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Selling Spectrum Rights

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“It has shades of the '49 California gold rush,” remarked one industry observer. “It’s the 21st century equivalent of the Oklahoma land rush,” said another.¹ The sought-after item is the radio spectrum, which the U.S. government has put on the auction block. The wavelengths on offer, formerly reserved for the military, are to be used for newly invented personal communications services (PCS): pocket telephones, portable fax machines, and wireless computer networks.

The auction is one of the biggest and most complicated in history. The spectrum on offer is estimated by the Office of Management and Budget (1993, p. 21) to be worth \$10.6 billion. Thousands of spectrum licenses are for sale.

The bidders include most U.S. telecommunications firms: long-distance, local, and cellular telephone companies and cable-television companies. After spending billions for the spectrum licenses, the firms will invest still bigger sums installing transmitters and developing a customer base. The return is highly uncertain. The new PCS operators will compete not only with each other but also with entrenched cellular-telephone companies. The PCS technology is still being developed. The potential size of the market is unknown. (Will cordless telephones eventually replace many of the telephones now tethered by wires? Will the new wireless multimedia systems—carrying video and data as well as the spoken word—be in wide demand?) Successful bidders face daunting risks, but could make huge profits.

¹*Business Week*, November 29, 1993, p. 128; and Tom Wheeler, president of the Cellular Telecommunications Industry Association, in the *Financial Times*, October 18, 1993, p. VIII.

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The story of how the spectrum auction was designed is a case study in the policy application of economic theory. The major telephone companies and the government relied on the advice of theorists. Paul Milgrom, Robert Wilson, and Charles Plott were hired by Pacific Bell, Jeremy Bulow and Barry Nalebuff by Bell Atlantic, Preston McAfee by Airtouch Communications, Robert Weber by Telephone and Data Systems, Mark Isaac by the Cellular Telecommunications Industry Association, Robert Harris and Michael Katz by Nynex, Daniel Vincent by American Personal Communications, Peter Cramton by MCI, John Ledyard and David Porter by the National Telecommunications and Information Administration, and the author of this article by the Federal Communications Commission (FCC). This was perhaps the biggest use of economic theorists as consultants since that other telephone-industry revolution, the break-up of AT&T ten years earlier.

The analysis of how auctions work is one of the successes of modern mathematical economics. Developed to try out new ideas in game theory, auction theory has turned out to have considerable practical content. The theory looks at the strategy of competition: how bidders choose their bids, not knowing the value of the item for sale and not knowing what their rivals know; and what the seller can do to stimulate the bidding competition, not knowing how much any of the bidders is willing to pay.² When the theorists met the policy-makers, concepts like Bayes-Nash equilibrium, incentive-compatibility constraints, and order-statistic theorems came to be discussed in the corridors of power.

The Decision to Auction

Spectrum licenses used to be assigned by administrative decision. Prospective license-holders filed applications and the Federal Communications Commission held comparative hearings to decide which applicant was the most worthy. This method broke down under its cumbersomeness: there was a big backlog of unassigned licenses. Congress replaced it with lotteries, assigning each license randomly among the applicants. The lotteries succeeded in assigning licenses quickly, but the prospect of a windfall gain attracted large numbers of applicants: there were nearly 400,000 applications for cellular licenses. In one not atypical case, an obscure group called the RACDG partnership was chosen by lottery in 1989 to run cellular telephones on Cape Cod; the partners then sold their license to Southwestern Bell for \$41 million. The total value of cellular licenses the government gave away during the 1980s, according to a

²Wilson (1969, 1977) started the theory of auctions. Milgrom and Weber (1982a) developed many of the ideas used in designing the spectrum auction. For surveys of the theory, see McAfee and McMillan (1987), Milgrom (1987, 1989), and Wilson (1992); and on its practical content, see McMillan (1992, chs. 11–13).

Commerce Department estimate, was \$46 billion.³ Congress could not shrug off such figures.

Auctioning spectrum rights is not a new idea. The U.S. Congress held hearings on it as early as 1958, and R. H. Coase advocated it in a 1959 article. A 1985 FCC discussion paper showed that auctions would be workable (Kwerel and Felker, 1985). New Zealand legislated spectrum auctions in 1989, as did the United Kingdom in 1990. It was not until August 1993, however, that Congress passed legislation giving the FCC the authority to auction licenses. The FCC was to "design and test multiple alternative methodologies" for competitive bidding, and auctioning was to begin in May 1994. Auctioning did not change property rights: the restrictions on what the spectrum can be used for remain as before. A license lasts for a fixed term of up to ten years, but renewal is almost automatic provided it is being used appropriately. The Act specifies a range of aims for the auction: achieving an "efficient and intensive use of the electromagnetic spectrum;" promoting rapid deployment of new technologies; preventing excessive concentration of licenses; and ensuring some licenses go to minority-owned and women-owned companies, small businesses, and rural telephone companies (U.S. Congress, 1993, pp. 80–83).

The Act downplays revenue as an objective, and by its actions also the government showed that revenue was not its overriding objective (as, indeed, it should not be). If revenue had been paramount, the government could have offered a single monopoly license in each region—at the cost, obviously, of creating future inefficiencies. The government allocated a large swath of spectrum for PCS (120 megahertz, as compared with 50 megahertz for cellular telephones), even though maximizing revenue would have meant allocating less spectrum. Nevertheless, the wide publicity given to the forecasts of over \$10 billion to be raised in the auction put pressure on the FCC to generate revenue.

The FCC canvassed a variety of auction-design possibilities and made some preliminary recommendations in its October 1993 Notice of Proposed Rule Making, and then called for comments from the industry. Over 220 firms and lobby groups filed submissions (some written by academics). The auction structure chosen by the Commissioners in March 1994 followed the recommendations of the FCC officials. Although pork-barrel politics had shaped the debate on whether to use auctions, the auction-design process was driven not by politics, but by economics.

Theory helped to answer key questions of auction design. Which of the basic auction forms should the government use? An open auction, in which bidders raise their bids until only one remains, who wins and pays the final bid? A first-price sealed-bid auction, in which each bidder submits a single sealed bid

³For more on the methods the U.S. government has used for allocating the spectrum, see Kwerel and Felker (1985), Kwerel and Williams (1993), U.S. Department of Commerce (1991), and Congressional Budget Office (1992). The estimate of cellular-license values, based on the stock-market value of cellular firms, is from U.S. Department of Commerce (1991, p. D6). The Cape Cod story is from the *New York Times*, May 30, 1991, p. A1.

and the high bidder wins, paying that bid? Or a second-price sealed-bid auction, in which each bidder submits a single sealed bid and the high bidder wins, but the price is the second-highest bid? Should the licenses be auctioned in sequence, or should they all be bid for at once in a large simultaneous auction? Should the government help the bidders to aggregate licenses by accepting bids for combinations of licenses, or should it allow only bids for individual licenses? How should the auction be structured to promote the interests of minority-owned and other designated firms? Should the government demand royalty payments? Should reserve (or minimum) prices be imposed? How much should the bidders be informed about their competition? Faulty choices over issues such as these could mean the auction produces a mismatch of licenses to firms, or the government misses out on revenue it could have earned, or the auction in some way breaks down.

Cautionary Tales from the Antipodes

That auction design matters is illustrated by the experience of the innovator in the field of spectrum auctions, New Zealand, which began auctioning the spectrum for radio, television, and cellular-telephone use in 1990. Following the advice of a U.S.-U.K. consulting firm, National Economic Research Associates (NERA), the government adopted second-price auctions (NERA, 1988). Politically embarrassing newspaper headlines resulted, as winners paid prices far below their bids (Mueller, 1991). In one extreme case, a firm that bid NZ\$100,000 paid the second-highest bid of NZ\$6. In another the high bid was NZ\$7 million and the second bid NZ\$5,000. (NZ\$1 equaled US\$0.55.) An Otago University student bid NZ\$1 for a television license for a small city; no one else bid so he won and paid nothing. The revenue fell far short of the advance estimate: the cellular licenses fetched NZ\$36 million, one-seventh the NZ\$240 million that NERA had predicted.

The auction form had a political defect. By revealing the high bidder's willingness to pay, the second-price auction exposed the government to criticism, because after the auction everyone knew that the firm valued the license at more than it paid for it. This scope for criticism would exist even if it was unjustified, in that the auction had generated the best possible price. But theory says the auction form had another defect. No reserve (or minimum) prices were imposed. More revenue would have been earned if there had been reserve prices because, when there are few bidders (as in New Zealand), a reserve price substitutes for the missing bidding competition. The government abandoned the second-price auctions following the complaints in the media, and now uses first-price sealed-bid auctions instead. The auctions worked better than the alternative, bureaucratic decisions. They assigned the spectrum to its highest-value users, and did so quickly and with low administrative costs. But less revenue was raised than could have been.

An Australian government auction illustrates that it pays to think through the details of auction design. Two licenses for satellite-television services were offered in April 1993 by first-price sealed-bid auction. What followed was high comedy—though it did not seem funny to the communications minister, Senator Bob Collins, who almost lost his job. An opposition politician called it “one of the world’s great media license fiascos.” The licenses were won by dark-horse bidders called Hi Vision Ltd. and Ucom Pty. Ltd., who beat the favorites—including a consortium of the big players, Rupert Murdoch, Kerry Packer, and Telecom Australia—by offering startlingly high bids of A\$212 million and A\$177 million. (A\$1 equaled US\$0.68.) The government hailed the auction results as opening up “a whole new era,” bringing new firms into the closed shop of the Australian television industry. The press quoted one of Hi Vision’s directors expressing confidence in his firm’s ability to raise the bid amount, despite having issued capital of just A\$100.

It soon became apparent that the two parvenu bidders had, in the Australian argot, pulled the wool over the eyes of the government. They had no intention of paying their bids; they had bid high merely to guarantee they won. They had also put in a series of lower bids—reportedly up to 20 such bids at A\$5 million intervals. The two proceeded to default on their highest bids, which meant that the licenses had to be re-awarded at the next-highest bids, also theirs. The government had neglected to require a deposit, so default cost the bidders nothing. The prices cascaded down as Ucom and Hi Vision failed to produce the cash for their bids. Four months later, after several defaults by the same two bidders, Ucom paid A\$117 million for its license, A\$95 million less than its initial bid. Shortly afterwards Ucom sold it to a firm called Australis Media Ltd., earning an agreeable A\$21 million profit. The cascading continued on the other license for another five months, with Hi Vision dropping out but then other firms successively defaulting on their bids. The final price was A\$77 million, A\$100 million less than the original bid. The successful bidder for the second license was none other than Ucom—which then sold it to a joint venture called Continental Century.⁴

This botched auction delayed by almost a year the introduction of pay television into Australia, already one of the few countries in the world still without it. The flaw in the auction rules, the source of the cascading bids, was the absence of a penalty for default, which meant bids were not meaningful.

⁴The saga did not end with the award of the licenses. Outsmarted by the upstarts, the Murdoch-Packer-Telecom consortium belatedly tried some gaming of its own, seeking to undermine the auction. It investigated using alternative technologies for delivering pay television, to squeeze the two new entrants out of the market. It tried to make a side-deal to gain control of another satellite license that the government had reserved for the state-run Australian Broadcasting Corporation. When that failed it sued to overturn the auction outcome, alleging the government had not complied with the bid guidelines; it withdrew its suit five minutes into the court hearing. (This story has been pieced together from reports in the *Age*, the *Australian*, the *Australian Financial Review*, the *Financial Times*, and the *Sydney Morning Herald* between April 1993 and March 1994.)

The lesson is that the fine print matters. Any oversight in auction design can have harmful repercussions, as bidders can be counted on to seek ways to outfox the mechanism.

What Is the Role of Theory in Auction Design?

Any kind of auction will result in better matches of licenses to firms than allocating the licenses at random, as was done before. But some kinds of auctions work better than others: this was why so much effort went into designing the spectrum auction.

What makes the spectrum auction distinctive are the potential efficiencies from license aggregation. The FCC divided the United States geographically and the spectrum by wavelength, making over 2,500 licenses. There are 51 major trading areas (MTAs), each of which has two large blocks of spectrum (of 30 megahertz). There are also 492 basic trading areas (BTAs), subdivisions of the MTAs, each of which has four spectrum blocks (one of 30 megahertz and four of 10 megahertz). Efficiencies will be realized if bidders succeed in aggregating some of the licenses.

The aggregation efficiencies rest on both engineering and economics. First, firms that have several licenses can spread their fixed costs of technology acquisition and customer-base development. Second, problems of interference at the boundaries of license areas mean there are production-cost economies from operating adjacent licenses. Third, several different, incompatible technologies are vying to become the industry standard. Consumers will value roaming capability—the ability to use the same telephone when they travel around the country—and this is more likely to be achieved if some firms own enough licenses to cover reasonably large areas. As well as these complementarities, there is also the opposite kind of interdependency: substitution among licenses. Each region contains several slices of the spectrum, so a firm that fails to win one license may bid for another in its place, and the auction design must be flexible enough to allow bidders to switch. It is impossible to foresee what will comprise efficient aggregations of licenses. Different firms want different license combinations. The ideal auction procedure should therefore be flexible enough to enable the bidders to construct their own aggregations.⁵

The government's multiple aims complicated the task of auction design: achieving an efficient outcome, promoting minority-owned and other designed firms, preventing monopolization. An extra goal, not written in the legislation

⁵The secondary market in licenses will help to correct any mismatches of licenses to firms that result from defects in auction design (as it did when the licenses went by lottery). This does not, however, render auction design unimportant. The secondary market is likely to be thin; transactions costs will limit its ability to fix inefficiencies.

but critical, was that the auction not misfire and cause political damage. Revenue was low on the list. These objectives are not necessarily in conflict with each other. Pursuing efficiency, for example, is usually consistent with pursuing revenue (because efficiency usually means awarding the license to the bidder willing to pay the most). The auction designers took the view that, after the other aims had been met, the auction form should be chosen to maximize revenue.

Theory has limits. Any nontheorist will readily assent to this proposition; but it is useful to be specific about where those limits lie. First, while theory can identify the relevant variables, it cannot tell us much about their size. Theory sometimes shows that there are effects that work in opposite directions from each other, and data are needed to establish which effect is likely to be dominant. Second, transactions costs arise in carrying out some of the policies that the theory recommends, and these costs may swamp the theoretical benefits of the policies. Third, implementing a recommendation of the theory may require knowledge that is unavailable. In particular, some of what auction theory identifies as optimal seller strategies depend on the distributions of bidders' valuations, which were not known. Fourth, the theory does not specify an unambiguously best form for the spectrum auction, which is so complex that no existing theorem covers it.⁶

Each of these limits of theory was met during the spectrum-auction design process. Judgment and guesswork were needed to merge the various partial theories, to weigh the government's various objectives, to estimate the relative sizes of the different effects, and to evaluate whether a proposed scheme was workable. Laboratory experiments also were used to test whether people bid as the theory predicts, and to look for hidden gaps in the rules that might leave the auction open to manipulation by the bidders.

Open Auction or Sealed Bids?

The FCC, following the theorists' recommendation, chose an open auction ahead of a sealed-bid auction. The advantage of an open auction is that it

⁶The main shortcoming of the existing theory is the lack of a model of aggregation of the items for sale. Engelbrecht-Wiggans and Weber (1979), Milgrom and Weber (1982b), Palfrey (1983), Hausch (1986), McAfee and McMillan (1988), Maskin and Riley (1990), and McAfee and Vincent (1993) model auctions of multiple items, but without interdependencies. Gale (1990) models an auction with aggregation efficiencies and shows that the seller optimally bundles all the licenses; but the assumption that full aggregation is ideal makes this inapplicable to the PCS auction. Lang and Rosenthal (1991) model the auctioning of items that are substitutes for each other. Bernheim and Whinston (1986) characterize equilibria in the bidding for combinations of items, assuming the bidders know each others' valuations. Much of what is known about multi-unit auctions with interdependencies comes from experiments: Grether, Isaac, and Plott (1981, 1989), Rassenti, Smith, and Bulfin (1982), Banks, Ledyard, and Porter (1989), Brewer and Plott (1993).

reduces the force of the “winner’s curse.”⁷ The high bidder is the one who most overestimates the value of the item for sale, and thus may find, too late, that it has paid more than the license is worth. However, with billions of dollars at stake (and, for that matter, having been advised by economists) the bidders might anticipate the winner’s curse when they decide their bids. A bidding firm that understands the winner’s curse avoids falling victim to it by bidding cautiously, discounting its own estimate of the license’s value. This discount is large—and rational bidders bid low—if the estimates can range widely around the true value. If bidders bid to avoid the winner’s curse, then anything that improves the bidders’ information is to the government’s advantage, in that it induces the bidders to be less cautious.

Theory says, then, that the government can increase its revenue by publicizing any available information that affects the licenses’ assessed value: providing assurances about future regulatory developments, or announcing how much new spectrum will be allocated to telecommunications in the future.

By the same logic of winner’s curse avoidance, an open auction yields more revenue than a sealed-bid auction (Milgrom and Weber, 1982a). In a first-price sealed-bid auction, the price is based solely on the winner’s own initial value estimate. In an open auction, by contrast, each bidder gets some indirect information about the other bidders’ estimates from their bids, so the bidders are more confident and, on average, bid higher.

Two caveats apply to the choice of an open auction. First, the spectrum-auction bidders are likely to be risk averse, given the huge sums being bid. Bidder risk aversion tends to make bids higher in a sealed-bid auction than in an open auction (Riley and Samuelson, 1981). Whether the winner’s curse effect exceeds the risk-aversion effect is an empirical issue. Second, if bidder collusion is anticipated, the government might prefer a sealed-bid auction, because it deters collusion more effectively than an open auction (Milgrom, 1987). The FCC and the economist-consultants judged these two effects to be outweighed by the bidders’ ability to learn from others’ bids in the open auction.

Instead of using a conventional open auction, in which the bidders call out their bids, the FCC chose to run multiple rounds of sealed bids, announcing the bids after each round, and with a minimum bid increment between rounds. This has the informational advantages of a literally open auction, but offers the

⁷The winner’s curse was first identified by Wilson (1969). Auction theory has two basic models: the common-value model and the independent-private-values model. The spectrum auction has aspects of both of these polar cases (so the bidders’ valuations are affiliated: Milgrom and Weber, 1982a). Values are private insofar as different bidders have different stocks of capital, labor, and knowledge, and so different prospects for earning profits from the licenses. Values are common, on the other hand, insofar as there is uncertainty about technological possibilities and about consumer demand for the new mobile communication services: the bidders have their own estimates of technology and demand, but are trying to estimate the same number, the common value. The secondary market also induces a common-value aspect, as the bids reflect guesses of the prices that will rule there. Winner’s curse effects reflect common values.

government extra control. With oral bidding, the bidders automatically know against whom they are competing. With multiple-round sealed bidding, the government can choose what to tell the bidders about the competition. Although the winner's curse idea suggests full information release—all bid amounts and bidder identities—fears of anticompetitive behavior suggest concealing the bidders' identities during the bidding; revealing identities may help bidders to collude. The compromise was to announce the bids during the bidding, but not the bidders' identities.

Simultaneous or Sequential Auction?

The most contentious question during the auction-design process was whether the licenses should be sold in sequence or simultaneously. The debate pitted theoretical virtues against practical feasibility. A simultaneous mechanism promises efficient aggregation of licenses; but the skeptics questioned whether it can realistically deliver on this promise.

Sequential auctions are the usual practice when multiple related items (parcels of real estate, coins, stamps) are sold. The advantage of the sequential method, as some of the economists pointed out, is its administrative simplicity; also, bidders know which licenses they already own and which have gone to others.⁸ A drawback of the sequential mechanism in the case of spectrum licenses is that it impedes aggregation by eliminating backup strategies. A bidding firm may rethink its evaluation of one of the early licenses in the light of the bidding activity it observes on the later licenses; but in a sequential setting the bidder cannot go back. Also, predatory bidding can occur (Pitchik and Schotter, 1988). A bidder may try to drive prices for the early licenses up to excessive levels so the winners will be unable to afford to compete for the later licenses.

A simultaneous auction with multiple rounds of bidding allows bidders to take advantage of any information revealed during the bidding. It gives bidders, bidding license by license, full flexibility in constructing license aggregations, and in being able to switch to their backup aggregations should their first-choice aggregations turn out to be too expensive. Its symmetry prevents predatory bidding. Thus a simultaneous mechanism, if it works, creates better

⁸If a sequential mechanism is used, should the licenses covering the largest populations go first or last? For efficiency, the best ordering is large to small, as the large regions are the key parts of any aggregations. This ordering may mean sacrificing some revenue. The bidders learn from the early bidding, so the winner's curse discounts are smaller—and bids higher—the more regions have already been sold. If the smaller regions go first, then by the time the big regions are sold the winner's curse effect is reduced. An opposite revenue effect also exists, however: as the large-to-small ordering generates more efficiency, it raises the potential revenue and may raise realized revenue. Since Congress said efficiency had precedence over revenue, large-to-small was the recommended ordering.

license aggregations than a sequential mechanism. The crucial question about any simultaneous mechanism is whether it is workable. It will fail unless an effective stopping rule can be devised.

The two simplest stopping rules are inadequate. One would be to close licenses one by one, as the bidding ceases on each. But this is not really a simultaneous auction: it is effectively sequential, with a random ordering of the licenses. Another simple stopping rule leaves all licenses open until bidding ceases on all. This gives bidders complete flexibility in constructing aggregations, but gives them little incentive to bid actively: they could hold back, waiting for others to show their hands. A bidder wanting to game the mechanism could repeatedly bid on one small license, causing it to take interminably long to close. An effective stopping rule, then, must (1) end the auction in a reasonable time; (2) close the licenses almost simultaneously, to aid license aggregation; and (3) be simple enough to be understandable by the bidders.

Three stopping rules were discussed. One, offered by Paul Milgrom and Robert Wilson, keeps all licenses open until all close, but reduces gaming by means of an activity rule. Bidders must specify in advance, and pay deposits on, the total number of licenses they intend to own. In each round, a bidder must be active on a minimal number of licenses (a specified fraction of the bidder's pre-announced total), which means either being the current high bidder or putting in a bid that exceeds the current high bid by at least the specified increment. The mechanism has three phases, each with an increasingly stringent activity rule. A second stopping rule, offered by Preston McAfee, closes each license separately as the bidding stops on it, but tries to ensure that all licenses close at roughly the same time by slowing down the bidding as final prices are approached. It does this by reducing the minimum bid increment for a given license as the number of active bidders falls, so that when only two bidders remain the price rises slowly. The third stopping rule, offered by the FCC staff and the author of this paper, uses the skewedness of the population distribution among licenses. A relatively small number of licenses (one-fifth) account for 50 percent of the U.S. population: define these licenses to be the core. The all-open-until-all-close rule applies to the licenses in the core. After the core licenses close, all at the same time, the bidding continues in the remaining, smaller licenses, with license-by-license stopping on them. This mechanism therefore permits full efficiency in the core licenses, and sacrifices efficiency to speed of closing in the smaller licenses.

For bids to be meaningful, there must be some penalty on bidders who withdraw their bids (an important consideration, as the Australian example shows). If bids can be freely withdrawn, then the bidders cannot infer any reliable information from each other's bids. How to ensure sincerity of bidding without unduly restricting the bidders' flexibility to shift to backup plans needed a judgment call. One proposal was that, when a bidder withdraws while having the highest bid, the government require the bidder to pay the difference between its bid and the price at which the license ultimately sells (thus

having the bidder compensate the government for the loss it causes by renegeing on its bid).

The rules of a simultaneous auction, then, are necessarily quite complicated. Critics pointed to a risk of system breakdown: either from an inadvertent gap in the rules that allows bidders to game the mechanism, or from a clerical flaw in the bid-transmission process. The bidders also must be capable of processing a lot of information. The proponents of the simultaneous mechanism (including the author of this article) replied that the potential gains from achieving good license aggregations justified a little complexity.⁹

The FCC, in announcing the auction rules in March 1994, left itself the option of choosing from a range of auction forms, depending on the degree of license interdependency and whether the license values are high or low. "Because the Commission expects most licenses to be of high value and interdependent, it found that simultaneous multiple round auctions . . . should be the Commission's preferred auction design. . . . Because of the superior information and flexibility provided by simultaneous multiple round auctions, this method will facilitate efficient aggregations across spectrum bands" (FCC, 1994, p. 2). The FCC left itself the possibility of using sequential auctions in those cases where the licenses have little interdependence, or single-round sealed bidding where there are large numbers of low-value licenses. For the simultaneous auction, the FCC chose the stopping rule that keeps the bidding open on all licenses until bidding stops on all. An activity rule would be used to ensure the auction closes within a reasonable time. Bidders would be required to pay a substantial deposit, so as to limit the bidding to serious bidders. Bid-withdrawal penalties were imposed to ensure sincere bidding. A high bidder withdrawing its bid during the course of the auction would have to pay the difference between its bid and the price for which the license ultimately sold. For withdrawing a bid after close of the auction there would be an extra 3 percent penalty.

Should Combinational Bids Be Permitted?

Should bidders be permitted to bid on combinations of licenses—that is, bids for bundles of licenses together—or should bids be accepted only

⁹A precedent—a large-scale simultaneous auction that worked—is the 1992 sale by Czechoslovakia (as it was then) of shares in nearly 1,500 state-owned firms (Svejnar and Singer, 1992). The auction was Walrasian. In the first round, the privatization ministry set a price per share. A bid, by vouchers, consisted of a request for a stated number of shares at the set price. In subsequent rounds, the ministry set the price as a function of earlier-round excess demands or supplies. Only five rounds were held, so price adjustments between rounds had to be large and misjudgments occurred, with some big swings from excess demand to excess supply and back. The Czechoslovakian auction was successful, however, in that it established equilibrium relative prices for the firms' shares, and disposed of all but 7 percent of the 22 million shares.

license-by-license? Private-sector auctions sometimes use combinational bidding when the items are worth more together than separately. When a factory is being sold, for example, the buildings and machines are offered as a set as well as piece by piece (Cassady, 1967, pp. 156–61). In the spectrum auctions it is possible that the license complementarities are large enough that, for efficiency, one or more firms should cover the entire country. This means winning every one of a large number of licenses (51 in the case of MTAs, 492 in the case of BTAs). With so many licenses to be won, it is possible that idiosyncratic events in a few auctions might prevent the efficient aggregation from being achieved. Because of a worry that the FCC had doomed the industry to fragmentation by dividing the nation into so many pieces, some suggested aggregation be aided by allowing nationwide bids, with the nationwide bid winning if it exceeds the sum of the highest bids on the individual licenses.

Theory says, however, that with nationwide bidding, licenses may not end up with the firms that are willing to pay the most (Palfrey, 1983). Nationwide bids can reduce the bidding competition, as the nationwide bidders refrain from driving up the separate-license prices. There is a free-rider problem. Separate-license bidders may not raise their bids by enough to beat a nationwide bidder because only part of the gain from raising their bid accrues to them. As a result, a nationwide bidder may win even though the total value of licenses if awarded separately would exceed the nationwide bidder's value. The auction is biased toward the nationwide bidders.¹⁰ A variant of the nationwide proposal sought to mitigate this implicit favoritism by handicapping nationwide bidders: putting a premium on any nationwide bid, so it wins only if it is at least, say, 5 percent more than the sum of the individual bids (as is sometimes

¹⁰Imagine there are three bidders, E, W, and N, and two licenses, East and West (this example is due to Preston McAfee). Firm E values owning East alone at \$2 billion, West alone at \$1 billion, and the nation at \$3 billion. Firm W values East at \$1 billion, West at \$2 billion, and the nation at \$3 billion. Firm N values East at \$1.6 billion, West at \$1.6 billion, and the nation at \$3.3 billion. Suppose first that nationwide bidding is not allowed. In the two open auctions, W wins West at a price slightly above \$1.6 billion (which is the price at which the second-last bidder, who happens to be N, drops out), and E wins East at slightly above \$1.6 billion. This is the ideal outcome, in that the licenses go to their highest-value users. The total value of the licenses to their new owners is \$4 billion, of which the government gets a little over \$3.2 billion. Now suppose there is a national auction in addition to the separate auctions. Anticipating winning the nationwide auction, N has no incentive to bid for the separate licenses. Only E and W bid for them, so the price in each stops at slightly more than \$1 billion. All three bidders compete in the national auction. Firm N wins the nationwide bidding at slightly above \$3 billion, which is where both E and W drop out. The nationwide bid of \$3 billion exceeds the sum of the two separate bids, so the nationwide bidder N wins. This is not the efficient outcome: the total use-value is \$3.3 billion and government revenue slightly above \$3 billion. The free-rider point is that E and W would have to raise their nationwide bids by a total of \$1 billion to beat N; but neither alone will raise its bid this much, as that would mean bidding more than value. Now make one change to the example: increase N's value of the nation to \$4 billion, so ideally N would win the nation. But N wins even without nationwide bidding, by bidding slightly more than \$2 billion in each separate auction.

done in the private sector; see Cassady, 1967, p. 160). Most of the economists recommended against permitting nationwide bids, even with a premium.

The ideal level of aggregation may not be nationwide. Some subnational aggregations are likely to be efficient. A more ambitious mechanism allows bidders to express their preferences over aggregations (Banks, Ledyard, and Porter, 1989). Bidders may bid for groups of licenses, in any combinations they choose. A group bid wins if it exceeds the sum of the individual bids. Experiments have found that this mechanism works better than separate-license bidding when the bidders' preferences are idiosyncratic, in that bidders rank the various aggregations differently. (One source of aggregation idiosyncrasies is government regulation: firms that already own cellular licenses are limited in the amount of PCS spectrum they can own in the same region.) If the different bidders have reasonably similar rankings across alternative aggregations, on the other hand, they can construct their own aggregations from individual auctions, and there is no need for combinational bidding. The disadvantage of the full-combinational mechanism is its complexity: both for bidders in understanding how it works and for the government in running it. A huge number of possible combinations exists (for the 492 BTA licenses, more than 10^{148}). Computer or other administrative breakdowns may occur. In the judgment of most of the economists involved in the auction design, the complexity costs outweighed the potential efficiency gains: the full-combinational mechanism was ahead of its time.

The FCC decided that bids for combinations of licenses should not be permitted in a simultaneous auction (at least not before significant proven advances have been made in combinational bidding procedures). If a sequential auction is used, and if it is clear that some particular level of license aggregation is efficient (such as nationwide), then the FCC might adopt combinational bidding, possibly with a bid premium.

How to Aid Designated Bidders?

Congress required the FCC to "ensure that small businesses, rural telephone companies, and businesses owned by members of minority groups and women are given the opportunity to participate in the provision of spectrum-based services" (U.S. Congress, 1993, p. 81). Theory says that auctions usually produce efficient outcomes: in most cases the winner is the bidder with the highest use-value for the license. This argues for *laissez-faire*: letting level-playing-field auctions determine who gets the licenses. Favoring certain bidders is justified, on the other hand, if bidders' willingness to pay does not reflect social value, because of externalities or capital-market imperfections, or for distributional reasons.

The FCC initially proposed that one-fourth of the spectrum for sale be set aside for bidding by the designated firms only. A skeptic might question this policy for its arbitrariness. Why does one-fourth give the right amount of correction: why not one-third or one-fifth? Also, setting aside some of the licenses lowers revenue by reducing the bidding competition. Theory offers an alternative way of aiding the designated bidders (Myerson, 1981; McAfee and McMillan, 1987, pp. 714–16). The government could allow any firm to bid on any license, but give the designated firms a price preference. With a preference of, say, 10 percent, a designated firm would win if its bid was no more than 10 percent less than the highest nondesignated-firm bid. This is a free-lunch policy. It would not only address the public-policy goal of increasing the number of licenses won by the designated firms, but it would also actually increase the government's revenue. Most of the designated bidders, presumably, have a lower willingness to pay for the licenses than the nondesignated firms (otherwise there would be little need for preferences). With level-playing-field bidding, they would therefore impose little competitive pressure on the nondesignated firms, who could get away with bidding relatively low. A price preference for the designated firms stimulates the bidding competition, forcing the nondesignated firms to bid higher. If the government sets the price preference at the right level, its revenue-raising effect (from the higher bids from the nondesignated firms) outweighs its revenue-lowering effect (from the chance that a designated firm wins and pays a low price). The net effect of the price preference, therefore, is to increase the government's revenue.

A difficulty in applying price preferences is in knowing the appropriate level at which to set them: the only practical approach would be to experiment with different levels (between, say, 5 and 15 percent). As with other choices between price and quantity tools (for example, in the environmental arena), quantity controls can seem more predictable, while price-based instruments seem more uncertain. But, as a rule of thumb, a 10 percent preference would result in about 10 percent more of the licenses being won by designated firms than would have happened without the preference.

In the end, the FCC retained the ability to favor designated bidders in a variety of ways, by using set-asides, price preferences, or installment payments. The FCC also said it would monitor any resale of licenses by these firms. To prevent what it called "unjust enrichment" by auction winners, the rules on resale require any designated firm selling its license to return to the government that part of the profit earned from the sale that is attributable to the artificially low purchase price.

Another kind of special treatment is the award of pioneer preferences. In December 1993 the FCC gave licenses to Omnipoint Communications, Personal Communications, and Cox Enterprises, as a reward for their having developed new PCS technologies. This removed from the auction three of the most valuable licenses, covering New York, Los Angeles, and Washington D.C. Had

they been auctioned, they might have fetched up to \$1 billion—an implausibly generous reward to the inventors.

Should Royalties or Reserve Prices Be Used?

Should winning bidders make a single up-front payment, or should the government extract royalties based on value in use? Theory says royalties increase the revenue from the sale. A three-way tradeoff exists (McAfee and McMillan, 1986; Laffont and Tirole, 1987). Royalties have two revenue-raising effects. First, royalties shift to the government part of the risk otherwise borne by the firm and, if the firm is risk-averse, raise the firm's willingness to pay. Second, and more subtly, royalties stimulate the bidding competition, for they reduce the effect of differences in valuations among the bidders. The cost of using royalties, on the other hand, is that they act as a disincentive to post-auction investment, since the license-holder keeps only a fraction of any revenue generated. The theory shows that, on balance, royalties benefit the government. Royalties on spectrum licenses are probably unworkable, however, since the government would have to compute the profits attributable to the licenses. In a telecommunications firm with multiple lines of business, it would be difficult to isolate the profit from the license alone, and easy for the firm to use creative accounting to understate it. The FCC decided against royalties.

Should the government impose reserve (or minimum) prices? Theory says it should. A reserve price, if set at the right level, can raise the government's revenue by driving up the price in the event that all bidders except one place little value on the license (Myerson, 1981; Riley and Samuelson, 1981). But the reserve price has its effect only when bidding competition is weak. The U.S. spectrum auctions (unlike in New Zealand, with its small population) will probably attract enough bidders to make reserve prices unnecessary. The FCC decided reserve prices, if used at all, would only be on licenses for which only two or three firms had applied to bid.

Spectrum Auctions and Auction Theory

Auctioning spectrum licenses is an idea whose time has come. Nations with inadequate telephone systems—less-developed countries and the formerly Communist countries—are leapfrogging technologies and going straight to wireless rather than laying wires. Once telecommunications ceases to be a state monopoly, a method for allocating the spectrum must be chosen: administrative process, lottery, or auction. An auction offers two advantages over the alternatives: it not only raises revenue, but also identifies the firms with the

highest use-values for the spectrum. Egypt, India, and Colombia have auctioned cellular licenses. Argentina's 1993 cellular-license auction illustrates the variety of public-policy purposes to which auctions can be put. The competition was not over price, but over which bidder could offer to set up cellular-telephone service in the fastest time. A consortium including GTE and AT&T won by promising to provide cellular service across a vast area of Argentina's countryside in only one month.¹¹

The FCC's spectrum auction is unprecedented in its use of economic theory in the design of the auction. The theorists' contribution showed in the choice of an auction with multiple rounds of bids; in the preference for a simultaneous auction when licenses are interdependent and have high value; in the form of the stopping rule and the use of an activity rule for the simultaneous auction; and in the nature of the bid-withdrawal penalties. The FCC's adoption of a simultaneous multiple-round auction ahead of a sequential or a single-round-sealed-bid auction—which are more conventional but arguably less effective for selling spectrum licenses—was a triumph for game theory. The auction runs through the summer and fall of 1994. The intriguing next step will be to appraise its performance.

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¹¹*Financial Times*, January 25, 1994, p. 6; *Wall Street Journal*, January 28, 1994, p. A8; *New York Times*, November 9, 1993, p. C16.

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