Ascending Prices and Package Bidding: Further Experimental Analysis*

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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") 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 their prices, 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 the 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 distinguish conditions under which the CCA achieved substantially higher efficiency in the lab than the SAA from other conditions under which the SAA achieved higher efficiency. 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 their most profitable bundle at prevailing prices, and to bid on a package only when they were not holding a provisionally winning bid. This straightforward simulation model was reasonably successful in distinguishing 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 important 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 than in the corresponding SAA auctions, despite the contrary predictions of the simulator. We hypothesized that the names given to bidders in the experiment ("regional" or "global"), which

[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.

corresponded to the items that held positive value for them, could have provided an additional cue to human bidders, while the simulated bidders were guided only by prices.

Applications of the straightforward simulator to this fixed-costs environment creates a possibility that differs from any we found in the geographic synergies environments, namely ones in which the straightforward bidding simulator resulted in CCA outcomes that are fully efficient, or nearly so, but also required that items be split between the large bidder and at least one of the smaller bidders. On average these new auction profiles resulted in substantially lower efficiency in the CCA auctions compared to the SAA auctions. Thus, taken as whole, the data from both the present experiment and the earlier one indicate that 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 likely to achieve high efficiency compared to SAA auctions. But when the named packages do not correspond to the efficient outcome, 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. This result is of some practical importance since the auctioneer is likely to have some idea about bidder preferences, and has some flexibility in defining the items up for bid along with the corresponding auction mechanism in such a way as to achieve maximum efficiency.

Two other key results are reported in addition to this: First, bidders often made bids that deviated significantly from their underlying demands at the prevailing prices – a behavior that we will call "strategic bidding." For example, local bidders sometimes bid on packages containing items with zero value, while still dropping out on these items before becoming stuck with them. This form of strategic bidding serves as a partial antidote to the "threshold problem," in which local bidders fail to coordinate in competing with the global bidder. Second, given how subjects actually bid, in conjunction with the limitations of the straightforward simulation model, a simple extension of the simulation model is developed. This alternative simulator provides a marked improvement in the ability to predict high CCA efficiency in those cases where named packages do not correspond to the efficient allocation which should prove useful in future explorations of bidding behavior. In addition, comparing the predictions of the alternative simulator relative to the data as compared to the straightforward simulator serves the underscore the deficiencies in the straightforward simulator.

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 Nissan (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; 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* for their efficiency-relevant or core-relevant packages in an auction, then the outcome of the auction will be efficient or in the core, respectively.[2]

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.[3] So the question becomes: what might guide bidders to even 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.[4] 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 as in most cases these packages will correspond to the 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.

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

[3] 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.

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

As such, when these named packages correspond to the efficiency-relevant or core-relevant packages in the auction, and bidders bid sufficiently aggressively on them, one can expect (near) efficient or core outcomes.

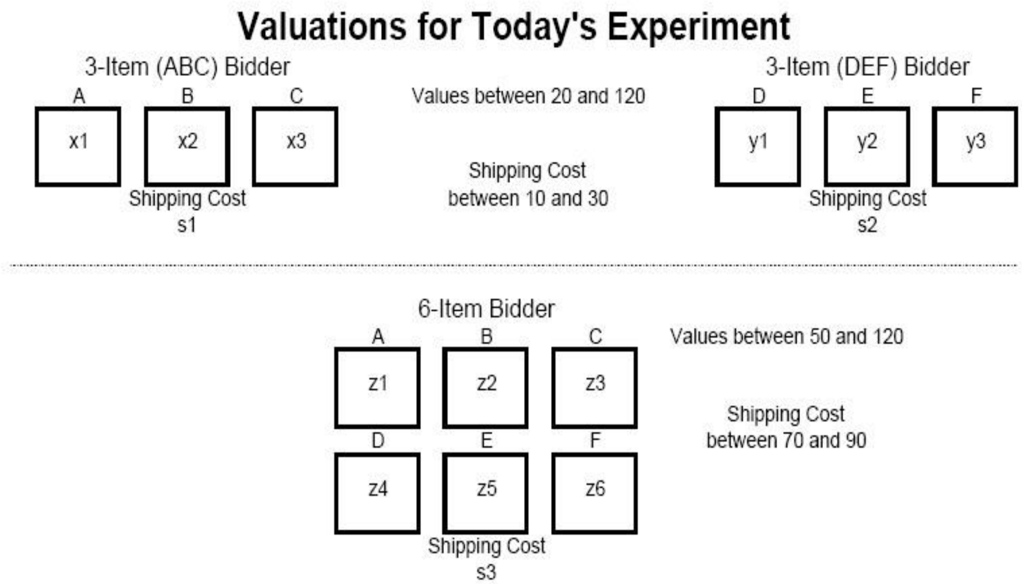
The named packages can be further understood as follows. In many practical auctions, bidders have some idea about how other bidders value different packages. When it is also commonly observed that bidders bid on only a few packages, it is more important for bidders to coordinate on certain combinations. 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, he would bid on the packages that are complementary to other bidders' package bids. If the named packages fit together in this way, then they may become a focal point of bidders' package bids. Our results suggest that bidders are able to bid on relevant packages if information about bidders' demand is publicly known and the relevant packages are the named packages.

In our experiment, bidders' interests in packages are known to all bidders: There are two local (or regional) bidders with value for items ABC and DEF respectively, 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 are of particularly high value to them.

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), 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.[5] Local bidders wanting to purchase additional items incurred a second fixed shipping cost equal to the 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).



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].[6] The four-item auctions were the same as the six-item auctions but with standalone items C and F dropped.

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

[6] 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.

The simulations employed three sets of 100 random draws based on this valuation structure, with 100 simulations for each random draw.[7] 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, four types of valuation profiles were selected for employment in auctions with human agents as follows:[8]

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 profiles achieved very high efficiency in CCA auctions and had significantly higher efficiency compared to SAA auctions.[9]
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.[10]
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.[11]
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 employed in KLM as they did not show up 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

[7] 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.
[8] The full set of profiles used and the simulation results are contained in the online data appendix.
[9] These valuation profiles were simply referred to as "Easy" in KLM.
[10] These valuation profiles were referred to as "Medium Hard" in KLM.
[11] In KLM these profiles were simply referred to as "Hard".

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.

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 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.[12] Thus, those items with price increases in the current round were easily identifiable as items which two or more bidders were actively competing for.[13]

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

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

Following each round, bidders were privately informed about which, if any, of their bids was a provisionally winning bid.[14] 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."[15] 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 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.

[14] Tentative winning bids were *not* announced in either Porter et al. (2003) or in Brunner et al. (2007).

[15] 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.

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.[16]
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.[17] 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 at the previous round's price. The round is then rebid with the revised prices and constraints.

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.[18] 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

[16] 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.

[17] The minimum bid requirement would not apply in this case, as there would be no current high bidder for the item in question.

[18] See the online instructions for complete details regarding this and the rest of the bidder aids provided.

that purpose next to each package. Checked 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 for both local and global bidders, 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.[19] Subjects were provided with starting capital balances of 150 ECUs. Any profits earned in an auction were

[19] In sessions where average earnings were lower than advertised the conversion rate was increased at the end of the session.

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.[20] Subjects' computer screens reported only their own outcome until the end of the auction, when the full allocation of units to all bidders in their auction was reported along with a final analytics screen that they could play with. 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, with it reduced to 15 seconds after round 12 or so, to speed things up. 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 four item CCA and SAA auctions, as well as in the six item CCA and SAA auctions.[21] 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 series of sessions. For subjects completing all three sessions, average earnings for the six-item auctions were $119, with minimum earnings of $59

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

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. 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).[22] If bidders bid on only a small number of packages, they may miss the relevant packages or not bid sufficiently aggressively on them.

The relevant data about limited bidding are reported in Table 2, where columns 2 and 5 report the average number of packages bid on in each round along with the number of profitable packages available to bid on (in parentheses) for global and local bidders, respectively. 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.[23] 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 7.2 packages in each round on average (out of 59.5 profitable packages available to bid on), with bidders bidding on their most profitable package 63.9% of the time, and bidding on their second most profitable package 50.0% 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 2.1 out of 4.8 profitable packages.[24] With the exception of global

[22] If the efficient outcome is unique, this condition is also necessary for full efficiency.

[23] 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:

[24] 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.

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.[25]

[Insert table 2 here]

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 the requirement: on average in the CCA4 auctions they bid at least once during the auction 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 packages they could bid on, with local bidders bidding on 4.9 out of the 7 possible 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 3 reports data for those auction rounds in which the named packages were *different* from the most profitable ones. As shown, when there

[25] 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.

was a conflict between the named package and the most profitable package and bidders chose to bid on only one of the two, the most profitable package attracts substantially more attention. Note, however, that the named package alone, or the named package *and* the most profitable package together, attract 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 below.

[Insert Table 3 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 immediately. 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.[26] 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) given the bid patterns, 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 package 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

[26] 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.

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 4 here]

Table 4 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.[27] 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.[28] 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 would not want to extend the auction, as these may well be jeopardized by setting off new rounds of competition.

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 4 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 mitigates the threshold problem here is that some 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 six item auctions, 39.5% of all local bids consisted of packages with one

[27] All calculations here are conditional on bidders not having exhausted their profit opportunities.
[28] The standard error, as opposed to the standard error of the mean here is 84.2, almost the same as the average foregone profits.

or more zero value items. This decreased to 9.4% 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 for these packages (11.0% of their provisionally winning bids). But they rarely got caught winning packages of this sort as there were only 2 cases out of 160 where local bidders won a package containing one or more zero value items. Bidders varied a lot in terms of strategic bidding of this sort: 27.5% (11 out of 40) made these bids 40% of the time or more versus 35.0% who made these bids 5% of the time or less (with 5 out of these 14 never making a bid of this sort).

This strategy can compensate for the threshold problem with no negative side effects provided local bidders can avoid getting stuck with zero value items, which was almost always the case.[29] Bidding on packages containing zero value items has a number of additional advantages for local bidders as (i) it can help speed up the auction and (ii) they can impose costs on the global bidder thereby potentially helping them to win items that they would not otherwise win. [30]

B. 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.[31] This normalized efficiency measure yields a mean efficiency of 0% with random assignment of the items versus 100% for the surplus-maximizing assignment.

Table 5 reports efficiency for CCA and SAA auctions with four and six items, with results reported for each of the four auction categories specified in the experimental design. Two measures are reported, average efficiency across auctions within a category and the frequency with which 100% efficiency was achieved. Efficiency differences between the CCA and the

[29] For example, if the ABC bidder keeps driving up the prices for the DEF bidder, then the DEF bidder is forced to respond. Otherwise, the DEF bidder may lose the chance to bid profitably in later rounds. In either case, the ABC bidder compensates for any potential threshold problem. Reexamination of local players' bids in KLM show comparable frequencies of bidding on packages containing one or more zero value items, along with only one instance where they got caught winning such a package. In spite of this KLM report a relatively modest threshold problem.

[30] There is also evidence for global bidders acting strategically in a possible effort to drive out one or the other of the local bidders: In the CCA6 auctions there are 20 possible three-item packages for global bidders to bid on, which if done randomly would result in bidding on ABC or DEF 10% of the time. However, of the three-item packages bid on, 14.5% involved either ABC or DEF.

[31] 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.

corresponding SAA auctions are reported in the last two columns, along with two-tailed non-parametric test statistics for these differences.

We begin by looking at differences between the four auction categories for the CCA auctions. Within the CCA auctions, efficiency is clearly at its highest level in the Easy/Named auctions, those in which the straightforward bidding simulator yields 100% efficiency and the named packages correspond to the efficient package allocations. For both four and six item auctions both efficiency measures are significantly higher in the Easy/Named versus the Hard/Named auctions ($p < 0.05$ for CCA6; $p < 0.01$ for CCA4) so that in this respect the straightforward simulator has some predictive power.[32] Comparing Hard/Named and Hard/Unnamed auctions, both efficiency measures are significantly higher for the Hard/Named four item auctions ($p < 0.01$), with the percentage of auctions achieving 100% efficiency significantly higher in the six item Hard/Named auctions as well ($p < 0.01$).[33]

The really interesting result in Table 5 is that efficiency is significantly higher for both efficiency measures in the Easy/Named versus the Easy/Unnamed auctions ($p < 0.01$ for all cases). Further, one cannot reject a null hypothesis of any difference in average efficiency between the Hard/Unnamed and the Easy/Unnamed auctions at anything approaching conventional levels. The same is true with respect to the percentage of auctions achieving 100% efficiency for the six item case, although the percentage achieving 100% efficiency is significantly higher for the Easy/Named auctions with four items ($p < 0.05$ one-tailed test). The implication of these results is that is that simulations based on straightforward bidding for the most profitable package systematically fail to identify when CCA auctions will be most efficient, and that a more reliable predictor consists of identifying those auctions in which bidders named packages correspond to the efficient outcome.

Table 5 also shows that those CCA auction categories achieving relatively high efficiency (the Easy and Hard Named profiles) had significantly higher efficiency than the corresponding SAA auctions. And that the CCA auctions generating relatively low efficiency (the Easy and Hard Unnamed profiles) often had lower efficiency than in the corresponding SAA auctions.[34]

[32] Based on 1-tailed Mann-Whitney tests for average efficiency and a two sample proportion test for frequency of achieving 100% efficiency.

[33] Although average efficiency is higher in six item Hard/Named auctions as well, the difference is not statistically significant at conventional level ($p = 0.13$; one-tailed Mann-Whitney test).

[34] Table 5 has the seemingly odd result that in the four item Hard/Unnamed auctions mean efficiency is slightly higher in the CCA than the SAA auctions, but the Mann-Whitney test indicates that mean efficiency is significantly

Even when the simulator predicts relatively low efficiency for the CCA auctions but the named packages correspond to the efficient outcome as in the Hard/Named auctions, the CCA auctions reliably achieve higher efficiency than the corresponding SAA auctions. Collapsing the four categories in Table 5 into two categories, those auctions where the efficient outcome corresponds to named versus unnamed packages shows that for the former the CCA achieves higher efficiency than the SAA, whereas for the latter the SAA achieves higher efficiency than the CCA (see Table 6).

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.[35] 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 Hard/Unnamed CCA auctions it generates lower efficiency compared to straight forward bidding.

C. Seller Revenue: Following Milgrom (2007) we use the minimum revenue in the core as the competitive-revenue standard in package auctions. The core for package allocation problems has a competitive auction 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

lower ($p < 0.10$, two tailed test). The Mann-Whitney test is consistent with the fact that two thirds of the SAA auctions achieve 100% efficiency compared to a little over one third of the CCA auctions, and that the Mann-Whitney test is based on ranks of bids. There are a few SAA auctions with relatively low efficiency pulling the mean down.

[35] 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.

losing bids. For comparing across auction profiles Table 7 reports revenue as a percentage of the minimum revenue in the core. These data, and the data in Table 8 on distance from the core, are reported in terms of the collapsed categories used in Table 6. This is based on the clear and striking differences in efficiency between the two collapsed categories, with the data in Tables 7 and 8 complementary to the efficiency data.[36]

The selection of auction profiles paid little if any attention to predicted revenue and 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.

[Insert Table 7 here]

Revenue as a percentage of minimum revenue in the core averages 90% or better for both CCA and SAA auctions, with revenue occasionally greater than the minimum revenue in the core. Having dropped the obvious cases of collusion from the CCA6- Series 1 auctions, we are unable to reject a null hypothesis of no differences in revenue between CCA and SAA auctions in any of the cells in Table 7 ($p > .10$, two-tailed Mann-Whitney tests).[37] However, *within* the CCA6 auctions, revenue is significantly higher in the unnamed profiles compared to the named profiles ($p < .05$). So although efficiency is lower in the CCA auctions when the efficient outcome does not correspond to named packages, revenue is higher.

D. Bidder Profits: Table 7 reports profits as a percentage of the efficient allocation.

Profits are higher in the CCA compared to the SAA auctions when named packages correspond to the efficient outcome ($p < .05$ with four items; $p > .10$ with six items). And they are lower than profits in the SAA auctions when unnamed packages correspond to the efficient outcome ($p < .10$ for both four and six item auctions).

Looking at profits within each auction mechanism, profits are higher in the CCA auctions when named packages correspond to the efficient outcome than when they do not.[38] But profits are lower within the SAA auctions when named packages correspond to the efficient outcome.[39] These profit patterns are the mirror image of those reported with respect to seller revenue, but are

[36] This is not to say that efficiency outcomes, particularly in the efficient ≠ named package category, are homogenous; see Section F below.

[37] Statistical tests for Table 7 are all two-tailed Mann-Whitney tests using each auction as the unit of observation.

[38] Pooling all bidders' profits together, for four and six item auctions $p < 0.05$ and $p < 0.10$, respectively, under a two tailed Mann-Whitney test.

[39] Pooling all bidders' profits together, for four and six item auctions $p < 0.01$ and $p < 0.10$, respectively, under a two tailed Mann-Whitney test.

somewhat more extreme as these differences are statistically significant at conventional levels with respect to profits, but are not statistically significant with respect to revenue (with the exception of the six item CCA auctions).

E. Distance from the Core: Table 8 reports the scaled distance from the core for the different auction profiles. The scaled distance is 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. Both the average scaled distance and the percentage of auctions achieving zero distance are reported, along with statistical tests comparing CCA and SAA auctions.

When the named packages correspond to the efficient outcome, average distance from the core is greater under SAA than CCA auctions ($p < 0.01$ for four item auctions, $p > 0.10$ for six item auctions), with the percent of auctions achieving zero distance from the core larger for CCA than SAA auctions ($p < 0.01$ and 0.05 for four and six item auctions respectively). When unnamed packages correspond to the efficient outcome, there is no consistent pattern between CCA and SAA auctions: Average distance from the core is greater in the SAA four-item auctions compared to the corresponding CCA auctions (statistically significant at the 10% level for percent of auctions with zero distance from the core). For the six-item auctions average distance from the core is smaller under SAA than CCA ($p < 0.05$), but the frequency with which auctions achieve zero distance from the core is greater in the SAA auctions.

To sum up, the general pattern is one of greater efficiency, with outcomes closer to the competitive equilibrium under CCA than SAA auctions when named packages correspond to the efficient outcome. The reverse pattern holds when unnamed packages correspond to the efficient outcome.

F. 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 2 and 3). 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 and 40% of the time (randomly) bid on their second most profitable package as well.[40] While this alternative simulator is still just a rough approximation to bidder behavior, it is a significant step in the right direction without being so detailed as to be non-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., for about half of the Easy/Named 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 profiles.

Two sets of regressions, reported in Table 9, are reported to compare the two simulators. The regressions at the top of the table use auction efficiency as the dependent variable. The bottom set of regressions are probits where the dependent variable takes the value 1 for auctions that achieve 100% efficiency and 0 otherwise. Robust standard errors accounting for clustering at the level of the individual auction profile are employed in both cases.

For the regressions reported at the top of Table 9 right-hand-side variables include a dummy for profiles in which the efficient allocation corresponds to unnamed packages (DU = 1; 0 otherwise), the efficiency prediction for that profile for the straightforward simulator ($EFFIC_S$), or the alternative simulator ($EFFIC_A$), along with an interaction term between the efficiency prediction and the DU dummy (EFFIC*DU). The specification employing the efficiency predictions from the straightforward simulator fails to capture any significant variation in the efficiency data as the Wald test for right-hand-side variables exclusive of the constant is not statistically significant at conventional levels. The alternative efficiency simulator captures some of the variation in the data, as the DU dummy is negative and statistically significant, as is the $EFFIC_A$*DU interaction term. That is, the alternative simulator captures some of the variation in efficiency outcomes in cases where named packages do not constitute the efficient allocation. The failure of the alternative simulator to capture any statistically significant variation in the

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

efficiency data in cases where the efficient allocation corresponds to the named packages has to do with the fact that (i) there is essentially no variation in efficiency within the Easy/Named category and (ii) efficiency is reasonably high in the Hard/Named category regardless of whether the alternative simulator predicts relatively high or low efficiency.

The probits in the bottom half of the table tell a similar story. The interaction terms between the DU dummy and the efficiency measures have been dropped in both cases as neither one achieves statistical significance at anything approaching conventional levels. The DU dummy is negative and statistically significant in both specifications ($p < 0.01$). The efficiency predictions based on the alternative simulator achieve statistical significance ($p < 0.10$), but the coefficient value for the straightforward simulator is not significant at conventional levels ($p = 0.16$).

We reach two conclusions based on these results: First, they confirm the relatively weak predictive power of the straightforward regarding package auction efficiency documented earlier. Second, and more import, they indicate that it is possible to develop a relatively simple alternative simulator that predicts auction efficiency with some accuracy when the unnamed packages correspond to the efficient auction allocation.

IV Conclusions

According to the theory articulated in KLM, combinatorial auctions lead to good (efficient or core) allocations when bidders bid sufficiently aggressively on relevant packages during the auction. To understand the performance of combinatorial auctions in practice, that theoretical observation needs to take account of our experimental observation that bidders bid on just a few packages, even in relatively small auctions when bidding on many packages is at least conceivable, as this pattern of bidder behavior poses a particular problem for combinatorial auctions like the CCA.

Combinatorial auctions require that bidders identify 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 the SAA, in which bids are made on each item individually, the item bids define an implicit bid on every package, so that the relevant packages are never entirely omitted.

However, the SAA has its own limitations in the presence of strong complementarities between individual items. Its item bids prevent a bidder from expressing package values accurately, and that contributes to the *exposure problem*: a bidder who tries to buy a particular package risks being stuck with low-value subset of that package. Even when a bidder has the highest value for the complete package of all items, item bidding treats the competing bids as additive ("OR") bids, which may drive package prices too high and lead to inefficiency in that way.

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 pointed the bidder elsewhere. Our simulators for predicting outcomes omitted this cue, but it seems that the subjects in experiments did not: lab outcomes were more efficient than the simulators predicted when provisional profits were misleading but bidder names pointed to the efficient outcomes.

The experiment 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 new situations.

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 shared fixed costs. These new 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 is important in theory, has found relatively little support in many experiments.

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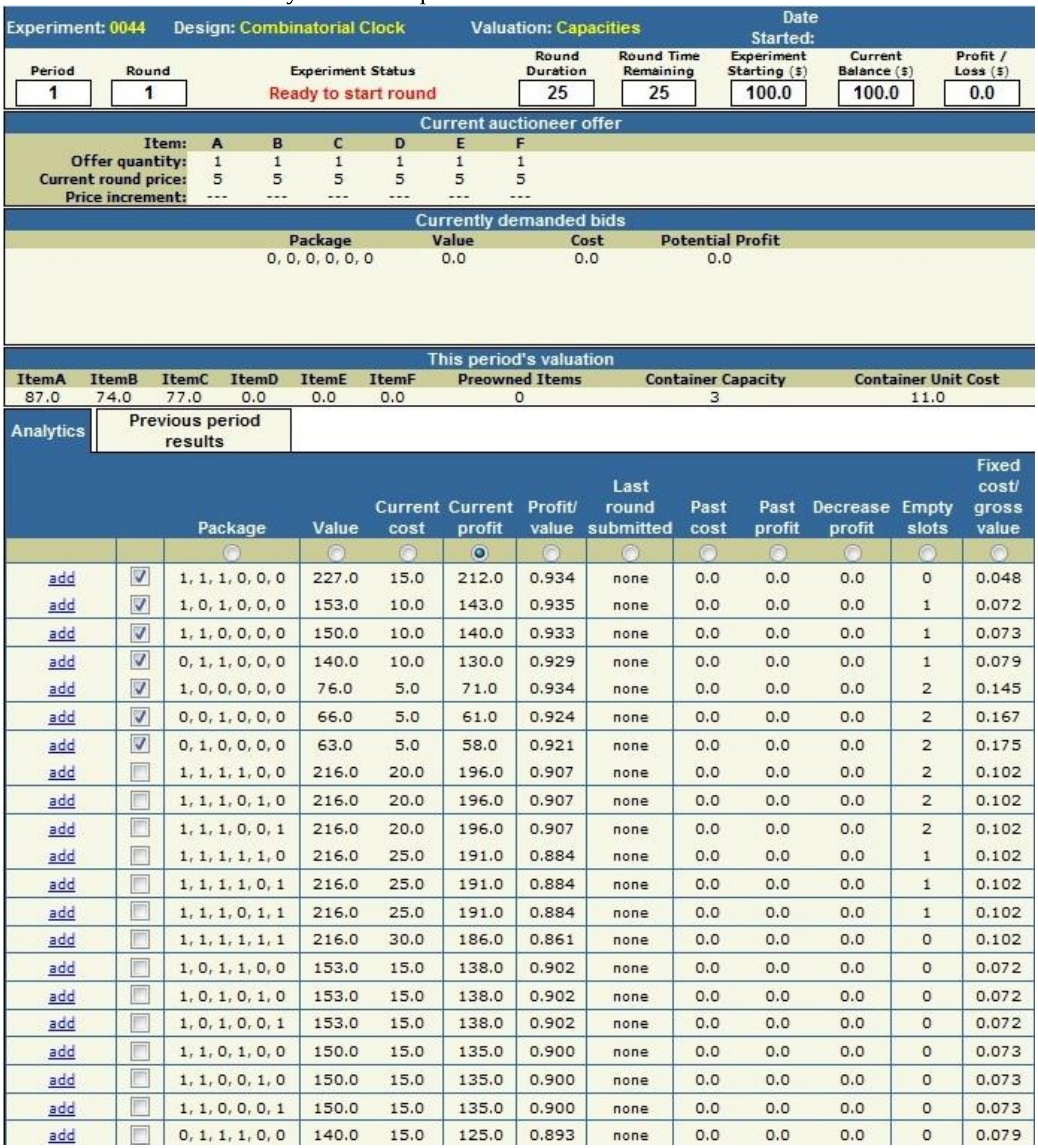
Figure 2
Layout of Computer Interface for CCA Auctions



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
Number and Type of Packages Bid on in CCA Auctions[a]
(Average number of profitable packages to bid on in parentheses)

	Global bidders			Local bidders[b]		
		Distribution of bids[c]			Distribution of bids[c]	
	Average number of bids	Percent most profitable	Percent 2nd most profitable	Average number of bids	Percent most profitable	Percent 2nd most profitable
CCA4 Auctions Rounds 1-5	4.0 (13.0)	73.8	64.6	1.8 (2.8)	90.8	59.8
Rounds 6-10	2.3 (9.8)	74.8	49.1	1.4 (2.4)	89.2	41.7
Rounds 11-15	1.7 (7.4)	79.6	43.0	1.3 (2.2)	90.3	31.3
Rounds > 15	1.4 (4.9)	86.7	23.9	1.1 (2.0)	95.8	14.3
CCA6 Auctions Rounds 1-5	7.2 (59.5)	63.9	50.0	3.3 (6.6)	79.1	65.3
Rounds 6-10	3.9 (54.1)	57.4	38.2	2.7 (5.8)	80.4	61.6
Rounds 11-15	3.1 (40.9)	65.4	46.1	2.1 (4.8)	81.7	52.5
Rounds > 15	1.8 (26.0)	64.5	30.6	1.5 (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 3
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 4
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	28.3% (13/46)	89.1 (23.4)
	Local	20.4% (43/211)	24.2 (4.8)
Winning bidders	Global	21.0% (34/162)	51.6 (6.7)
	Local	26.8% (55/205)	35.9 (5.7)

[a] Excludes several 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 5
Efficiency Outcomes by Auction Type

	Simulation Profile[a]	CCA Efficiency		SAA Efficiency		Differences (CCA-SAA)	
		Average[b]	Percent of Auctions 100% Efficient	Average[b]	Percent of Auctions 100% Efficient	Average[c]	Percent of Auctions 100% Efficient[d]
4 item auctions	Easy/Named (5)	98.7% (1.3)	97.2%	91.5% (3.1)	72.0%	7.2% (2.78)***	25.2% (2.87)***
	Hard/Named (5)	96.9% (1.2)	73.3%	84.1% (2.5)	20.0%	12.8% (4.15)***	53.3% (3.70)***
	Hard/Unnamed (6)	91.4% (1.9)	36.1%	90.3% (5.0)	66.7%	1.1% (-1.88)*	-30.6% (-2.47)**
	Easy/Unnamed (5)	93.3% (2.0)	60.0%	97.2% (1.6)	50.0%	-3.9% (-1.07)	10.0% (0.78)
6 item auctions	Easy/Named (5)	93.1% (1.5)	54.8%	90.0% (2.1)	25.7%	3.1% (2.23)**	29.1% (2.77)***
	Hard/Named (4)	90.5% (2.0)	36.6%	87.4% (2.0)	0.0%	3.1% (2.24)**	36.6% 3.62)***
	Hard/Unnamed (5)	90.3% (1.5)	11.1%	89.9% (2.2)	31.0%	0.4% (-0.78)	-19.9% (-2.42)**
	Easy/Unnamed (4)	88.7% (1.5)	15.7%	97.1% (1.2)	60.0%	-8.4% (-4.65)**	-44.3% (-4.27)***

[a] Number of different CCA auction profiles in parentheses.
[b] Standard error of the mean in parentheses.
[c] Mann-Whitney test statistic in parentheses.
[d] Binomial test statistic in parentheses.
*Statistically significant at the 10% level, two-tailed test.
** Statistically significant at the 5% level, two-tailed test.
*** Statistically significant at the 1% level, two-tailed test.

Table 6
Efficiency Outcomes when Efficient Outcome Equals Named versus Unnamed Packages

	Simulation Profile[a]	CCA Efficiency		SAA Efficiency		Differences (CCA-SAA)	
		Average[b]	Percent of Auctions 100% Efficient	Average[b]	Percent of Auctions 100% Efficient	Average[c]	Percent of Auctions 100% Efficient[d]
4 item auctions	Efficient = Named Package (10)	97.9% (0.9)	86.4%	88.2% (2.1)	48.9%	9.7% (4.52)***	37.5% (4.28)***
	Efficient = Unnamed Package (11)	92.3% (1.3)	47.0%	93.8% (2.7)	58.3%	-1.5% (-2.12)**	-11.3% (-1.28)
6 item auctions	Efficient = Named Package (9)	92.0% (1.2)	47.6%	88.9% (1.5)	14.3%	3.1% (3.33)***	33.3% (4.37)***
	Efficient = Unnamed Package (9)	89.5% (1.0)	13.3%	93.2% (1.4)	44.2%	-5.0% (-4.07)***	-30.9% (-4.66)***

[a] Number of different CCA auction profiles in parentheses.
[b] Standard error of the mean in parentheses.
[c] Mann-Whitney test statistic in parentheses.
[d] Binomial test statistic in parentheses.
*** Statistically significant at the 1% level, two-tailed test.

Table 7
Revenue and Profits in CCA and SAA Auctions
(standard error of the mean in parentheses)

	Revenue[a]		Profit[b]		Global profit[b]		Local profit[b]	
	CCA	SAA	CCA	SAA	CCA	SAA	CCA	SAA
4-item auctions Efficient = Named Package	97.8% (2.3)	102.6% (2.1)	23.3% (1.4)	13.5% (2.7)	6.9% (1.3)	1.9% (2.3)	8.2% (0.9)	5.8% (1.0)
Efficient = Unnamed Package	103.1% (2.7)	97.8% (2.8)	19.7% (1.9)	24.0% (3.4)	10.3% (1.5)	14.1% (1.8)	4.7% (0.6)	5.0% (1.3)
6-item auctions Efficient = Named Package	90.5% (2.1)	92.7% (2.3)	20.3% (1.5)	15.7% (2.2)	13.3% (1.4)	11.9% (1.7)	3.5% (0.5)	1.9% (0.6)
Efficient = Unnamed Package	95.7% (1.8)	93.5% (2.1)	17.7% (1.5)	20.7% (1.7)	9.3% (1.0)	11.9% (1.2)	4.2% (0.4)	4.4% (0.5)

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

Table 8

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

	Simulation Profile[a]	CCA Distance from the Core		SAA Distance from the Core		Differences (CCA-SAA)	
		Average[b]	Percent of Auctions Zero Distance	Average[b]	Percent of Auctions Zero Distance	Average[c]	Percent of Auctions Zero Distance[d]
4 item auctions	Efficient = Named Package (10)	11.5% (2.2)	42.4%	18.7% (2.3)	17.8%	-7.2% (-3.23)***	24.6% (2.72)***
	Efficient = Unnamed Package (11)	14.7% (1.9)	27.3%	18.3% (3.6)	13.3%	-3.6% (-0.30)	14.0% (1.93)*
6 item auctions	Efficient = Named Package (9)	22.7% (2.5)	19.4%	23.5% (2.8)	7.9%	-0.8% (-0.76)	11.5% (2.01)**
	Efficient = Unnamed Package (9)	20.4% (1.5)	3.8%	17.5% (2.4)	10.4%	2.9% (2.19)**	-6.6% (-1.77)*

[a] Number of different CCA auction profiles in parentheses.
[b] Standard error of the mean in parentheses.
[c] Mann-Whitney test statistic in parentheses.
[d] Binomial test statistic in parentheses.
* Statistically significant at the 10% level, two-tailed test.
** Statistically significant at the 5% level, two-tailed test.
*** Statistically significant at the 1% level, two-tailed test.

Table 9

Regression Results Comparing the Predictive Power of the Two Simulators

With auction efficiency as dependent variable:

Efficiency = 0.813 + 0.093 DU + 0.117 $EFFIC_S$ – 0.130 $EFFIC_S$*DU $R^2 = 0.02$; Wald $\chi^2 = 4.0$

(0.079)[a]   (0.114)   (0.085)   (0.146)

Efficiency = 0.905 - 0.272 DU + 0.016 $EFFIC_A$ – 0.289 $EFFIC_A$*DU $R^2 = 0.06$; Wald $\chi^2 = 25.0$[a]

(0.103)[a]   (0.134)[b]   (0.114)   (0.159)[b]

Probits for auctions achieving 100% efficiency:

Efficiency = -1.263 - 0.964 DU + 1.313 $EFFIC_S$ Pseudo $R^2 = 0.13$; Wald $\chi^2 = 17.0$[a]

(0.819)   (0.236)[a]   (0.940)

Efficiency = -2.653 - 0.873 DU + 2.762 $EFFIC_A$ Pseudo $R^2 = 0.14$; Wald $\chi^2 = 16.7$[a]

(1.45)[b]   (0.252)[a]   (1.577)[b]

[a] Statistically significant at the 0.01 level, two-tailed test.

[b] Statistically significant at the 0.10 level, two-tailed test.