

Why Auction the Spectrum?

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Abstract: Of the alternative spectrum-allocation methods--administrative process, lottery, first come first served, and auction--economic theory, as well as various countries' experiences, show that auctioning works best. As well as raising revenue, an auction assigns licenses to the firms best able to use them. Also, the auction can be designed to advance public-policy goals such as avoiding monopoly and directing licenses to minority-owned firms.

The electromagnetic spectrum is in demand, not only for traditional uses such as broadcasting but also, increasingly, for new forms of mobile telecommunications. How should governments decide who has the right to use the spectrum? Four methods have been used:

- administrative process,
- lottery,
- first come first served,
- auction.

Administrative process is the most common method around the world. Lotteries and first come first served have been used occasionally. As part of a broad reform of

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telecommunications regulation, the 1990s are seeing a worldwide trend toward using auctions.

Auctioning spectrum rights is an idea whose time has come. Auctions were first used by the New Zealand government in 1990, and have since been used in the United States, India, Colombia, Australia, the United Kingdom, Hungary, and Argentina. Of the four methods for allocating the spectrum, I shall argue that auctioning works best.

Administrative Process and Lottery

Administrative processes for deciding who receives the right to use the spectrum, sometimes dubbed "beauty contests," have the advantage of flexibility. The government can impose whatever criteria it chooses, and can thereby use the process to address its policy goals. The main drawback of administrative processes is the corollary of this flexibility: their lack of transparency.

The European Union countries and Canada use administrative processes to assign mobile-communications licenses (though in 1994 both the European Commission and the Canadian government began reviewing their procedures and considering the possible use of auctions).¹ The Canadian government describes its procedure as follows. "While this process requires the development of criteria for evaluating the quality of each proposal, those criteria are then applied by an in-house committee of experts without going through public hearings. Admittedly, the comparative process is time-consuming but it also guarantees the best fit against the Department's policies and criteria." The Canadian procedure has been described from the opposite perspective, however, that of a license applicant, as "Byzantine." Although some technical criteria are stated precisely, there are

¹ On the policy reviews, see European Commission, *Towards the Personal Communications Environment: Green Paper on a Common Approach in the Field of Mobile and Personal Communications in the European Union*, Draft, Directorate General XIII, Jan. 12, 1994, and Industry Canada, *Public Review of the Comparative Selection and Radio Licensing Process*, Ottawa, April 30, 1994.

other, subjective criteria, such as "the economic feasibility of the proposal, the effects on the telecommunications industry and industry concentration."² Not only are some of the criteria vague, but the weights assigned to the different criteria are unstated. It is hard for applicants to determine the basis for the government's decision. The winner, it often seems, is the firm that has hired the most effective lobbyists. The government does not explain to losing applicants why they did not receive licenses. The lack of transparency can be self-defeating. If applicants do not know what the government wants them to offer, they cannot offer it.

Most of Asia, including Japan, Singapore, Hong Kong, and South Korea, assigns the spectrum by administrative processes. Japan used a remarkably decentralized method for allocating radio-broadcast licenses in the 1950s. Although the law said the license should go to the applicant judged to contribute most to the public welfare, in practice the decision was delegated to the industry. Government officials told the contending firms to bargain among themselves to decide which of them should be awarded the license. Formal comparative hearings were then unnecessary, as there was only one applicant. For mobile-telecommunications licenses in 1988, when two firms were contending to enter to compete with the incumbent NTT, the Ministry of Post and Telecommunications (MPT) tried the same procedure: it asked the two firms to unify, so it would receive only one application. This time, however, the attempt to delegate the regulatory process failed, as the firms were unable to come to terms on a joint application. The MPT was forced to make the decision. It assigned the two firms to different regions.³

² The description of the Canadian procedure is in Benzoni, Laurent, and Kalman, Eva, *The Economics of Radio Frequency Allocation*, Paris, OECD, 1993, p.182. The allocation criteria are stated in Industry Canada, *Industry Canada's Three-Phase Selection and Radio Licensing Process*, Ottawa, April 30 1994, p.2.

³ Weinberg, Jonathan, "Broadcasting and the Administrative Process in Japan and the United States," *Buffalo Law Review* 39, Fall 1991, 615-735; Upham, Frank, "A Tentative Model of Japanese Regulatory Style," unpublished, NYU Law School, Sept. 1994; Nagai, Susumu, "Japan: Technology and Domestic Deregulation" in *Telecommunications in the Pacific Basin*, edited by E. Noam, S. Komatsuzaki, and D. A. Conn, New York, Oxford University Press, 1994.

The United States used to hold administrative hearings to allocate cellular-telephone licenses. The hearings were cumbersome: sometimes they would drag on for over a year. Glen O. Robinson, a former member of the Federal Communications Commission (FCC), described them as "the FCC's equivalent of the Medieval trial by ordeal."⁴ The delays were costly to the applicants, to the government, and ultimately to the public in services lost. The backlog of unassigned cellular licenses by 1982 forced Congress to replace the administrative hearings with an allocation method that worked more quickly and economically. It chose lotteries.

Lotteries have been rejected by the Canadian government because they would attract "frivolous applicants and speculators," and there is "no way to ensure the successful applicant's technical competence to develop, maintain and operate a public radiocommunications service."⁵ The United States experience of allocating cellular licenses by lottery during the 1980s bears out the Canadian analysis. 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. Many of the applicants lacked the technical expertise to run a cellular-telephone service. In one not atypical case, an obscure group called the RACDG partnership won by lottery the right to run cellular telephones on Cape Cod; later, the partners sold their license to Southwestern Bell for \$41 million. Assigning licenses at random is hardly likely to put licenses into the hands of the firms able to make the best use of them. Resale of the licenses on the secondary market might achieve this, but at the cost of delays and revenue lost to the government.

The first-come-first-served method is used by members of the European Union, for example, to allocate licenses for private mobile radio. First come first served, like a

⁴ Quoted by Kwerel, Evan R., and Felker, Alex, "Using Auctions to Select FCC Licenses," OPP Working Paper No.16, FCC, May 1985, p.3.

⁵ Benzoni and Kalman, 1993, *op. cit.*, p.181.

lottery, has the advantage of working quickly, but has the same random character and the same disadvantages as a lottery.

The US lotteries were widely agreed to be a failure, and in 1993 Congress decided to switch to auctions for the new mobile-communications licenses. Auctions achieve several purposes, as I shall discuss. An auction can both achieve an efficient allocation--that is, assign the licenses to the firms able to make the best use of them--and raise revenue for the government--an important consideration in an age of government deficits. The government can also design the rules of the auction to address various policy goals, such as avoiding monopoly and directing licenses to minority-owned firms.

Auctioning Reveals License Values

The government needs to know how highly the firms value the licenses if it is to allocate licenses to firms efficiently. A bid reveals, approximately, the bidder's valuation of the license. The bid underestimates value, since the bidder is bidding for some profit. Bids are quite close to values, however, if (a) there are enough bidders to generate significant bidding competition; and (b) bidders are reasonably confident of the precision of their value estimates.⁶ An auction, therefore, is not just about raising money. An auction serves a similar purpose to comparative hearings, in that it reveals information: how valuable the bidders believe the license to be, and which bidder values it the most. As the FCC puts it, "since a bidder's ability to introduce valuable new services and to deploy them quickly, intensively, and efficiently increases the value of a license to that bidder, an auction design that awards licenses to those bidders with the highest willingness to pay" promotes the efficient use of the spectrum.⁷

⁶ As the theory of auctions shows: Wilson, Robert B., "A Bidding Model of Perfect Competition," *Review of Economic Studies* 44, Oct. 1977, 511-518; Milgrom, Paul, and Weber, Robert J., "A Theory of Auctions and Competitive Bidding," *Econometrica* 50, Sept. 1982, 1089-1122.

⁷ FCC, "Third Report and Order," Washington, DC, May 10 1994, p.6.

The social value of a license, to a first approximation, is equal to the most efficient firm's valuation of it. This statement needs careful qualification. If there are externalities associated with holding a license--that is, some of the costs and/or benefits of the firm's activities fail to be reflected in prices--then social value is not the same as private value. Furthermore, if the firm acquires some monopoly power upon obtaining the license, social and private values diverge. These caveats are specific and quantifiable. If they are important, these effects can be estimated and added to private values, as revealed by the bids, to produce an estimate of the social value of the license. If the externalities are small or nonexistent, on the other hand, the bids themselves represent social-value estimates. In either event, the bids reveal useful information. In the case either that externalities are small or that they are of a similar size across the different firms, the high bidder is the efficient firm--that is, the firm that, from a social point of view, should hold the license--and so the auction process picks the right firm.

Auctions are quicker and more economical than administrative allocation. The FCC has estimated that the cost of assigning cellular licenses--the sum of the firms' costs of filing their applications, the government's administrative costs, and the public's losses from delayed services--is six times higher for administrative hearings than for auctions. Some time and effort are needed initially in designing the auction rules, but once in place the auction assigns licenses smoothly, as the New Zealand spectrum auctions illustrate.⁸

Auctions, unlike administrative hearings, are transparent. Auctioning forces the government to be explicit about its criteria, since in an auction the rules must be stated fully in advance. After the auction, the applicants know why they won or lost. In this sense, auctions are more fair than administrative allocation. The openness of auctions

⁸ The New Zealand auctions performed badly in raising revenue, but did succeed in assigning licenses to firms quickly and with low administrative costs: see Mueller, Milton, "New Zealand's Revolution in Spectrum Management," *Information Economics and Policy* 5, 1993, 159-177. The FCC cost comparison comes from Kwerel and Felker, *op cit.*, p.20.

can prevent the suspicion of undue influence, impropriety, or even corruption that sometimes arises when decisions involving large sums of money are made behind closed doors. In France's 1994 administrative decision on who would be its third supplier of mobile telecommunications services, for example, the government's decision was ostensibly to be based on the firms' technical proposals and investment plans. "The project which is the most viable on these criteria," said an official, "will be the one selected." In fact, the decision went up to the prime minister, Edouard Balladur, who had to choose among three companies each of which had political clout: Lyonnaise des Eaux, whose chairman used to be a senior official in Mr Balladur's Gaullist RPR party; Alcatel Alsthom, one of France's largest industrial groups, at that time suffering some financial difficulties; and Bouygues, among other things the operator of France's leading television channel ("a far from negligible asset in a pre-election period," noted the newspaper *Libération*). The license went to Bouygues. In South Korea's 1992 administrative decision over a cellular license, the winner, the Sunkyong group, whose chairman happened to be related to President Roe Tae-Woo, relinquished its license in the face of a scandal following allegations by the unsuccessful applicants of government favoritism.⁹ If auctioning had been used in these cases instead of the administrative decision-making, controversy could have been avoided.

Auctions Are a Public-Policy Tool

Auctions can do more than raise revenue and generate an efficient match of licenses to firms. Auctions are a flexible policy tool. The government need not run an auction simply as high-bidder wins, but instead can use it to address a variety of policy

⁹ On France: *Financial Times*, Sept. 23 1994, p.2, and Oct. 6 1994, p.24. On Korea: Galbraith, Mike, "Better Services in the Pipeline as Deregulation Quickens," *Asia-Pacific Telecommunications*, 6, Dec. 1993, pp.10-11, and "Sunkyong Fulfills Cellular Dream," *Asia-Pacific Telecommunications*, 7, Mar. 1994, p.1.

goals. The countries using spectrum auctions have adopted a range of criteria for awarding licenses.

If the government wants to redress past wrongs by assigning some of the licenses to minority-owned and women-owned firms, it can design the auction to account for this, in several ways. It can set some licenses aside, and permit only the designated firms to bid on them. Further, it can give the designated firms a price preference, under which a designated firm wins the license if its bid is within some set amount of--say, no more than 10 percent below--the highest nondesignated-firm bid. The US spectrum auctions use both of these methods to ensure some licenses go to minority-owned firms, women-owned firms, small businesses, and rural telephone companies. In the auctions for narrowband spectrum the designated firms were offered up to a 40 percent preference, so if they won a license they paid 40 percent less than their bid. In addition, the designated firms were allowed to pay in installments. In the broadband auctions, 30 megahertz of spectrum, one-fourth of the spectrum on offer, is set aside for the designated firms. FCC chairman Reed E. Hundt said this is "the single most important economic opportunity made available to women and minorities in our country's history."

Still other public-policy goals can be addressed while using auctions. If the government judges that the market system does not sufficiently reward technological innovation, it can offer incentives to innovators similar to the set-asides or preferences for designated firms. The United States, for example, offers pioneer preferences, under which the government rewards a firm it judges to have made a crucial innovation by awarding it a license at a reduced price.

The government can guard against monopolization by imposing rules limiting the amount of spectrum within a given geographical region that a single firm may hold, as the United States does. Even without such a safeguard, auctions automatically help prevent undue industry concentration, for it is usually easier for new firms to enter the telecommunications industry under auctions than under administrative processes. When

the Hong Kong government announced the creation of new mobile-communications licenses and proposed simply inviting the four existing cellular operators to take up the new licenses, critics claimed the government's proposals could "perpetuate an unofficial price-fixing cartel." Auctions would result in a more competitive telecommunications market, the critics said, because they would allow new players in. India introduced auctioning specifically to lower entry barriers and to encourage new firms to provide telecommunications services.¹⁰

If the government wishes to ensure local ownership and control of the telecommunications industry, it can reserve some or all licenses for domestically owned firms. Alternatively, the government could promote domestic control by offering a price preference to domestic bidders over foreign bidders (similar to the Canadian government's policy in procurement tenders, in which a foreign firm must outbid a Canadian firm by at least 10 percent to win a contract). In the United States, according to the Communications Act of 1934, a firm holding a license must be at least 80 percent US-owned. The government of Colombia, when it auctioned cellular licenses, imposed a particular ownership pattern by offering two licenses per region and specifying that only firms that were majority state-owned could bid for one of the licenses. Also, all the bidders for the other, private-sector licenses were consortia that included both foreign telephone companies and Colombian interests.

Universal access--the provision of services to small and remote communities--can be achieved by writing rules requiring the firms to offer service to the remote locations. Auctioning requires simply that the rules be set in advance so that the firms understand at the time of bidding what the government will require of them should they win. Argentina adopted an extreme solution to the universal-access problem in its 1993 cellular-license

¹⁰ On Hong Kong: Ingelbrecht, Nick, "PCN Proposal Favours Existing Operators," *Asia-Pacific Telecommunications*, 7, Mar. 1994, p.3. On India: Nadkarni, Shirish, "India Licences to Go under the Hammer," *Asia-Pacific Telecommunications*, 6, Nov. 1993, p.2.

auction. The competition was not over price, but over which bidder could provide cellular-telephone service across a vast area of Argentina's countryside in the fastest time. A consortium including GTE and AT&T won by promising to set up the cellular service in only one month.

Any criterion used in the awarding of licenses by administrative hearings can also be used within the auction method, provided only that that criterion is capable of being stated explicitly and precisely, and is announced before the auction. Auctioning is consistent with managed competition.¹¹

Flawed Arguments Against Auctioning

Certain flawed arguments against auctioning arise repeatedly. Two of them go as follows. (These happen to come from Canada's Department of Communications, but they are standard and could have come from other countries' spectrum regulators.) First, auctions "eliminate our discretion in the selection process and diminish our capabilities as spectrum managers." Second, "the concept of 'owning' spectrum is not consistent with [the] principle of 'leasing' and can lead to problems if decisions are subsequently made to recover and reallocate the spectrum."¹² The first of these arguments misses a crucial point, and the second is simply wrong.

In an auction, the rules must be stated in advance. It is correct, therefore, to say that auctions eliminate the government's discretion, in that they prevent the government from awarding licenses on unannounced criteria, or from changing the criteria in the middle of the process. Auctions do not prevent the government, however, from imposing

¹¹ The theory of auctions as a public-policy tool is developed by McAfee, R. Preston, and McMillan, John, *Incentives in Government Contracting*, Toronto: University of Toronto Press, 1988, Ch.9; and McAfee, R. Preston, and McMillan, John, "Government Procurement and International Trade," *Journal of International Economics* 26, May 1989: 291-308.

¹² Responses to a 1992 OECD questionnaire: Benzoni and Kalman, *op. cit.*, 1993, pp.181-182.

whatever selection criteria it wants. The government can design the auction, as noted earlier, to favor certain kinds of firms, to reward innovators, to prevent monopoly, to ensure domestic ownership, and so on. Auctioning merely requires the government to say clearly and precisely what the criteria are, and to stick to them. Auctions reduce the scope, in other words, for arbitrary bureaucratic decisions. Auctions do indeed eliminate some government discretion. In an open society, however, that kind of discretion should be eliminated.

The second argument, equating auctioning with ownership of the spectrum, rests on a misconception. There is no reason why auctioning leads to ownership. Introducing auctions need not in any way change the property rights associated with a license. What the US government, for example, is auctioning is not the spectrum, but spectrum *rights*, as the legislation is careful to specify.¹³ The same restrictions on spectrum usage apply under the auctions as applied when the licenses were allocated by administrative process; the license lasts for the same number of years as before; and the same provisions under which a license-holder forfeits its license for improper use or hoarding remain in force. The United States limited its switch to auctions, moreover, to licenses for paging and personal communications services; it does not auction broadcasting licenses. Introducing auctioning does not change what is being allocated; all that changes is the method for deciding who receives it.

A case may well exist for rethinking the fundamentals of spectrum property rights, as New Zealand and Australia have done. The choice among alternative uses for the spectrum, for example, could be made by market methods instead of being dictated by the government. Whether to use a particular wavelength block for, say, cellular-telephone or paging services could be decided according to the relative values of the alternative uses, as revealed by the potential user-firms' bids. The current nonmarket

¹³ US Congress, Omnibus Budget Reconciliation Act of 1993, Conference Report [HR 2264], Title VI, "Communications Licensing and Spectrum Allocation Improvement," Report 103-213, Aug. 4, 1993.

methods for deciding the uses of the spectrum probably result in inefficient uses: according to one estimate, "permitting just one ultra-high-frequency television station in Los Angeles to voluntarily use its assigned spectrum for cellular telephone service could increase net social welfare by over \$1 billion." In France, also, it has been estimated that spectrum has a much higher value when used for cellular-telephone services than when used for television.¹⁴ The broader issue of what spectrum property rights mean, however, is separable from the narrower issue of how to decide, given the property rights, which firms should receive licenses. Auctioning licenses does not in itself necessitate any change in property rights.

The spectrum should be given away and not auctioned, some say, because auctioning must increase the price that telephone-service customers ultimately pay. As the European Union's Green Paper on mobile communications puts it, auctions have "the danger of excessive transfers to the public budget or for other purposes, to the detriment of low tariffs for the users."¹⁵ To argue this, however, is to confuse fixed and variable costs. A firm that cares about profits bases its price on its marginal cost: that is, the cost of supplying one additional unit of the service. The auction price is paid before any service is provided--it is a fixed cost--so is not part of the marginal cost of supplying the service and does not affect the price charged to customers. There is a caveat to this fixed-cost argument. If capital-market frictions mean that the more the firm borrows, the higher the interest rate it must pay, then the extra debt added by the auction price could

¹⁴ The estimates are from Kwerel, Evan R., and Williams, John R., "Moving toward a Market for Spectrum," *Regulation* 16, 1993, 53-62 (the quote is from pp.53-54), and Benzoni, Laurent, and Kalman, Eva, "The Economics of Frequency Spectrum Allocation," unpublished, France Télécom, Oct. 1994. Using the market to allocate spectrum to alternative uses was advocated long ago by Coase, R. H., "The Federal Communications Commission," *Journal of Law and Economics* 2, Oct. 1959, 1-40. On the deeper reform of spectrum property rights, see Mueller, *op.cit.*; Mueller, Milton, "Technical Standards: The Market and Radio Frequency Allocation," *Telecommunications Policy* 12, Mar. 1988, 42-56; Traylen, Jeremy, "The Radiocommunications Act: Some Key Issues," unpublished, Victoria University, New Zealand, June 1994; and Bureau of Transport and Communications Economics, *Management of the Radio Frequency Spectrum*, Canberra, Australian Government Publishing Service, 1990.

¹⁵ European Commission, *op. cit.*, p.26.

result in the firm's investing less and having a higher marginal cost. It seems unlikely, however, that this is a large effect. This caveat aside, the auction revenue is a pure transfer from the firm's profits to the government. The price to users would be the same whether the government sold the spectrum or gave it away.

In practice, because of the way the politics of spectrum allocation work, auctioning tends not to raise but to lower the price of the final services. Most governments that allocate the spectrum administratively do so in such a way as to restrict competition, promoting the interests of the incumbent firms over those of consumers. If administrative processes allow competition at all, they allow only two or three competitors into the market. Auctioning lowers entry barriers and brings increased competition. The US auctions will add, in each region, three to five new suppliers of mobile telephone services to the existing cellular suppliers, resulting in stiffer competition and lower prices.

A moralistic argument against auctioning is sometimes made. The government should not sell spectrum rights because the spectrum is a public resource, which should, as of right, be freely available. As a French opponent of auctioning put it, "the spectrum belongs to the public domain and therefore cannot have a price."¹⁶

Reality undermines this claim. The spectrum, being in limited supply, ends up having a price attached to it indirectly if not directly. Even when the initial allocation is by administrative process, the final allocation of spectrum to user-firms is often via the market: either by the purchasing of licenses in the secondary market (as in the United States), or by the buying of firms to obtain their licenses (as in Canada and the United States). Since many of the given-away licenses are eventually sold, the question in practice is not whether they should be sold but whether the government or a firm should receive the money. Even when the firm that is assigned the license is the firm that

¹⁶ Quoted by Benzoni and Kalman, 1993, *op. cit.*, p.106.

ultimately puts it into use, there is still an implicit price associated with the license. This implicit price can be strikingly high. Spectrum access, it has been estimated, accounts for almost a half of the selling price of a US television station, and for over a half of the market value of a British cellular-telephone company. The US Department of Commerce has calculated that the cellular-telephone licenses that the government gave away during the 1980s boosted their recipients' stock-market values by a total of \$46 billion.¹⁷ Spectrum rights do have a price, even when they are given away.

The public-resource argument is a two-edged sword. Precisely because the spectrum is a valuable public resource, it could be argued, it is unfair that it be given away to a few fortunate recipients. The beneficiaries of the spectrum give-away are large corporations. Ordinary people pay for this largesse, for if the government auctioned spectrum rights, the proceeds would go into the public coffers instead of corporate profits.

Auction Design

Auction design matters. Failures of auction design can result in the wrong firms receiving licenses or in the government missing out on revenue. The rules of the auction must not have gaps, for bidders will seek ways to outfox the mechanism. Modern economic theory has studied the design of auctions. 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 decide their bids, not knowing the value of the item for sale and not knowing what their rivals know; and

¹⁷ The US television estimate is by Levin, H. J., "Economic Effects of Broadcast Licensing," *Journal of Political Economy* 72, April 1964, 153-155; the British cellular estimate is by Benzoni and Kalman, 1994, *op. cit.*; and the US cellular estimate is in US Department of Commerce, *U.S. Spectrum Management Policy: Agenda for the Future*, Washington, DC, NTIA, 1991, p.D6.

what the seller can do to stimulate the bidding competition, not knowing how much the bidders are willing to pay.¹⁸

The FCC used the theory, and the theorists, during 1993 and 1994 in designing the US spectrum auction. Theory helped to address the key questions of auction design: the so-called winner's curse and license aggregation.

The winner's curse refers to the fact that the winning bidder is likely to be the firm that has the most overoptimistic estimate of a license's value. Anticipating the winner's curse, bidders bid cautiously. An open auction, in which bidders get indirect information of their rivals' value estimates through their bids, softens the effect of the winner's curse and induces more aggressive bidding than in a single-round sealed-bid auction. Given how complicated the bidders' decision are, however, it was judged necessary to slow the auction down somewhat, to give the bidders time to process information and to consult their headquarters. The theorists' recommendation, therefore, was to use a multiple-round auction, with the results of the previous round announced before the next one begins.

The licenses are interdependent. Firms trying to build a regional or nationwide presence may have to purchase several licenses. The licenses complement each other; the value of an aggregation of licenses may exceed the sum of the values of the separate licenses. The auction form must be flexible enough that bidders are able to construct their preferred license aggregations. To achieve this flexibility, the theorists recommended a novel auction form: a simultaneous auction (devised by Paul Milgrom and Robert Wilson of Stanford University and Preston McAfee of the University of Texas, Austin). Instead of selling the licenses in sequence, one by one, the licenses

¹⁸ For surveys of auction theory, see McAfee, R. Preston, and McMillan, John, "Auctions and Bidding," *Journal of Economic Literature* 25, June 1987, 699-738; Milgrom, Paul, "Auction Theory," in Bewley, Truman, ed., *Advances in Economic Theory*, Cambridge: Cambridge University Press, 1987, pp.1-32; Milgrom, Paul, "Auctions and Bidding: A Primer," *Journal of Economic Perspectives* 3, Summer 1989, 3-22; and Wilson, Robert B., "Strategic Analysis of Auctions," in Aumann, R. J., and S. Hart, eds., *Handbook of Game Theory with Economic Applications*, Vol. 1, Amsterdam: North-Holland, 1992, pp.227-280. On auction theory's practical content, see McMillan, John, *Games, Strategies, and Managers*, Oxford: Oxford University Press, 1992, Chs. 11-13.

would all be open for bidding at the same time; and all the licenses would remain open until bidding ceased on all of them.¹⁹

The FCC addressed the license complementarities and the winner's curse by adopting the multiple-round simultaneous auction. The first two implementations of this auction form in July and October 1994, selling thin slivers of the spectrum for paging services, were a spectacular success.²⁰ The narrowband licenses sold for a total of over \$1 billion (more than \$3.00 per megahertz per person), far above most prior estimates. The bidding data show that the multiple-round simultaneous auction served both to stimulate the bidding competition and to allow the bidders to build efficient license aggregations.

Conclusion

Auctions work better than the other spectrum-allocation methods. Auctions

- are transparent and fair;
- generate revenue for the government;
- reveal the firms' estimates of license values;
- assign licenses to firms quickly and economically;
- can be designed to incorporate a wide range of public-policy goals.

¹⁹ For more on the designing of the US spectrum auction, see McMillan, John, "Selling Spectrum Rights," *Journal of Economic Perspectives* 8, Summer 1994, 145-162.

²⁰ Auctions of a further 120 megahertz of broadband spectrum for personal communications services run from December 1994 through the first half of 1995.