"The Greatest Auction in History"

by

R. Preston McAfee,

John McMillan,

and

Simon Wilkie[1]

[1] Caltech and Yahoo Research; Stanford University; and University of Southern California, respectively.
John McMillan passed away before this manuscript was complete, so it does not reflect his gift for engaging exposition. This paper does not necessarily represent the views of our employers.

In August, 1993, President Clinton signed a historic law granting the U.S. Federal Communications Commission (FCC) the authority to auction spectrum licenses.[2] This law dates back to Coase's 1959 proposal to sell the radio spectrum. Congress gave the FCC until August, 1994 to begin the first auction. To someone inexperienced in the activities of large bureaucracies, a year sounds adequate to design and operate an auction, but it is remarkable that the FCC was able to meet this requirement and commence its first auction on July 25, 1994. In order to run an auction, the FCC needed to choose an auction design, and in order to do that, it was required by law to provide adequate time to file formal comments and reply comments on its proposed procedures. These comments, along with staff recommendations, were used by the FCC commissioners to determine an auction form that would survive judicial challenge. Finally the FCC staff then implemented the Commission's decision, relying on outside contractors to develop auction software. Timely implementation was particularly challenging given that the Commission decided on a novel auction method, the *electronic simultaneous multiple round bidding* auction, based on economic advice.

Congress and many economists underestimated the number of choices in designing an auction. In modern business parlance, auctions have many "dials and levers" that can be used to tweak the performance and outcomes, but the very presence of these choices creates an enormous economic and political challenge. This paper describes how that challenge was met using modern game theory . The efforts of economists led to what William Safire called "the greatest auction in history," using methods that have been copied round the world to sell over US$100 billion in radio spectrum.

Auctions weren't seriously considered for awarding spectrum licenses until two other methods ran into difficulty. The bureaucratic mainstay, administrative allocation by comparative hearing, began to break down as the value of the items to be allocated increased. Hearings and court challenges take years, incurring large costs for both participants and the government. Congress replaced these cumbersome administrative procedures with lotteries in 1982. The potential for a windfall gain from winning a license resulted in nearly 400,000 applications for cellular licenses. With so many applications, the magnitude of the total private expenditures in obtaining licenses (rent seeking) was large for a process that only by accident assigns licenses to parties that value them most highly.

When Congress mandated the use of auctions, expert academic economists became involved primarily because neither the potential bidders nor the FCC had experience in auctions. The FCC hired John McMillan as a consultant to advise them on auction design. The major bidders hired economists, including Paul Milgrom, Robert Wilson, Preston McAfee, Barry Nalebuff, Peter Cramton, David Salant and Rob Gertner, to write comments to file with the FCC on auction design and to advise them on bidding strategy during the auction.

The absence of a history of auctions at the FCC was a significant advantage to the Commission in developing a novel and appropriate design based on recent advances in auction theory. It is incredibly difficult for a bureaucracy to change an existing methodology that works moderately well, even if an alternative is clearly superior. Change involves career-destroying risks and opens lobbying doors that might result in worse choices. In the design of the PCS auctions, the absence of an existing default meant that all designs were on the table. Moreover, the use of academic economists helped focus the debate on the public interest, rather than the firms who in most cases paid their bills. Academic economists were generally unwilling to defend their clients' goals when these goals conflicted with the social interest. In addition, the determination

[2] Omnibus Reconciliation Act of 1993. U.S. Public Law 103-66. 103rd Cong., 1st sess., August 10, 1993.

of FCC Chairman Reed Hundt to "do the right thing" helped prevent the agency capture all too common in Washington.

The FCC Auction Issues

Congress mandated that the FCC auctions should:[4]

- promote efficient and intensive use of the electromagnetic spectrum
- promote rapid deployment of new technologies
- promote economic opportunity and competition by dissemination of licenses to a wide variety of applicants
- recover for the public of a portion of the value of the public spectrum resource

Economists emphasized four goals: simplicity, efficiency, revenue, and diversity. Although simplicity was not a goal specified by Congress, nor a goal found in economics texts, economists recognized immediately that, because the spectrum auctions were conducted for the first time with inexperienced bidders, the auction design needed to be simple to understand. A complex design was likely to be misunderstood, leading to unintended choices and inefficient outcomes.

A second aspect of simplicity, and one harder to implement, requires that a simple strategy be optimal, or nearly optimal, behavior in the auction. For example, "bid your estimated value" is a reasonable strategy in a Vickrey auction[5] but a terrible strategy in a first-price (winners pay their bid prices) sealed-bid auction. A first-price sealed-bid auction has the property that bidding sensibly requires assessing the bidding strategies of rivals, a hard thing to do in a static game. Thus, the first-price sealed-bid auction, while simple to understand, has no sensible simple strategy for participants. Economists were very much concerned that they could articulate simple bidding strategies for bidders that would perform well. It was expected that novice bidders would probably adopt such strategies.

Congress mandated some form of efficiency, which economists generally interpreted to mean that the bidders with the highest value obtain the license. Were there only one license, efficiency would not have been a significant challenge. However, there were thousands of licenses available, spanning different geographic regions and distinct spectrum bands. Efficiency then meant both figuring out which aggregations of licenses made sense, and doing so without substantial delay, because delay itself is a cost. With the exception of some work on bundling, economic analysis provided little guidance. Efficiency requires appropriately defining licenses both geographically and across spectrum bands, and designing the auction mechanism to award those licenses. In defining the geographic scope of licenses one must consider the ability of the auction mechanism and secondary markets to efficiently aggregate small licenses into larger coverage areas versus the ability of secondary markets to efficiently disaggregate large licenses into smaller areas.

Before the broadband PCS auctions, some economists argued for dividing the country into large regions (or even the entire nation). The problem with this band plan was that most of the potential bidders owned some portion of the existing cellular spectrum and generally would be seeking to buy the complement of their existing holdings. Indeed, limits on ownership precluded them from buying in areas where they already had holdings. Large regions would not permit

[4] Section 309(j) of the Communications Act, 47 U.S.C. § 309(j).

[5] It is equilibrium behavior only in the relatively specialized private values environment.

purchase of complementary holdings in the auction; leading to few bidders or requiring divestiture of existing holdings by participants.[6]

Other economists argued for dividing the nation into many small geographic areas, without proposing an auction that would be likely to facilitate efficient aggregation, relying on secondary markets to achieve efficiency. Based on experience with administrative assignment and lotteries we know that high transactions costs in secondary markets can delay and in some cases prevent altogether the efficient aggregation of spectrum. The cellular spectrum allocated earlier remained a patchwork of ownership, with incomplete roaming agreements, even twelve years later. History suggests that getting the initial allocation substantially right was very important for the speed of comprehensive deployment of wireless services.

A major challenge to efficient allocation is the presence of local synergies in value. Local synergies generally arise from three distinct motivations – creation of seamless roaming, elimination of boundary interference and advertising or managerial scale economies. Ausubel, Cramton, McAfee and McMillan (1997) find evidence of such synergies in the bidding. The history of spectrum license aggregations suggested that it was difficult to forecast the shape of efficient assignments. GTE created an aggregation of licenses in the Southwest along interstate highways; McCaw had a similar aggregation in the Northeast. Both resulted in a spidery allocation, strange in appearance until compared with an interstate highway map. Moreover, new services might require spectrum in unanticipated geographic concentrations, it seems important to let the market choose the allocation in the process of the bidding.

Most of the academic economists involved in the design considered revenue to be an important goal. With the US's substantial government debt and prevailing deficit, revenue had value beyond the strict dollar amount raised, as increased revenue permitted a reduction in distorting taxation. Revenue has an additional importance, however. Revenue is evidence that high value bidders are being selected, that is, revenue is itself evidence that the price system is working. In principle, of course, higher revenue need not signal allocative efficiency, a fact easily seen by noting that the monopoly quantity has higher revenue than the efficient competitive price.

The 1993 legislation authorizing auctions directed the FCC to "disseminate licenses to a wide variety of applicants, including small businesses, rural telephone companies, and businesses owned by member of minority groups and women." Collectively these groups came to be known as "designated entities." Historically, the US government has favored such groups by set-asides. In a set-aside, a portion of the items for sale (or contracts to buy) are reserved for the designated entities. This is a potentially costly means of meeting the Congressional requirement; McAfee and McMillan (1988) have argued that price preferences, in which the designated entity obtains a bidding credit or can submit a given bid at less cost than other bidders, are a more effective and less costly means of achieving the same ends. The FCC has used bidding credits, spectrum set-asides, and installment payments to promote participation by designated entities. It discontinued use of installment payments in 1997.

Most of the auction design discussion, among the economists, FCC staff, and participating companies came down to eight basic choices discussed in the subsequent sections.

[6] MCI, the only major telephone company with no existing spectrum holdings, was a strong proponent of the national license. This was one of the most obvious examples of self-interested lobbying.

Ascending versus Sealed-bid

The most fundamental choice in auction design is whether to use a once-and-for-all bid or permit revision of bids over time. Governments generally choose sealed-bids over ascending bids; corporations are more likely to prefer ascending bids.

The usual view is that a simultaneous sealed-bid is more difficult to rig than an ascending auction. A member of a conspiracy to rig the bids can cheat on the conspiracy by submitting a bid secretly; thus sealed bids encourage breakdown of cartels. In contrast, a cartel can punish a deviation in an oral auction immediately. On the other hand, sealed-bids open the door to collusion with a government official, who secretly reports on others' bids to one of the bidders. Sealed-bids are less susceptible to collusion among the bidders, but more susceptible to malfeasance by government officials. In any case, organized conspiracy was not anticipated to be a problem.

Ascending auctions differ from sealed-bids in the release of information: in an ascending auction, bidders can respond to the behavior of others during the course of the auction. This ability to revise bids in light of the behavior of others has consequences developed by Paul Milgrom and Robert Weber (1982), and on average increases the revenue in the auction in a symmetric environment. The ascending auction reveals information about the bidders to the bidders. Revealing information reduces the size of the information rents obtained by bidders, increasing prices on average. This positive relationship between revenues and information transmission during the auction has been labeled "the linkage principle" in, e.g., Milgrom (1989).

In addition, when bidders are asymmetric, sealed-bid auctions will tend to select inefficiently, while ascending auctions will tend to be more efficient. Intuitively, the reason is that, in a sealed-bid auction, a strong bidder faces less competition than a weak bidder. The strong bidder faces the field minus herself, while the weak bidder faces a field which includes the strong bidder. Thus a strong bidder will seek a higher profit, while a weak bidder, facing stronger competition, will bid closer to actual value. The strong bidder will sometimes lose in circumstances when it has the higher value. In an ascending auction, the strong bidder would revise its bid upward to win, were it actually the high value bidder.

Ascending auctions have the virtue of reducing regret: bidders need not "leave money on the table," the euphemism for a bid substantially higher than the second highest bid. Such bids make the bidder appear to pay too much, which could harm the bidder's career even if the bid was in fact *ex ante* optimal. In an ascending auction, actual competition, rather than an expectation about competition, forces bids to the level achieved, reducing regret.

While the weight of the economic literature favored ascending auctions, the case was far from transparent, primarily because of the history of government auctions using sealed-bids, including the Department of the Interior's off-shore oil auctions, which use a simultaneous sealed-bid auction of as many as 150 distinct tracts. That the Department of the Interior continues to use such a flawed mechanism demonstrates the difficulty of changing the status quo.

Simultaneous versus Sequential

Auctioneers Christie's and Sotheby's have sold billions of dollars of goods by sequential oral auctions, and there was a strong sense that what is good enough for antiques sellers is good enough for the US government. Several economists persisted in the view that the simultaneous designs were unnecessarily complicated, both for the government to implement and for bidders to participate. This view still previls in some circles. As will become clear, the nature of spectrum auctions renders this view naïve.

In a sequential design, licenses are ordered and then sold in a series of auctions. When the amount a bidder is willing to pay for an item depends on the other items it acquires, sequential auctions deny the bidder crucial information. Consider a bidder who values two items separately at $1 each, but collectively at $3. This bidder on the first item would be willing to pay up to $2, provided it expected the third item to sell for no more than $1. On the other hand, having bought the first item, the bidder would now be willing to pay up to $2 for the second item, even though this creates a $1 loss on the pair. This problem for the bidder is known as the exposure problem: holding one item exposes one to a loss created by the complementarities in values. The bidder has to forecast the price of future items to bid sensibly on the earlier items. This need to forecast creates a dilemma for the bidder, whether to bid safely and probably lose, or bid aggressively and wind up stuck holding an incomplete aggregation. Only a combinatorial design avoids the exposure problem, at the expense of creating other problems.

Sequential auctions are problematic when items are substitutes as well as complements. Suppose two identical items are auctioned sequentially and a bidder wants only one. When bidding on the first item the bidder must guess the selling price of the second item. There is no reason to expect that selling price will be the same for both items, and bad guesses may result in the items not being awarded to the parties who value them the most. Empirical auction data have shown such inefficiency to be a problem. In particular Gandal (1997) demonstrated that use of sequential auctions for cable TV franchises in Israel affected revenues, and arguably affected efficiency. Similarly it has been argued that sequential auctioning by country of 3G licenses in Europe lead to the inflation of early prices and collapse of prices in countries later in the sequence, although many economists view this as implausible.

A major problem for sequential designs is the ordering of licenses, especially when different orderings advantage different firms. The orderings for sequential sale of broadband PCS licenses proposed by different parties included largest to smallest, smallest to largest, east to west, and west to east. Ordering induces a bias; particular firms care more about some markets than others and will prefer learning from the markets they care less about first. In addition, sorting out the most important markets prior to less important complementary markets is advantageous. No ordering is neutral, which created a problem for supporters of sequential designs: they disagreed about the ordering. Thus, there was little support for any one sequential design even though a majority of the economists initially supported sequential designs.

Another serious problem of sequential designs is timing. Proponents of sequential designs generally considered selling dozens of licenses per day. Since some of the most valuable licenses were expected to – and did – run hundreds of millions of dollars, a sequential design required making billion dollar decisions in the course of a single day. While companies can execute a billion dollar decision in a day, they cannot reasonably incorporate new information in the process, because changing a billion dollar decision usually requires days or even weeks of deliberation at the senior management level. Running sequential auctions in a timely manner – completing hundreds in a month or two – would generally reduce the utility of information gleaned by the auctions themselves, forcing bidders into a pre-specified set of strategies. Such a reduction vitiates the major advantage of ascending auctions: information release.

In contrast to sequential auctions, simultaneous designs were not well-understood, and proponents had to solve a variety of problems. The most famous simultaneous design – the "silent auction" used by charities, has physical locations for each of the items for sale. Because bidding closes on all items at the same time, it requires bidders to have as many bidding agents as the number of items they desire. The alternative – "simultaneous multiple round bidding" or SMR, was proposed as a solution to this problem. In the SMR, all of the licenses are available for bidding, in each of discrete rounds. The minimum bid on any one license is increased over the previous round by a percentage. Bidders can bid on any or all of the licenses in a given round, with the maximum bids from the previous round becoming the basis for the next round of bidding. This solution created a different problem. A bidder would like to first see what others are willing to pay, and then choose the items that represent the best value. That is, every bidder had an optimal strategy of waiting until the others had completed their bidding. Were all the bidders to follow this strategy, of course, then there is no bidding at all. The standard solution in the literature due to Charles Plott (see e.g. Plott, Wit and Yang, 2003) involves a positive probability of ending the auction, which itself creates a probability of inefficiency, regret and frustration by participants and government alike.

The solution invented by Paul Milgrom and Robert Wilson is the activity rule – each bidder must be active (have the standing high bid or make a new bid) in every round on a specified fraction of the licenses they hope to win. Thus, a bidder that seeks 12 licenses would, under a 50% activity rule, be required to bid on at least six licenses. (After the first auction activity was defined in terms of bidding units to account for differences in license sizes. Each license was assigned bidding units equal to the product of the amount of spectrum in MHz, and population in the license area.) This puts pressure on bidders to bid, while still allowing them the flexibility to substitute to other licenses if the licenses on which they are currently bidding become too expensive.

The magnitude of the activity rule determines the ease of substitution. With a low activity requirement, bidders can readily substitute from one set of licenses to another, because they hold few of the licenses they hope to purchase, and thus have lots of "purchasing capacity." Assuming bidders are generally only bidding on the licenses required to maintain activity, price increases will stall when the potential demand for licenses at current prices is about one over the activity rule times the available amount of spectrum. Thus, the activity rule needs to be tightened over the course of the auction or prices will come to a stop even though excess demand remains. The first auctions used a three phase system: initially a 33% activity requirement, then a 67% requirement, followed by a 100% requirement.[8]

This design, created primarily by academic economists, has become known as the *FCC Auction*. The key advantages of this auction design relative to all others are that it promotes (i) the timely release of information and (ii) substitution by buyers. If a price increase on one or more licenses renders that group more expensive, a buyer can switch to another group, usually with no penalty but at worst with a modest penalty. This substitution is facilitated by several complementary features, including the activity rule itself which directly permits substitution, the gradual

[8] A literal 100% requirement, when applied to unequally-sized licenses, is a bad thing because of integer problems. Integer problems themselves gave bidders headaches in FCC auctions. The Mexican spectrum auctions had the additional problem that Mexico City was a huge portion of the entire country. As a result, the modern design "squashes" or levels the license size, preferably to values which are easy to combine into substitutes. In Mexico, the license "sizes", for the purposes of evaluating the activity rule, were set at 1, 2, 3, 4, 6, 12 (Guadalajara) and 24 (Mexico City), to promote substitution. These are quite different from population sizes; the squashing makes it easier to substitute between Mexico City and a group of other licenses.

tightening of the activity rule,[9] the design of the licenses for sale into "similar sized" units, and the modest withdrawal penalty that forces bids to be meaningful expressions of willingness to pay while still encouraging the assembly of efficient aggregations.

The success of the FCC auction is perhaps most dramatically illustrated by the second narrowband (paging frequency) licenses. Here thirty licenses were sold. There were 6 frequency bands each sold in 5 geographic regions. Four of the sets of regional licenses were aggregated into national licenses, and similar licenses sold for similar prices; indeed, the single price anomaly was the consequence of a failed attempt to game the auction, resulting in a withdrawal and a low price for that license. (With the withdrawal penalty, the license sold for a similar price.) Bidders were able to aggregate the licenses they desired, and prices appeared competitive.

Combinatorial Bids

A combinatorial bid involves the ability to bid on a package of licenses as an all or nothing bid. Various combinatorial bidding methods were promoted by academic economists. The two main forms initially proposed were (i) to permit bidding on any subset and allow the bidders to revise their bids, using an SMR format, until bidding stopped, or (ii) have individual licenses plus a national license.

Combinatorial auctions have the advantage that bidders can express their demands directly – a bidder who wants three licenses can bid on them as a unit. Combinatorial auctions provide a solution to the exposure problem identified above. However, combinatorial auctions are more complex - there are a lot of potential combinations. And there is the "threshold" or "free rider" problem – the potential that bidders on subsets of a larger package will not be able to combine their bids to beat the bid on the larger package even when the sum of the value of the subsets exceeds the value of the package. As with all free-rider problems, there is a risk that the bidders fail to bid enough. The risk of lower revenue and inefficiency due to the threshold problem, along with the potential complexity of implementing a combinatorial auction deterred the FCC from selecting it in spite of serious support among academic economists. Nevertheless, combinatorial auctions remain a vibrant area of research and a continuing interest of the FCC. Indeed since then significant experimental and theoretical research has suggested ways to mitigate the threshold problem, see for example DiMartini et al. (1998), Marx and Matthews (2000), and Ausubel, Cramton and Milgrom (2006).

Reserve Prices

In the traditional theory, reserve prices represent a trade-off between revenue and efficiency; efficient reserve prices are the seller's value, usually set to zero as a modeling artifact, while the monopoly reserve price is substantially in excess of the seller's value. Economists divided on the issue of reserve prices along the lines of the importance they gave to efficiency and revenue.

From a static point of view any positive reserve price conflicts with efficiency when the license is not sold.[10] However, a new, dynamic view of reserve prices emerged from the FCC auctions. A

[9] A 100% activity rule makes substitution difficult. Suppose a bidder seeks 6 contiguous licenses but doesn't care where the six are. At 100% a bidder can only move without risk of penalty on the licenses whose prices increased; if prices of three increased, the bidder faces substantial risk of being left either paying penalties or stuck holding the remaining three.

seller who fails to sell has the option of selling in the future; thus the seller's value may not be the seller's *use* value, but instead the value of a buyer not yet present; if the seller expects to sell at a higher price in the future, it may be efficient not to sell today. This may be the case when new technologies are possible, technologies that will be resisted by incumbents since the technologies supplant existing services. The question then is should private parties or the FCC keep this "option value." In light of allegations of stockpiling of spectrum by incumbents, reserving spectrum for future technologies could be important. The threat of stock-piling by incumbents provides a rationale for public rather private holding of idle spectrum,[11] but there is by no means a consensus on this point.

Size of Increments

The use of rounds of bidding forces a decision on a bid increment – what is the minimum increase between rounds? Too small, and the auction will take too many rounds, wasting time and effort. Too large and the auction will allocate the licenses inefficiently. The consensus recommendation was created by an insight of Paul Milgrom. Halving the step size or increment approximately doubles the time required to complete the auction. However, inefficiency arises only in the circumstance where the bidder with the second highest value wins because the high value bidder is unwilling to pay the second-highest value plus an increment. The loss in value is at most an increment, and moreover only occurs when the second highest value is close to the highest value, which has a probability proportional to the size of the increment, so the loss is approximately proportional to the bid increment squared. Consequently, even quite large increments – say 10% – have an efficiency impact proportional to the square of the increment, or 1%. Milgrom's argument persuaded most economists that substantial increments were not very costly to efficiency and hence represented the best way to speed up auctions. The exception to the consensus was, by and large, from those in favor of continuous time auctions.

In spite of the consensus among economists, business and the FCC remained leery of large increments and the FCC instead employed an increment accelerator rule, which determined the size of the increment by the amount of competition present in preceding rounds.

Bidder Preferences

An innovative feature of the FCC auction was the use of price preferences or bidder credits, in addition to set asides, to favor designated entities. A bidder credit is akin to the idea of handicapping in sports. Suppose a designated entity, because of lack of capital or expertise, has a 10% lower value on average. Then the auction can level the competition by providing a 10% bidder credit – that is, charging the designated bidder only 90% of their bid.

Bidder credits are advantageous over set-asides for at least seven distinct reasons. First, bidder credits rather than set asides increase competition in the SMR auction. The designated entities become more effective bidders thanks to the handicapping, while the non-designated entities are some competition for the licenses that would otherwise be set-aside. Second, bidding credits set a price or value for promotion of designated entities, thereby permitting resale at a cost of

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[10] Unused spectrum is lost. Use of the spectrum doesn't inhibit future use of the spectrum. Thus, social efficiency calls for full utilization. This full utilization is mitigated by an installed base of equipment to use the spectrum and the sale of spectrum interacts with standards on use.
[11] See Cramton, Skzyracz and Wilson (2007).

refunding the bidder credit.[12] Third, the inefficiency of promoting the designated entities may be reduced, because designated entities win auctions only when they are close to the willingness to pay of the other firms, relative to a set-aside. Fourth, revenues may increase over the levels that would prevail without any bidder credits, because for small levels of bidder credit, the increase in competition outweighs the inefficient allocation.[13] Of course, revenue will fall as the bidder credit gets larger than the disadvantage of the designated group. Fifth, the tendency for set-asides is to create very small licenses, so-called "ghetto licenses," perhaps because non-designated entities lobby hard to prevent the setting-aside of valuable licenses that could lead to meaningful competition. Thus, using a universal modest bidder credit, applicable to all licenses, will prevent the creation of ghetto licenses and permit the designated entities to compete effectively for all licenses. Sixth, price preferences are a versatile instrument, capable of giving distinct levels of preference to different categories of designated entities, e.g. the credit may vary with the size of the small business, although the Supreme Court then ruled such practices illegal[14]. Seventh, price preferences naturally apply to partial ownership, by giving partial credit.

The FCC used 25% bidder credits in the first narrowband auction, but none of the licenses were won by designated entities. The credit level was increased to 40% in the second narrowband auction, and all the licenses available for bidder credit were won by designated entities. It is not clear, unfortunately, whether the success in the second auction was due to the increased bidder credit, or the increased time to prepare; some of the designated entities seem to be firms that came into existence to take advantage of the bidder credits. Indeed, supporting the 'designer firm' theory, the actual prices paid for the licenses net of the bidder credit were just slightly below the prices paid for licenses not eligible for bidder credits, suggesting that the designated entities were nearly competitive with the non-designated entities.

Spectrum Caps

Spectrum caps – a limit on the amount of spectrum any one participant may hold in a given geographic area – are a simple means of insuring adequate competition in the final product market. The existing structure of the wireless market was a duopoly by design. The sale was intented to foster competition, and the spectrum caps were set such that an incumbent could not purchase a 30 MHz license in its existing footprint, guaranteeing at least 3 new entrants in every market. The FCC aimed to have five competing firms in every geographic market.[15] An important characteristic of spectrum caps is that they are substantially easier to enforce than antitrust laws.

Revealing Bidder Identity

In a standard oral auction, it is difficult although not impossible to conceal the identities of the bidders. However, in an auction with multiple rounds of bidding done on computers, it becomes

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[12] The amount of the bidder credit should not be confused with the social value of favoring the designated entities, nor the size of the disadvantage they face. Generally optimal bidder credits will be somewhat less than the social value of favoring the entities, since the bidder credit must trade off the revenue obtained against the desire to increase participation by the entities. Second, the bidder credit may be larger or smaller than the disadvantage faced by the entities. Revenue maximization requires bidder credits that are positive but smaller than the disadvantage, since a fully compensating for the disadvantage causes the designated entities to win too often.

[13] Allocative inefficiency has a zero first order effect, while the change in competition has a first order effect, around a zero credit.

[14] *Adarand v. Pena* 15 S. Ct. 2097 (1995).

[15] The FCC subsequently abolished the ownership cap and drafted industry specific merger review guidelines that were never released.

possible to conceal the identity of the bidders from other bidders. Concealment can be accomplished by reporting only the price bid on each license, and not the identity of the firm that bid, or by giving bidders ID numbers and revealing the bidder number but not the mapping from real bidders to bidder IDs.

The disadvantage of concealing bidder identities is that there is information content not just in what was bid but in who did the bidding. In particular, a bid by a company completing a national license on a "hole" may be a less significant indicator of value than a bid by a start-up. Perhaps more empirically relevant, there are technological scale economies, so knowing whether a large GSM technology carrier is bidding may matter substantially to the smaller carriers, who hope to have access to handsets which become available only if a large player buys spectrum. Thus, the identity of other bidders could potentially matter for valuation. A second disadvantage, which was entertaining if not economically significant in the first narrowband auction and potentially significant in later auctions, is that bidders spend a lot of time trying to figure out which bidder ID corresponds to which bidder.

There are two main advantages to reporting only prices. First, because concealed identities make defection from a cartel agreement harder to punish, concealing identities should reduce the likelihood of behavior ranging from price-fixing to "tacit understandings." Second, concealed identities make it much harder to "game" the auction. An example of such gaming involved the Australian spectrum auctions in which one bidder was attempting to assemble five adjoining licenses and the spoiler continued to bid on the middle license, in a strategy that became known as "giving the middle finger." When all that is observable is the price, such a punishment strategy is much less likely to succeed. For a description of the use of such strategies in an FCC auction, see Cramton and Schwartz (2002). In the end, the FCC chose to conceal identities but reveal bidder IDs in the first auction. As this auction was run by bidding in a booth like a polling booth, it was relatively easy to deduce which bidder ID went with which company.

How to Design Efficient and High Revenue Auctions

How well did the economists do in designing the auctions and what have we learned since? The FCC has run over 70 auctions in the past decade. From this wealth of experience we can distill several key lessons and principles. In summary form, these principles are:

- Promote information revelation by
    - Using ascending auctions
    - Providing bidding tools for analyzing bids
- Promote substitution:
    - Sell licenses simultaneously
    - Make the licenses similarly sized
    - Squash and "round" the license sizes for the auction activity rule calculations
    - Progressively tighten activity rules
- Make the problem solved by participants easier:
    - Provide bidding tools for analyzing and submitting bids
    - Use fixed increments
    - Squash and "round" license sizes
    - Conceal identities of bidders
    - Allow enough time between rounds for good decisions
- Simple, transparent rules

Conclusion

Academic economists, working with FCC staff, created an auction form that has been used to sell over a hundred billion dollars of spectrum in dozens of countries. The design reflected tradeoffs that were understood only because of the development of auction theory in the 1980s, and thus implemented recent innovations in economic analysis. The FCC auction performed well by a variety of measures and seems to have balanced revenue and efficiency.

The FCC auction has rightfully been credited as an important impetus to the adoption of game theoretic techniques in the business world. The utility of economists in the private sector, long a subject of derision, was forcefully demonstrated by the application of sophisticated game theory in this real world setting.

The role of economics and the economist in the FCC auctions was not to prove a theorem that provided an optimal mechanism for some particular setting. Instead, it was to use the existing theory to identify the most important factors, design a system that accommodates the needs of market participants, generally in as simple a manner as possible, and identify the features that may be important. Theory, then, is a guide, not a destination.

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