Peter Cramton, “Ascending Auctions,” *European Economic Review* 42:3-5 (1998) 745-756.

Ascending Auctions

Peter Cramton*

Abstract

A key question of auction design is whether to use an ascending-bid or a sealed-bid format. The critical distinction between formats is that an ascending auction provides the bidders with information through the process of bidding. This information is a two-edged sword. It may stimulate competition by creating a reliable process of price discovery, by reducing the winner’s curse, and by allowing efficient aggregations of items. Alternatively, the information may be used by bidders to establish and enforce collusive outcomes. Ex ante asymmetries and weak competition favor a sealed-bid design. In other cases, an ascending auction is likely to perform better in efficiency and revenue terms. Moreover, information in an ascending auction can be tailored to limit collusion.

JEL No.: D44 (Auctions)

Keywords: Auctions, Multiple-Item Auctions, Spectrum Auctions

Please send comments to:

Professor Peter Cramton
Department of Economics
University of Maryland
College Park MD 20742-7211

Peter@Cramton.umd.edu

(301) 405-6987 fax (301) 405-3542 web www.cramton.umd.edu

*I have benefited from many conversations with Lawrence M. Ausubel. I am grateful to the National Science Foundation for financial support. I have advised several bidders and governments in spectrum auctions. The opinions expressed are my own.

Ascending Auctions

Peter Cramton

At an early conference on spectrum auctions, I remember sitting next to a professional auctioneer and asking him to compare auction formats. His reply was emphatic: "Every auctioneer knows that English [ascending] auctions raise the most revenue." His confidence was a bit troubling in light of the ambiguous results in auction theory, and mixed results from experiments. Herein lies an attempt at explaining the virtues (and pitfalls) of ascending auctions in practice.

With neither theory nor experiments providing definitive results, it is easy to conclude that which auction format is best is an empirical matter. How one would go about answering this empirical question is difficult at best, since rarely do we see multiple formats being used in easily comparable settings. Certainly, it is easy to think of instances where a particular format has done remarkably well in generating revenues. Consider, for instance, the Federal Communications Commission's C-block ascending auction. It would be difficult to imagine that bids would have been higher under sealed bidding. Prices in that auction escalated to the point where bidders had to go back to investors with revised business plans that would justify the doubling of prices from an earlier auction. (Indeed, prices went so high that many winners are now unable to pay up.) On the other hand, BellSouth's recent $2.5 billion bid for the premier license in Brazil's sealed-bid cellular auction was $1 billion more than the next highest bid.[1] This bid of $139 per person was the highest price paid to date for a mobile phone license. BellSouth's stock fell $1.25 per share following the announcement of the outcome. It is hard to imagine that an ascending-bid format would have pushed the second-highest bidder (AT&T) above $2.5 billion.

Ascending auctions have been used for thousands of years. Sotheby's has relied on ascending auctions, since 1744, and Christie's, since 1766. Surely if ascending auctions performed badly these institutions would have changed their ways.

I begin by presenting the reasons why ascending auctions are so successful. Then I discuss reasons for using a sealed-bid auction. The final section discusses various ascending auctions for the sale of many items.

I. Why ascending bid?

Auctions are fundamentally about allocating and pricing scarce resources in settings of uncertainty. Every auction asks and answers the basic question: who should get the items and at what prices? The popularity of an ascending auction stems from how well it answers this question. In an ascending auction, price and allocation are determined in an open competition among the bidders. The bidders willing to pay the most win and pay prices that no other bidders are willing to top.

Ascending auctions provide a process of price discovery. Value is socially determined through the escalation of bids. Rarely does a bidder enter an auction with fixed values for the items being sold. Rather the bidders learn from each other's bidding, adjusting valuations throughout the process. This process is especially important when resale is a possibility or more generally when others have information relevant to assessing the item's value. This open competition gives ascending auctions a legitimacy that is not shared by other auctions. Throughout the auction, every bidder is given the opportunity to top the high bid. The auction ends when no bidder is willing to do so. The winner can say, "I won because I was willing to pay a bit more than the others." Losers are given every opportunity to top the winning bid. Their loss stems solely from their failure to do so.

[1] *RCR*, July 14, 1997, p. 1.

The iterative price discovery in an ascending auction is most apt to generate reliable market prices. A sealed-bid auction forces the bidders to make guesses of the likely bids of the others. If these guesses are wrong, then the outcome may differ from what would result in a dynamic market. An ascending auction allows the learning needed to identify the intersection of supply and demand, and hence the market price.

A. Efficiency

This price discovery process is the source of the chief virtue of ascending auctions: efficiency. In the single-good case, ascending auctions are efficient under general conditions. Efficiency does not rely on symmetry, private values, or other unrealistic assumptions.[2] Of course, Vickrey has shown in the private value setting how efficiency theoretically can be achieved by sealed-bid auctions. However, experiments demonstrate that ascending auctions perform better than Vickrey auctions, because the incentive for playing the efficient dominant strategy is clearer to bidders (Kagel et al. 1987). A bidder with a value of $10 can see plainly in an ascending auction that dropping out below $10 is a bad idea, as is bidding beyond $10. This strategic simplicity not only promotes efficiency, but also encourages participation, since fewer resources are needed to figure out how to bid.

In auctions for multiple items, the efficiency question is more difficult and depends on which ascending auction is used, as I discuss later. The most natural format is the simultaneous ascending auction, used by the FCC in its spectrum auctions. In this auction, all items are on the block simultaneously. Bidders can raise their bids on any items and shift among items in response to price changes. This auction form makes a lot of sense for the sale of items with interdependent values. As the auction progresses, bidders get a better sense of final prices and assignments. This information is useful in deciding where to place bids. It allows efficient arbitrage across substitute items, and it improves chances that an efficient combination of complementary items will be obtained. Bidders can shift to better values as relative prices change, and can get a sense of whether it makes sense to go after a particular package of items. Of course, the process is imperfect, resulting in some inefficiency, but the dynamic price discovery goes a long way in realizing all gains from trade. On efficiency grounds it is hard not to recommend an ascending auction.

B. Revenue maximization

Efficiency is only one goal of the seller. Revenue maximization is an important, if not the overriding, goal in many cases. Hence, it is important to evaluate auction formats in revenue terms. Fortunately, revenue and efficiency are often not in conflict. Ausubel and Cramton (1996) show that, when bidders have flat demand curves in a symmetric private-value setting, the seller maximizes revenue by awarding the items to those with the highest values. More generally, the seller can do better by making use of information it has about bidders' values, and setting reserve prices and bidder-specific handicaps. However, such discriminatory practices are rarely acceptable and moreover the seller may not have useful information on the bidders' values. It is precisely this uncertainty that is prompting the auction in the first place. Hence, in most practical settings, it is reasonable to restrict attention to auction formats that treat the bidders equally and do not rely on subjective information about valuations.

The conflict between revenue maximization and efficiency is further reduced when one considers the desirable effects an efficient auction has on participation. Potential bidders are attracted to the auction based on the expected gains from participation. An efficient auction maximizes the gains from trade, which is the pie that is to be divided between seller and buyer. An attempt by the seller to extract additional revenues by setting a positive reserve discourages participation, which ultimately reduces revenues (Harstad 1990).

---

[2] Ascending auctions may not be efficient in settings with multidimensional signals. For example, in a setting with both common and private value components, the bidder with the highest common-value signal may top the bidder with the highest private value.

Efficient auctions do especially well when we introduce the possibility of resale. Consider an independent private value setting in which resale leads to an efficient assignment. By the Revenue Equivalence Theorem, the final outcome is the same whether the initial auction is efficient or inefficient, and so the bidders' expected payoffs are identical under either an efficient or inefficient initial auction. However, the seller loses any share of the gains from trade in the resale market, and so is best off adopting an efficient auction, where no resale takes place.

In the realistic case where bidders' values are affiliated, Milgrom and Weber (1982) proved an important revenue advantage of ascending auctions. The open bidding competition reveals information that the bidders then use in revising their estimates of value. As a result, uncertainty is reduced and so is the winner's curse. Bidders can safely bid more aggressively, increasing revenues to the seller.

A related behavioral effect is the comfort afforded the bidder in an ascending auction. The winner knows that others are willing to pay nearly as much. If one takes the highest bid of the others as the market price, then it is impossible to overbid by more than one bid increment. Indeed, at the time the final bid is placed, the winner knows that others are willing to pay *more* for the item. Raising the bid in this state seems especially attractive. (Of course, this reasoning is flawed, but it may be one reason bidders routinely fall into the trap of the winner's curse.) In contrast, in a sealed-bid auction, overbidding is a serious problem, especially when one is bidding as an agent for shareholders. How does the BellSouth bidding team explain why its bid of $2.5 billion beat the next best bid by $1 billion? In an ascending auction, one can always use the bidding of the others to justify a further raise. "If it is worth $x to them, why is it not worth that much to us? Aren't we a good company?" Not raising a bid is a confession of inferiority.

A final revenue advantage of ascending auctions comes from budget constraints and the way they are established and revised. In high stake auctions, like the FCC spectrum auctions, bidding teams typically face budget constraints, which are negotiated with the Board of Directors (or outside investors). Boards are wisely skeptical of the rosy forecasts found in some business plans. Hence, without evidence to the contrary, Boards may tend to substitute conservative estimates and approve a more limited budget as a result. Under sealed bidding, the bidding team is held to this limited budget. However, in an ascending auction, the bidding team can return to the Board with hard and fast "evidence" supporting their optimistic estimates: the high bids of the other bidders confirm how much these items are worth. In this way, budget constraints can be relaxed. Also, a simultaneous ascending auction enables the bidders to spend their entire budgets; whereas, in a simultaneous sealed bid, a bidder is unable to spend its entire budget, due to the uncertainty of winning.

This search for additional money was especially important in the FCC's C-block auction. The five-month duration of the auction gave bidders ample opportunity to seek more funds. For example, NextWave, the largest bidder with winning bids of $4.2 billion (41% of revenues), raised essential funds throughout the auction. In a letter to the Securities & Exchange Commission, on 3 February 1997, NextWave states, "the Company did not even have enough contingent Series B subscriptions to meet the FCC's 5% deposit requirement until shortly before the close of the C-block Auction." For NextWave and many of the other winners, raising additional funds during the auction was an essential element in winning licenses. These firms went into the auction with business plans that supported valuations of about $20 per person. The auction ended with the winners paying twice that.[3]

[3] The FCC has as of August 1997 collected only about 10% of this money (the initial deposit). Since the auction, the investment climate for wireless telephony has soured, making it impossible for the winners to make the required installment payments. The FCC is in the process of deciding whether to foreclose and reauction (and risk tying the licenses up in bankruptcy court) or to restructure the debt.

C. Privacy and Implementation

Another virtue of ascending auctions is privacy. The ascending process reveals only that the winners are willing to pay at least the amount bid. The upper portion of the demand curve is never expressed. Rothkopf et al. (1990) argue that this is one reason Vickrey's sealed-bid is auction is so rarely used. The incentive to bid your true value is lost if this information is relevant to subsequent transactions. Of course, the seller could choose not to make the winning bids public, but this may be difficult in some settings. In addition, corruption is more of a problem in the Vickrey auction. After receiving the bids the seller can submit a fake bid for just under the amount of the highest bid. Again, steps can be taken to mitigate this risk, but it may be impossible to eliminate this possibility.

An important implementation advantage of ascending auctions is that the open bidding process is less vulnerable to corruption than is sealed bidding. Although corruption is possible and does occur in ascending auctions, the open competition precludes the most frequent form of corruption in first-price sealed-bid auctions: leaking the high bid to a bidder who can then top it. Since in an ascending auction high bids are revealed to everyone, and can be topped by anyone, there is no need for secrecy.

A second implementation advantage is that ascending auctions avoid the commitment problem inherent in a sealed-bid format. A sealed-bid auction may be infeasible, because the seller cannot commit to rejecting higher bids. In the takeover context, where the Board is obligated to do the best it can for the shareholders, the Board may be forced to consider higher bids (lock-ups and break-up fees are imperfect ways around this problem). Moreover, since takeovers are initiated by an initial bid from a buyer, it is difficult for the seller to orchestrate a sealed-bid auction.

II. Why sealed bid?

One of the traditional reasons for sealed bidding is that it avoids the need to bring the parties together. The bidders may be dispersed geographically and it may be too costly to get them all together for an ascending-bid auction. This reason is now irrelevant. Today, communication technologies have advanced to the point where bidders can easily participate in ascending auctions without leaving the comfort of their homes. The Internet is used to conduct hundreds of ascending auctions each day with bidders worldwide. Security and reliability issues largely have been solved.

Simplicity is also an issue. Sealed-bid auctions would appear to be the easiest to implement. The seller need simply announce the form bids should take and give an address and date for bid submission. Again, technology has gone a long way to reducing the costs of an ascending auction for both the seller and the bidders.

Difficult bid evaluation is another reason for using sealed bids. Procurement auctions are usually sealed bid for precisely this reason. In procurement, price is often only one dimension of a bid. The quality of the job may be equally important, and it may be impossible for the auctioneer to fully specify how bids are to be compared. Provided there is sufficient time, this does not necessarily rule out an ascending bid process. Certainly bid evaluation is complex in takeovers, and yet takeovers often involve an alternating sequence of bids, which is characteristic of ascending auctions. High-stake procurement also commonly involves an iterative process, where bidders are given an opportunity to improve bids in light of initial bids.

A. Ex ante asymmetries

The efficiency of ascending auctions is not always a virtue. In particular, when there are ex ante asymmetries among the bidders, then an ascending auction may discourage participation by lower-valuing bidders. If a bidder knows that it will ultimately lose to the bidder with the highest value, then it has no incentive to participate. At the extreme, if all parties know which potential bidder has the highest value, then only this highest bidder is likely to bid in an ascending auction, and the auction ends at a price near zero. The advantage of a first-price sealed-bid auction in this setting is that it eliminates this zero-price equilibrium. The low-valuation bidders have an incentive to participate, since in equilibrium they win with positive probability at favorable terms. The possibility of an inefficient assignment is precisely what attracts the bidders that will discipline the highest-valuing bidder. These revenue benefits of first-price sealed-bid auctions are studied in Maskin and Riley (1996) in a private value model.

Klemperer (1998) considers the effect of ex ante asymmetries in an "almost" common value setting (see also Bulow et al. (1996)). He provides robust examples, demonstrating that in an ascending auction even minor asymmetries can lead to highly asymmetric equilibria that result in low revenues. In contrast, slight asymmetries in a first-price sealed-bid auction have only a slight effect on revenues. The intuition for the result comes from the winner's curse. Suppose there are just two bidders in a common value setting, except one has a slight advantage. This advantage enables the bidder to bid more than its rival. But the rival's response to this more aggressive bidding is to bid less. Because of the winner's curse, the bids are strategic substitutes (a higher bid by one implies a lower bid by the other). The advantaged bidder can then increase its bid more, because of the less aggressive bidding of the rival. This multiplier effect can turn small asymmetries in values into large asymmetries in ascending-bid strategies and yield low revenues. In settings with significant participation costs, this can lead to nonparticipation by all but the most advantaged firm.

If the seller knows the extent of the asymmetry, then the seller can level the playing field by giving disadvantaged bidders an appropriate price preference. This practice is common in government procurement in the U.S., where small disadvantaged businesses are often given a 10 percent price preference. Bidding credits of from 10 to 40 percent were used in the FCC spectrum auctions to encourage participation by women, minorities, and small businesses. In the regional narrowband auction, these preferences had the effect of stimulating competition and significantly raising revenues (Ayres and Cramton 1996). Of course, the government's use of credits is crude, since rarely does it have good information about the extent of asymmetries among bidders. In most private auctions, even if one knew the extent of asymmetries, it would not be permissible to use that information to discriminate among bidders.

In auctions for public resources, it is common for interested parties to comment on preliminary rules before the final rules are set. One way to identify situations with large asymmetries is to listen to the comments from bidders. Bidders with high values tend to favor ascending auctions; whereas, bidders with low values prefer sealed bidding. If only a single bidder is insisting on an ascending auction, then it is more likely that there is a large asymmetry favoring this bidder. In this case, a sealed-bid auction probably should be used.

B. Risk Aversion

Risk aversion in private value auctions favors first-price sealed-bid auctions on revenue grounds (Maskin and Riley 1985). In the symmetric, risk-neutral case, both ascending-bid and sealed-bid yield the same revenue. When the bidders are risk averse, the strategies in an ascending auction do not change (it is still a dominant strategy to bid up to one's value) so this same revenue is realized. However, in a first-price auction the bidders bid more aggressively, since due to risk aversion, the bidders prefer a larger probability of winning a smaller prize. When risk aversion is coupled with large asymmetries, the revenue gains from sealed bidding can be large. An example is a bidder pursuing "must win" items.

This revenue advantage of first-price auctions critically depends on the private-value assumption. In a private-value auction, the bidder can avoid all risk by bidding its true valuation: then win or lose the outcome is the same (a zero payoff). The same cannot be said in the realistic case of affiliated values. Then the winner's curse implies that aggressive bidding involves real risks. Indeed, sealed bids typically expose the bidder to additional risk and the best response is often to bid less aggressively or not at all. Even in the private-values case, the analysis above ignores the risk of leaving money on the table in a sealed-bid auction. This is a real risk in many auctions where the bidding team is acting as an agent and is rewarded based on its apparent performance.

C. Avoid collusion

Perhaps the most important reason for a sealed-bid auction is the avoidance of collusion. In an ascending auction, deviations from collusive agreements can be punished during the auction. In a sealed-bid auction, deviations cannot be punished in the auction. Hence, sealed bidding potentially admits a smaller range of collusive equilibria (Milgrom 1987). However, this distinction is often of little importance in practice. Most sealed-bid auctions are not one-shot deals. Rather there is typically a sequence of auctions, so deviations in an early auction can be punished in a later auction. Second, punishments can occur outside of the auction. Since collusion is illegal, there is little reason that colluders need be constrained by the law in devising punishment schemes. Certainly, there is a long history of collusion in sealed bid auctions. One cannot argue that sealed-bid auctions are immune to collusion. Even arguing that they are less apt to involve collusion is difficult to support with empirical evidence.

Nonetheless, sealed bidding does have an important advantage over ascending bids with respect to collusion avoidance. In ascending auctions for multiple items, the dynamic bid process can serve not only to enforce a collusive arrangement but also to *identify* one. In a simultaneous ascending auction for multiple items, the bidders can effectively use their bids to negotiate a division of the items. In a competitive auction, price is used as the assignment device. Bidders with lower valuations drop out in response to the higher prices. However, all bidders prefer a situation where prices remain low. A simultaneous ascending auction can offer a rich language to communicate preferences and threats, which can serve to identify a satisfactory split at low prices and then enforce it.

Ausubel and Cramton (1997) demonstrate how ascending auctions tend to expand the set of equilibria in both positive and negative directions. Whether the goal is efficiency or revenue maximization, the seller may be better or worse off with an ascending auction design, depending on how effective the bidders are at using the rich bid strategies to coordinate on low-price equilibria. With full-information, it is a simple matter to construct examples of zero-price equilibria. Private information complicates the “negotiation,” but even in this case zero-price and low-price equilibria often exist.

Not all ascending auctions give the bidders the same ability to identify and enforce collusive arrangements. An important design decision then when using an ascending auction is how much information to reveal to bidders and what restrictions to place on bids. This decision is fundamental to the tradeoff between efficient information revelation and the potential for collusive outcomes. At one extreme are the FCC spectrum auctions, which to date have revealed all bids and bidder information and have imposed few restrictions on bids. At the other extreme is an auction that just reports high bids and restricts new bids to be exactly one increment higher. An ideal auction attempts to allow information that facilities a competitive process (e.g., the reporting of high bids), but limits information that is more apt to support collusion. This issue will be addressed in the next section.

III. Ascending Auctions for Multiple Items

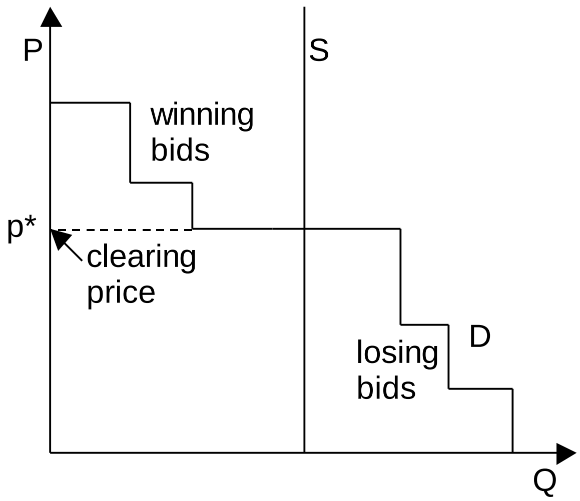
In this section, I discuss the many different ways that ascending auctions can be implemented when selling multiple items. Even in the case of a single item, what is meant by an ascending auction needs to be clarified. The standard ascending auction for a single item is the English auction in which the standing high bid is posted and the auctioneer asks for improvements from the floor. The auctioneer exercises discretion in setting bid increments and in recognizing bidders. A variant is the ascending clock auction, in which a continuous or discrete clock indicates the standing high bid and the bidders press a button to exit from the competition. Typically, the number of remaining bidders is posted with the standing high bid. I first consider how these ascending auctions are implemented when selling identical items, like electricity or Treasury debt. Then I consider interdependent items, like the FCC spectrum licenses.

A. Identical items

Multi-unit ascending auctions can be conducted in two basic ways: with demand schedules or with an ascending clock.

With the demand schedule approach, bidders submit a demand schedule in each round. The schedules are aggregated to form the demand curve. Typically, demand schedules are required to be step functions, but piecewise linear schedules are permitted in some settings. A sample demand curve appears in Figure 1. The clearing price where demand intersects supply defines the tentative split between winning and losing bids. If this were the final round, those bids above the clearing price would be filled, those at the clearing price would be rationed, and those below the clearing price would be rejected.

Figure 1. Sample Demand Curve



To promote reliable price discovery an activity rule is needed. The activity rule prevents bidders from holding back initially and then submitting large bids after the other bidders have revealed their information. In most situations, the bidders will have (weakly) downward sloping demand curves. In this case, a simple yet powerful rule can be used without distorting behavior. The rule has two elements:

1. All bids must be entered in the initial round (that is, the total quantity that a bidder bids for cannot increase).
2. Any losing bid that is not improved in the next round is permanently rejected. The improvement must exceed the clearing price by at least the minimum bid increment.

This activity rule is the one-sided variant of a rule proposed by Wilson (1997) for the California Power Exchange's day-ahead electricity auction. The rule is based on the concept of revealed preference. Bidders are required to improve losing bids at the first opportunity. A failure to improve a losing bid is taken as presumptive evidence that the bidder's valuation is below the minimum bid (one increment above the prior clearing price). In this one-sided setting, prices only increase, so the unimproved bid can be permanently rejected.

The activity rule forces the bidders to bid in a way that is consistent with a downward sloping demand curve. A competitive process results in which winning bids get topped by losing bids. The process repeats until the clearing price reaches a point where a sufficient number of bidders find it sufficiently unattractive that excess demand falls to zero. At this point there is no further pressure to improve bids and the auction ends.

Two alternative pricing rules are commonly used: uniform pricing and pay-your-bid pricing. With uniform pricing all the winning bidders pay the final clearing price. Uniform pricing has the advantage that everyone pays the same price. Under pay-your-bid pricing, each winning bidder pays the price bid. In a sealed-bid design, the distinction between uniform and pay-your-bid pricing is large. In an ascending auction, the distinction is much less important, since winning bids under pay-your-bid pricing are apt to be close to the final clearing price in equilibrium. The reason is that a bidder has little incentive to raise the bid much more than one bid increment above the clearing price. Hence, pay-your-bid pricing shares the main advantage of uniform pricing.

Pay-your-bid pricing does have an important advantage over uniform pricing in an ascending auction. With uniform pricing, the bidders can submit bid schedules that create strong incentives for the other bidders to reduce demand. In particular, they can bid in such a way that the demand curve is quite steep above the clearing price. Faced with this steep curve, it is a best response for bidders to drop their losing bids, rather than continue to bid a large quantity, which would result in much higher prices. This is similar to the problem with uniform pricing in static auctions emphasized by Wilson (1979) and Back and Zender (1993), but here the problem is magnified, since the ascending process gives the bidders the opportunity to coordinate on a low-price equilibrium. For this reason, pay-your-bid pricing should be preferred in ascending auctions.

Better still is the ascending clock auction. The clock indicates the current price. In each round, the bidders submit the quantity they are willing to buy at that price. If the total quantity bid exceeds the quantity available the clock is increased. The bidding continues until the quantity bid is less than the quantity available. The good is then allocated at the prior price, and is rationed for those that reduced their quantity in the last round.[4] The activity rule in this case is simply that each bidder cannot increase its quantity as prices rise.

This design shares all the advantages of the pay-your-bid auction, and has several additional advantages:

1. It is easier to implement for both seller and buyers, since a buyer only bids a single quantity in each round, rather than a schedule.
2. There is no possibility of undesirable bid signaling, since only the total quantity bid is reported.
3. It avoids the mechanism for collusion under uniform pricing, yet yields a single market-clearing price.

A difficulty with all the approaches described above is that they are inefficient (Ausubel and Cramton 1996). In each case, bidders shade their bids in order to keep the price down. Large bidders tend to shade more than small bidders, since a particular price effect has a bigger impact on profits for a large bidder. This differential shading leads to an inefficient outcome. Large bidders win too little and small bidders win too much.

Ausubel (1997) proposes an alternative ascending clock auction that achieves efficiency. In the Ausubel auction, items are awarded when they are "clinched" and the price paid is the amount on the clock at the time of clinching. An item is clinched when it becomes mathematically impossible for the bidder not to win the item (that is, excess demand would fall to zero before the bidder could reduce its demand to zero). This pricing rule implements Vickrey (1961) pricing in an ascending format. Efficiency is restored without losing the advantages of an ascending-bid format.

[4] The closing rule can also use bisection to hit the clearing price more closely: increase price if there is excess demand; decrease price if there is excess supply; each price step bisects the highest price with excess demand and the lowest price with excess supply.

B. Interdependent items

A more difficult auction is the sale of many interdependent items. In this case, a bidder cares about the package of items it wins. Some items are substitutes and others are complements. The value attached to any particular item depends on which other items are won. The FCC spectrum auctions are an example. In spectrum auctions, there are often synergies from buying licenses that are adjacent (either in frequency or geography).[5]

The theory of auctions in this setting is not well developed. Nonetheless, it is known that when complementarities are not too strong, a simultaneous ascending auction works well in practice. McAfee, Milgrom, and Wilson proposed this auction design for the FCC spectrum auctions. It has been used successfully in spectrum auctions in the U.S., Mexico, and Australia.

In a simultaneous ascending auction, all items are on the block at the same time. In every round, a bidder can bid on any of the items. The auction does not close until bidding has ceased on all items; that is, until a round goes by in which there are no new bids on any of the items.

There are three critical features of this method. First, the ascending-bid design allows the bidders to react to information revealed in prior rounds. This reduces the winner's curse, enabling the bidders to bid more aggressively. Second, by auctioning all the items simultaneously, bidders are able to react to prices across items. Since bidder valuations depend on the collection of items held, providing this price information on related items is essential to the formation of efficient packages of items. The simultaneous sale of related items in an ascending auction gives the bidders the flexibility they need to express these value interdependencies. In addition it assures that similar items sell for similar prices. Third, keeping the bidding open on all items until there are no new bids gives the bidders flexibility in switching among various packages as prices change.

The success of these auctions is documented in Cramton (1995, 1997), McAfee and McMillan (1996), and Milgrom (1998). Overall, the auctions have performed well on both efficiency and revenue grounds. However, in some of the auctions, especially those with more limited competition, it appears that some revenues have been lost due to strategic demand reduction or undesirable bid signaling.

Little can be done to prevent demand reduction in this setting without introducing other inefficiencies. For example, Klemperer's (1997) proposal to use an ascending auction to identify the top-two bidders and then have a sealed-bid auction to identify the winner would work well if there were no value interdependencies. But with these interdependencies and the importance of budget constraints, the outcome might be quite inefficient, if the final packages have a more random structure. Of course, if resale is efficient then this is not a problem, but there is little reason to expect that resale costs would be slight.

In contrast, undesirable bid signaling can be eliminated by imposing restrictions on the bids and limiting the information provided between rounds. First, bids can be limited to three significant digits. In the FCC spectrum auctions, there are hundreds of cases of bidders using the trailing digits of bids to signal to other bidders. This "code bidding", although usually ineffective, sometimes helps bidders negotiate a split of the items at low prices. The codes can indicate either how the items should be split up or what the punishment will be in the event a particular suggestion is ignored. In settings where bidder collusion is especially a problem, a second step can be taken: only announce the standing high bids, rather than both the bids and the bidders' identities. Without observing the bidder identities, it is impossible for the bidders to propose and enforce a division of the items without direct (and illegal) communication.

[5] See Ausubel et al. (1997) and Moreton and Spiller (1998).

IV. Conclusion

Neither the theory nor the empirics are sufficient to conclude ascending auctions are superior to sealed-bid auctions. However, the case for ascending auctions is strong. The dynamic price discovery process of an ascending auction simply does a better job of answering the basic auction question: who should get the items and at what prices? Ascending auctions perform well on both efficiency and revenue grounds across a variety of settings. Two factors may favor sealed bidding – ex ante asymmetries and weak competition. In other cases, an ascending auction design is probably best. However, steps should be taken to limit the possibility of collusive outcomes in an ascending auction. This is accomplished by setting reserves, by imposing bid restrictions, and by limiting the information bidders receive during the auction.

References

Ausubel, Lawrence M. (1997), "An Efficient Ascending-Bid Auction for Multiple Objects," Working Paper 97-06, University of Maryland.

Ausubel, Lawrence M. and Peter Cramton (1996), "Demand Reduction and Inefficiency in Multi-Unit Auctions," Working Paper No. 96-07, University of Maryland.

Ausubel, Lawrence M. and Peter Cramton (1997), "Auctioning Securities," Working Paper, University of Maryland.

Ausubel, Lawrence M., Peter Cramton, R. Preston McAfee, and John McMillan (1997), "Synergies in Wireless Telephony: Evidence from the Broadband PCS Auctions," *Journal of Economics and Management Strategy*, 6:3, 73-103.

Ayres, Ian and Peter Cramton (1996), "Deficit Reduction Through Diversity: A Case Study of How Affirmative Action at the FCC Increased Auction Competition," *Stanford Law Review*, 48:4, 761-815.

Back, Kerry and Jaime F. Zender (1993), "Auctions of Divisible Goods: On the Rationale for the Treasury Experiment," *Review of Financial Studies*, 6, 733-764.

Bulow, Jeremy, Ming Huang, and Paul Klemperer (1996), "Toeholds and Takeovers," Working Paper, Stanford University.

Cramton, Peter (1995), "Money Out of Thin Air: The Nationwide Narrowband PCS Auction," *Journal of Economics and Management Strategy*, 4, 267-343.

Cramton, Peter (1997), "The FCC Spectrum Auctions: An Early Assessment," *Journal of Economics and Management Strategy*, 6:3, 7-71.

Harstad, Ronald M. (1990), "Alternative Common-Value Auction Procedures: Revenue Comparisons with Free Entry," *Journal of Political Economy*, 98, 421-429.

Kagel, John H., Ronald M. Hartstad, and Dan Levin (1987), "Information Impact and Allocation Rules in Auctions with Affiliated Private Values: A Laboratory Study," *Econometrica*, 55, 1275-1304.

Klemperer, Paul (1998), "Almost Common Value Auctions: The 'Wallet Game' and its Applications to Takeover Battles and Airwaves Auctions," *European Economic Review*, 42, forthcoming.

Maskin, Eric and John Riley (1996), "Asymmetric Auctions," Working Paper, UCLA.

Maskin, Eric S. and John G. Riley (1985), "Open and Sealed-Bid Auctions: Auction Theory with Private Values," *American Economic Review*, 75, 150-155.

McAfee, R. Preston and John McMillan (1996), "Analyzing the Airwaves Auction," *Journal of Economic Perspectives*, 10, 159-176.

Milgrom, Paul (1998), *Putting Auction Theory to Work*, forthcoming, Cambridge, England: Cambridge University Press.

Milgrom, Paul (1987), "Auction Theory," in Truman Bewley (ed), *Advances in Economic Theory - Fifth World Congress*, Cambridge, England: Cambridge University Press.

Milgrom, Paul and Robert J. Weber (1982), "A Theory of Auctions and Competitive Bidding," *Econometrica*, 50, 1089-1122.

Moreton, Patrick S. and Pablo T. Spiller (1998), "What's in the Air? Interlicense Synergies and Their Impact on the FCC's Broadband PCS License Auctions," *Journal of Law and Economics*, 41, forthcoming.

Rothkopf, Michael H., Thomas J. Teisberg, and Edward P. Kahn (1990), "Why Are Vickrey Auctions Rare?" *Journal of Political Economy*, 98, 94-109.

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

Wilson, Robert (1979), "Auction of Shares," *Quarterly Journal of Economics*, 94, 675-689.

Wilson, Robert (1997), "Activity Rules for the Power Exchange," Report to the California Trust for Power Industry Restructuring, March 14.