 0 at the 10% level, two-tailed test.

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

Table 11

Comparing Straight Forward Simulator with Alternative Simulator:

Mean Absolute Differences Between Predicted and Actual Efficiency

(standard errors in parentheses)

	Straight Forward Simulator	Alternative Simulator	Difference: Straight Forward less Alternative Simulator
All Auction Profiles	0.124 (0.006)	0.086 (0.005)	0.037*** (0.005)
Named Auctions	0.100 (0.008)	0.070 (0.007)	0.030*** (0.006)
Unnamed Auctions	0.145 (0.009)	0.101 (0.007)	0.044*** (0.008)

*** Significantly different from 0 at the 1% level or better, two-tailed paired t-test