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Auctioning The Airwaves:

The Contest for Radio Spectrum

by

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1. Introduction

A recently enacted amendment to the Communication Act of 1934 directs the FCC to establish a system for using auctions to allocate the use of radio spectrum for a new generation of wireless communications called PCS (personal communications services).[1] The legislation is revolutionary in its proposed use of auctions as a mechanism to more efficiently allocate the use of this scarce national resource and for raising funds to reduce the national deficit.[2] The auctioning of radio spectrum raises a unique and unprecedented set of economic and public policy issues that are key to achieving the goals set forth in the legislation. Many of these issues concern policy makers not only in the U.S., but also in other countries, such as Canada, which plan to allocate spectrum in the near future. The purpose of this paper is to discuss these issues and to evaluate their likely impact on the outcome of the spectrum auctions.

The spectrum auctions are important because of their potential impact on the evolving market for Personal Communication Services (PCS). These services will introduce new mobile telecommunications technologies in the 2 GHz band, that will permit access to a variety of voice, data, and video communications services, using small, lightweight wireless telephone handsets, wireless computer networks, portable fax machines and other graphic devices.[3] The spectrum auctions are also important because the deployment of PCS may have a significant impact on the demand for

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[1] The amendment was enacted on August 10, 1993, as part of the Omnibus Budget Reconciliation Act of 1993, which added a new section 309(j) to the Communication Act of 1934 (as amended, 47 U.S.C. §151-713, Communication Act).

[2] The Congressional Budget Office (CBO) estimates that the auction could raise $1.3 billion to $5.7 billion (see *Auctioning Radio Spectrum Licenses*, CBO study, released on March 1992).

[3] PCS is distinguished from the currently available cellular services by its use of low-powered handsets, and smaller cell sites, thereby making the PCS handset more portable and less expensive.

in designing the auction procedures if the legislative objectives are to be accomplished. One critical issue is the design of the auction format. Auctions can be conducted on a sealed-bid basis or on an open-outcry basis in either Dutch format (i.e., descending-price auction which is used in Holland to sell tulips) or English format (i.e. ascending price auctions). The use of spectrum could be awarded to the highest bidder at a price representing the highest bid (in a first-price auction), the second highest bid (in a second-price auction), or possibly as a more complicated function of all bids. Different auction formats present bidders with different optimal bidding strategies, and possibly with differing abilities to influence the outcome of the auction. From a public policy perspective, a well designed auction format should lead to an efficient outcome, i.e., the spectrum should be awarded to the most qualified bidder(s), and bidders should be deterred from engaging in socially wasteful attempts at market manipulation. At the same time, a key argument in favor of auctions, as opposed to comparative hearings or lotteries, is their ability to raise significant revenues. Hence, the revenue generating capabilities of different auction formats is also an important consideration.

A second issue to be considered relates to the number of licenses to be granted and the geographical area (i.e., local or national) to be covered by each license. The FCC plans to allocate a total of 120 MHz across the U.S. for licensed PCS services, which is three times the spectrum originally allocated for cellular services. The licensed allocation in each geographical service area has been channelized into seven blocks: two 30 MHz channel blocks, one 20 MHz channel block and four 10 Mhz channel blocks. The service areas adopted have been designated as Major Trading Areas (MTAs) for the two 30 Mhz channel blocks and Basic Trading Areas (BTAs) for the remaining channel blocks.[5] There are 51 MTAs and 492 BTAs under the FCC's plan, implying that the total

[5] The MTAs and BTAs are generally defined by the Rand McNally 1992 Commercial Atlas and marketing guide 123rd Edition. Their boundaries are been drawn on a county-line basis and they take account such factors as physiography, population distribution, newspapers circulation, economic activities, highway facilities, railroad service, and suburban transportation.

expenditure on such acquisitions would be offset by the enhancement of the spectrum's value.

A fifth issue relates to the FCC's concern for small businesses and entrepreneurs being able to compete for a share of the market. Fairness and equity considerations can be accommodated by permitting such participants to form coalitions that will submit joint bids for licenses, or by providing them with special financing schemes that will allow them to defer license fee payments in case they win. Such arrangements, however, may have conflicts with economic efficiency considerations, especially since small firms may be riskier than large firms in terms of their ability to successfully deploy capital intensive technologies and develop new services.

Finally, there is an issue of standardization. There are alternative digital technologies that could conceivably be deployed. The principal rivals are CDMA (Code Division Multiple Access), and TDMA (Time Division Multiple Access).[6] These technologies, however, are mutually incompatible and devising a handset that can operate on both is currently not cost-effective. It has been suggested, therefore, that some pre-auction coalition-formation be permitted to enable potential licensees to agree on a single standard.

The remainder of the paper is organized as follows. Section 2 presents the general framework that economists use to evaluate different auction procedures and bidding strategies. In Section 3, we discuss a number of economic and public policy issues which need to be taken into account in designing the auction procedures such that the legislative objectives are accomplished. In Section 4, we show that there are several pitfalls in the auction procedure proposed thus far by the FCC. We recommend certain modifications to the FCC's proposal to avoid these pitfalls. Finally, in Section 5 we offer concluding remarks.

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[6] Under CDMA, by utilizing different codes, multiple users can occupy the same spectrum at the same time; all receivers see all signals but retrieve only the desired signal by using the appropriate code. Under TDMA, all users use the same channel but at different time slots. For more details about the debate regarding the two competing technologies see "TDMA vs. CMDA: The great digital cellular debate." *Telepony*, January 10, 1994, pp. 16-24.

pays. An outcome is said to be *efficient* if the object is allocated to the bidder who values it the most. The outcome of the auction determines the *payoffs* of the seller and of each bidder. A *Bayesian Nash equilibrium* is a collection of strategies satisfying a "self enforcing" property that requires that given the strategies of the all other bidders, no single bidder could improve his payoff by unilaterally changing his strategy. The seller's problem then is simply to compare equilibrium outcomes across auction procedures and pick the one that maximizes his objective.

In order to bid successfully in the spectrum auction, each bidder must base his bid on his "valuation" of spectrum being auctioned. Computing such a valuation could be a rather complicated task. An easy answer is that it be set equal to the present discounted value of the future stream of earnings from PCS. Quite apart from the inherent uncertainties related to predicting the demand for PCS, the radio technologies, network architectures and the associated costs, there are several other factors that could complicate this task. First, it matters who the other winners are, whether they currently offer local exchange, cellular telephone or cable T.V. services in the geographical area which the license covers and what services they intend to offer in the future. Second, future alliances, mergers and re-sale of licenses, as well as the extent of regulation and the intensity of competition in the market must be anticipated. Third, bidders should be aware of the possibility that future administrations may decide to auction additional spectrum. Moreover, even if the government could commit not to issue additional licenses, emerging digital technology may result in new competitors offering close substitutes for PCS.[8] Finally, the value of a license is also affected by the presence of incumbents in the parts of the spectrum that the license encompasses. The winner's projection about the negotiation process with the incumbent must also be factored in.

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[8] A case in point is the cellular communications market, in which Nextel Communication Inc. has purchased spectrum from taxi operators, and by using digital technology, has constructed a third cellular network in six major markets.

In practice, there are a variety of auction formats, the most prominent of which include first-price and second-price, sealed-bid auctions, a Dutch auction (descending-price, open-outcry auction), and an English auction (ascending-price, open-outcry auction). In sealed-bid auctions, each bidder submits a confidential bid, and the object is awarded to the highest bidder. The winner pays a price equal to his own bid in a first-price auction, but pays a price equal to the second-highest bidder's bid in a second-price auction. In open-outcry auctions, an auctioneer calls out prices to all bidders. In a Dutch auction, the auctioneer starts the price high and lowers it until some bidder claims the object. In an English auction, the auctioneer starts the price low and raises it, stopping when only one bidder remains.

On the surface, these four auction formats seem quite different. For example, a naïve comparison of these formats may lead a bidder to believe that he would be better off winning a second-price auction than a first-price auction -- after all it is preferable to pay the second highest bid rather than the highest one. This argument, however, misses a simple, yet subtle, fact: bidders behave differently under different auction formats. For example, in a second-price auction, bidding one's valuation is a *dominant strategy* i.e., it is the best the bidder can do regardless of the actions of others. This is because bidding higher than the true valuation would mean running the risk of paying more than the object is worth, while bidding less would only reduce the chances of winning, without affecting the price paid in case of winning. In a first-price auction, in contrast, bidders shade their bids below their valuations. Although this means that bidders may eventually lose the object, it also ensures them a lower payment in case of winning. In general, the fact that bidders behave differently in different auction formats leads to a remarkable conclusion, due to Vickery (1961):

The Revenue Equivalence Theorem: *When a single object is auctioned, bidders are symmetric, risk-neutral, and have independent private values, and the normalization assumption holds, the expected revenue of the seller is the same regardless of the auction format used, provided that the outcome of the*

then resold to others. This is likely to occur in the spectrum auction since some of the initial winners may fail to profitably provide the new service, while others may be pure arbitrageurs. In this case, a bidder's willingness to pay will be affected not only by his own valuation, but also by what the object would fetch if it were resold in a secondary market. Since the price in the resale market will depend on the willingness of others to pay, each bidder must take into account all the bidders' values in determining his own bid.

When values are correlated, a crucial phenomenon known as the *winner's curse* can emerge. Consider, for example, a first-price, sealed-bid auction. Paradoxically, winning is not necessarily good news for the winner, because it implies that his bid was higher than everybody else's. Thus, the winner has on average overestimated the value of the object and bid "too much". Or, if values are correlated because of the existence of a resale market, winning would indicate to the winner that, on average, others value the object less than he does, so if he ever wanted to resell it, he would probably lose money. Hence, the "curse" on the winner. The source of the curse is that while each value estimate is unbiased, the highest value estimate is necessarily biased upward. In other words, since the expected value of each e_i is zero, the highest e_i must have a positive expected value.

A crucial implication of the winner's curse is that each bidder should optimally shade his bid, recognizing that, if he wins, his bid would be the highest and may therefore be based on an overestimation of v. Failure to recognize this may prove to be costly: Capen, Clapp and Campbell (1971) suggest that bidders' ignorance of the winner's curse caused enormous over-bidding in offshore oil tract auctions during 1967-1969.[9]

Two important factors reinforce the winner's curse. First, as the number of bidders increases, the highest e_i is more likely to be high, so the likelihood of overbidding increases. Second, an increase in the uncertainty regarding the value of v will have a similar effect since it makes it more

[9] Additional evidence (both from experiments and from field data) is surveyed in Thaler (1988).

auction process.[10]

2.4 Asymmetric Bidders

Bidders in spectrum auctions are expected to have asymmetric information regarding the value of licenses across geographical areas. This is because bidders who currently operate in the geographical area covered by a license, either as local exchange carriers or as cellular services providers, may have better information about the demand for PCS in that particular area.

In general, the theory is ambiguous if bidders are asymmetric in the sense that their valuations are drawn from different distributions.[11] The source of this ambiguity is that it is no longer true that all auction formats are efficient. Hence, revenue equivalence breaks down. To see why, note first that in an English auction it is still optimal for each bidder to remain in the auction until the price exceeds his own valuation. Consequently, the English auction remains efficient even when bidders are asymmetric. This, however, is not necessarily the case for other auction formats. For example, an optimal strategy for a bidder in a first-price sealed-bid auction is to shade his bid by his estimated gap between his own valuation and the second highest valuation conditional on his own valuation being the highest. But, when valuations are drawn from different distributions, this estimated gap will be different across distributions, so the bidder with the highest valuation need not win the auction.

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[10] In practice, first-price, sealed-bid auctions are often used. There could be several explanations for using this format, which from the seller's point of view is apparently inferior. First, open-outcry auctions are more susceptible to "principal-agent" problems than sealed-bid auctions, because bidders are typically represented by agents, who may be operating with a limited set of instructions, and under enormous pressure. Moreover, communication between the principal and agent is limited; hence, mistakes can be made, which could work against the efficiency objective of the FCC. Second, as we explain in Section 2.7 below, English auctions are more susceptible to collusion than first-price sealed bid-auctions.

[11] In fact, even computing the equilibrium strategies in this case may be very hard. Marshal et al. (1992) propose numerical algorithms for solving bidding strategies in first price auctions for specific kinds of distributional asymmetry of bidders.

2 is willing to pay 9 to have at least one unit, bidder 1 will also have to bid 9 in the first round in order to win. Therefore, in order to win both objects, Bidder 1 has to pay a total of 18, leaving him with a payoff of 20 - 18 = 2. On the other hand, if bidder 1 loses the first unit, then he can win in the second round by bidding 1, which is the most that bidder 2 is willing to pay for a second unit. The payoff of bidder 1 in this case is 10 - 1 = 9. Bidder 1 is therefore better-off losing in the first round, since this enables him to win in the second round with a very low bid. In order to win in the first round, bidder 2 has to bid 2, which is the maximum that bidder 1 is willing to bid in this round.[12] The outcome of the auction is such that bidder 2 wins in the first round by bidding 2, and bidder 1 wins in the second round by bidding 1. Thus, the sequential auction yields an inefficient outcome and it raises a revenue of 3 instead of 10 in a simultaneous auction.

Sequential auctions may be inefficient for additional reasons. Hausch (1986) considers a sequential first-price sealed-bid auctions in which the outcome is revealed after each round. He shows that when values are correlated, a high valuation bidder may wish to underbid in the early rounds in order to deceive its rivals into believing that the value of the objects being auctioned is low. This deception has the advantage of softening the competition in late rounds and allowing the deceiver to buy for a low price late in the auction. The cost of this deception is that the high valuation bidder may lose in the early rounds even if his valuations are the highest. Thus, the outcome of the auction need not be efficient. This inefficiency can be avoided by conducting the auction simultaneously.

A related problem with sequential auction arises when bidders have constraints on their total budgets. Then, as Pitchik and Schotter (1988) show, some bidders (presumably, those with deeper

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[12] Let p denote the maximum bid of bidder 1 in the first round. Anticipating a payoff of 9 by losing the first round, and a payment of 9 in the second round if he wins in the first round, bidder 1 will set p such that 20 - 9 - p = 9. Thus, p = 2, so bidder 2 can win the first round by bidding slightly over 2.

can therefore be thought of as reflecting the willingness of risk averse bidders to pay a risk premium.[14,15]

2.6 Risk-Averse Bidders

The discussion in the previous paragraph leads us to the next issue: risk aversion. It has often been argued that large corporate entities are virtually risk-neutral with respect to any single transaction because their size allows them to spread their risks. However, the stakes at the radio spectrum auction are likely to be high even for large corporations because of their potential impact on the evolution of the markets for PCS and the resulting effects on local exchange and cellular telephone markets. Moreover, it must be kept in mind that the bidders in the auction are not the corporations themselves but individuals representing them. Success or failure at the auction could have a significant impact on the compensation and career prospects of these individuals. Therefore, we would expect bidders at the radio spectrum auction to be risk-averse.

When value estimates are correlated, a comparison of the seller's revenue across different auction formats yields ambiguous results (Milgrom and Weber, 1982a). In the independent private-values context, however, risk-aversion implies that the seller's expected revenues are higher in a first-price (discriminatory) auction than in a second-price (uniform price) auction (Harris and Raviv, 1981, Riley and Samuelson, 1981, and Maskin and Riley, 1984). The reason is that submitting one's true valuation remains a dominant strategy in the second-price (uniform price) auction. But, Thus, in a first-price (discriminatory) auction, in contrast, risk-averse bidders are willing to pay more than risk-neutral bidders to avoid the loss from failing to win the object.

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[14] For an alternative explanation for the afternoon effect observed by Ashenfelter, see Black and De Meza (1993).

[15] McAfee and Vincent show that under standard assumptions on risk aversion, the only symmetric equilibria in their model involve mixed strategies. Consequently, the outcome need not be efficient.

since the designated winner would actually have to pay his own high bid.[18]

In auctions of multiple objects, similar considerations apply. Thus, the above discussion suggests that collusion may be harder to sustain in discriminatory auctions (which are analogous to first-price auctions) than in uniform-price auctions (which are analogous to second-price auctions).

There are two important caveats to the above arguments. First, the arguments require that all valuations are common knowledge among the cartel members, i.e., there is no private information within the cartel. Second, if there is a large number of bidders, then, setting up, and enforcing, collusive arrangements among them would be very hard.

2.8 Information Acquisition

In English auctions, an optimal strategy for a bidder is to stay in the auction so long as the price is below his valuation. Thus, acquiring information in advance about the willingness of others to pay has no value. In sealed-bid or Dutch auctions in contrast, each bidder shades his bid. The optimal amount of bid shading depends on the bidder's information, so each bidder will have an incentive to devote resources to acquire information. Since this activity merely redistributes payments from uninformed to informed bidders, it has no value to society as a whole. Even worse, the existence of informed bidders drives relatively uninformed bidders away from the auction, and consequently, the seller's revenues tend to be lower. Moreover, as Matthews (1984) and Hausch and Li (1993) show, the cost of acquiring information also reduces the expected revenues of the seller, who indirectly pays these costs. Therefore, in this regard, English auctions have a significant advantage over sealed-bid and Dutch auctions.

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[18] First-price sealed-bid auctions, however, may be susceptible to collusion. Porter and Zona (1993) examine such auctions of contracts for state highway construction on Long Island in the early 1980's. They find support for the hypothesis that a bidding ring was formed in these auctions, such that in each auction one ring member was the designated winner, submitting a serious bid, with the remaining ring members submitting phony high bids.

in general it is impossible to determine which type of licensing system, national or regional, would lead to a more efficient market for PCS and would generate more revenues. The answer depends on the presence of scale economies and issues of standardization, as well as on the bidders' valuations of different regions.

A group of licenses may be more valuable than the sum of individual licenses if there are economies of scale or if technical standards and compatibility issues are important. For instance, a national licensee would have more customers than a regional or local licensees and would therefore be able to lower the per-customer costs of establishing the network, developing databases and advertising. Similarly, a national licensee would be able to adopt a single set of standards and generic requirements, thus enhancing the value of the service to users, and lowering the costs of his equipment. Achieving the same objectives when there are many local or regional licensees would require mutual agreements which may be difficult and costly to obtain.

An auction for a national license might also generate more revenue than an auction for regional licenses if bidders have preferences for particular regions. To illustrate this point, consider a simple example with two bidders, each of which values only one region. If the auction offers the rights to each region separately, then each bidder, realizing that the other bidder is not interested in "his" region, will bid the minimum acceptable amount. But, if the rights to serve the two regions are bundled into a national license, then the two bidders are forced to compete with one another, so the auction will raise more revenues for the government. At the same time, however, a national license will lead in this situation to a less efficient market for PCS, since the winner does not value one of the regions, in which case he may not deploy PCS technology in the most efficient manner. Alternatively, the winner may sell the license to someone else, but such a sale may lead to a delay in the deployment of PCS which the FCC wishes to prevent.

In contrast with the above arguments, it might be argued that an auction for a national license

10 MHz block for PCS, then as Nalebuff and Bulow (1993) argue, there is still a good reason to allow them to participate in the radio spectrum auctions and resolve their ownership conflicts later. The argument is as follows. Under the current rules, cellular providers can switch to PCS (on a large scale) only by divesting their cellular operations before the radio spectrum auction starts and then winning new licenses for PCS at the auction. Clearly, this strategy is extremely risky because it may leave them without any licenses. Thus, in order to increase the number of participants and allow current cellular companies to switch to PCS without taking undue risks, the FCC should lift the restrictions at least on the eligibility of cellular companies to participate in the radio spectrum auction. In addition, the participation of cellular companies in the auction may play a key role in mitigating the winner's curse due to their superior knowledge about the market for wireless communication services.

3.3 Incumbent Spectrum Rights

Some segments of the spectrum to be auctioned are currently being used for different communications purposes by different users, such as electric and natural gas utilities. Some of the existing uses would not be compatible with PCS and may cause interferences. Consequently, it will be necessary to eliminate these potentially conflicting uses of the spectrum. Historically, the government has left it to those granted new uses of the spectrum to clear up conflicts with existing users. Such a benign approach, however, has at least three major drawbacks. First, it complicates the problem of evaluating different spectrum blocks, especially since some blocks are less encumbered by existing users than others. Second, anticipating the need to privately negotiate settlements with existing users, bidders may bid less for the right to use the spectrum. Third, existing users may have an incentive to hold up the winning bidders in the negotiation process in an attempt to extract more surplus. Such attempts could lead to costly delays in the introduction of PCS.

These problems could be avoided if the government were to acquire rights from existing users

and more responsive to customer needs - are also questionable, especially since small firms are often start-ups with little or no experience. Moreover, even if these firms are currently successful, providing services on a large scale may be a very different story. Relying on small firms to provide new services is a gamble, which if unsuccessful, may hurt consumers.

Advocates of small entrepreneurs and firms have noted that if special financing provisions are not made for small firms or if some degree of consolidation of small firms is not allowed, the emerging market for PCS will be swamped by the large established companies with deep pockets. There is a variety of financing schemes that may be offered to small participants to ensure that they are not at a "disadvantage" in the bidding process. Fundamentally, all such schemes allow the participant to defer the payments of the license fee. The payment can either be made via installments or by means of a loan made by the government to the participant, which will be repaid over time. Typically, the interest rate to be applied to such payments is kept artificially low so as to provide the firm an incentive to participate.

From an economic point of view, such schemes have the following drawback. Winning a license is risky, because providing a new service may either turn out to be profitable or may turn out to be a losing proposition. However, the payment schemes discussed above shift the downside risk from the bidder to the government, since the bidder can default on its promised payment to the government if the license turns out to generate losses. Thus, any scheme that defers the payment of the license fee, effectively insures the bidder against losses at the government's expense. As the experience of the S&L's during the 80's has shown, such free insurance presents a strong moral hazard problem. In the case of the radio spectrum auctions, this could manifest itself in the form of overly aggressive bidding. Consequently, small firms may win licenses even if, in fact, they are not among the most efficient providers of PCS, and even if their likelihood of success is small. This effect introduces a distortion into the auction procedure and exposes the government and consumers

4. The FCC proposal

In this section, we provide specific comments on the FCC's Notice of Proposed Rule Making (PP Docket No. 93-253) regarding the implementation of Section 309(j) of the Communications Act. To be sure, designing an auction procedure to achieve the stated goals of the legislation is an extremely difficult task, and, indeed, the proposed set of rules in the FCC's notice are complex. Keeping these complexities in mind, we shall touch upon a small subset of the issues at stake. We begin by outlining several pitfalls in the set of rules that have been proposed, and then, we recommend modifications of the proposed auction procedure to avoid these pitfalls.

4.1 The FCC proposal for a combinatorial auction

One of the main innovative features of the FCC's proposal is the notion of a *combinatorial* auction. Under this procedure, bids are accepted for groups of licenses as well as for individual ones; subsequently, the appropriate aggregation of licenses is determined in a decentralized fashion. This feature is the focus of our comments. The objective of the combinatorial auction is to determine if there are economies of scale and scope and to facilitate aggregation of licenses when such economies do exist.[20] An alternative way to achieve such efficient aggregation would be to allow winners to trade their licenses after the auction ends. This trading process, however, may lead to costly delays in the introduction of PCS which the FCC may wish to avoid.

Specifically, the FCC's proposed procedure works as follows. There would first be a sealed-bid auction for a pre-specified groups of licenses, followed by a sequence of oral (English) auctions for individual licenses. If the highest bid submitted for a group of licenses exceeds the sum of the highest bids for the individual licenses, then the sealed-bid auction becomes "decisive". That is, the

[20] Recall that one of the goals of the legislation is to "promote efficient use of the spectrum." This requires that licenses be aggregated such that all economies of scale and scope would be realized.

licenses. Specifically, we claim that the FCC's proposed procedure is inherently biased in favor of individual licenses, so that efficient aggregation of licenses may not materialize.

The reason for the bias is due to the winner's curse, which causes bidders to shade their bids below their value estimates of the license. We argue that this problem is more severe in the sealed-bid round of bidding. The use of a sequence of auctions conducted through oral bidding in the subsequent round enables bidders to infer relevant information from the behavior of other bidders, thus ameliorating the winner's curse. This in turn weakens the incentive for bidders to shade their bids. Consequently, the auction for individual licenses may be decisive and licenses may be awarded on an individual basis even if this is inefficient.

The use of second-price auctions: The use of second-price auctions has been entertained by the FCC with the expectation that will help elicit true valuations for licenses. There are several reasons to believe that such expectations may be unjustified. First, it must be kept in mind, the truthful revelation property of second-price auctions requires each bidder's valuation for a license to be independent of the valuations of other bidders. This is highly improbable in the case of the spectrum auction, especially given the possibility of resale of licenses.

Moreover, even if the independence assumption were to hold, one still need not expect a truthful revelation of values as the only reasonable outcome. With combinatorial auctions, the winning bids in the sealed-bid auction determine not only the identity of the winner but could also determine <u>which auction is decisive</u> (i.e., whether licenses would be awarded on an individual basis or as a group). As a result, an equilibrium may exist in which bidder 1, say, submits an extraordinarily high sealed-bid, thereby ensuring that the sealed-bid auction is decisive. Given such a high bid, the best-response of others is to bid low to avoid the risk of winning the sealed-bid auction (which is also decisive) and having to pay the extraordinarily high price. These low bids, in turn, imply that bidder 1 will pay a low price for the entire spectrum (recall that in a second-price auction, the winner pays

with a limited set of instructions, and under enormous pressure. Communication between the principal and agent is limited; hence, mistakes can be made, which could work against the efficiency objective of the FCC.

4.3 An alternative auction procedure

Based on the earlier discussion, we now propose an alternative procedure for the spectrum auction. It should be emphasized that, given the huge number of licenses to be auctioned and the fact that their values are interrelated, it may be impossible to find a "perfect" auction procedure. Indeed, we do not claim that our procedure, described below, is perfect. We do believe, however, that our procedure represents a substantial improvement over the current FCC's proposal. Our proposal maintains the FCC's premise that the appropriate extent of aggregation of licenses be determined in a decentralized way. Thus, we take the combinatorial auction framework as given. But, in contrast to the FCC's proposal, our suggested procedure is a *simultaneous*, *first-price* and *electronic* auction.

First, we believe that in order to facilitate an unbiased comparison between the value of individual licenses vis-a-vis that of groups of licenses, the FCC should conduct the two auctions *simultaneously* using *the same auction format*.

Second, from an efficiency standpoint, we should be concerned not only with the question of whether licenses should be owned individually or aggregated into groups, but also with the question of *which* licenses should be grouped together. We believe that bidders should not be forced to place bids on pre-specified groups of licenses. Rather, we suggest that along with bidding for individual licenses, each bidder should be allowed to specify: (i) up to a certain number, k, of groups of licenses (a group of licenses can potentially contain the entire group of available licenses) which he wishes to buy; and (ii) a price for each group. Thus, if there are n individual licenses, each bidder will have to specify in each round of the auction at most n+k bids: n bids for individual licenses and at most

or her bids accordingly. On the other hand, given the administrative costs involved with running the auction and in the interest of a rapid deployment of PCS technology, the auction should not be allowed to proceed for too long. But, due to informational asymmetry, bidders may have an incentive to wait before making serious bids in an attempt to gain as much information as possible. Of course, if everybody adopts this wait-and-see strategy, the auction will never end. To address these issues, we propose that the FCC would set a minimum allowable incremental bid for each license. Such increments could be tied to the number of potential customers in the geographical area covered by the license. Clearly, the increments should be sufficiently high to prevent spurious raises by bidders who are interested in prolonging the auction process, but should not be too high as to choke off the bidding process.[25]

The suggested format in which the auction described above may be conducted is via electronic means. To explain how this might work, we provide the following simple example:

Suppose that there are five individual licenses labelled A,B,C,D and E, and three bidders labelled 1, 2 and 3. Each bidder sits at a computer terminal and enters a bid for each license individually -- a total of five bids (which could include a bid of zero indicating that the bidder is not interested in that particular license). Next, each bidder picks his most desirable grouping of the five licenses and places a single bid for this group. Suppose that bidder 1 chooses the group {A, B, C}, bidder 2 chooses the group {C, D, E} and bidder 3 chooses the group {D, E}. The first round of bids is then posted on everybody's monitor. Subsequently, each bidder has an opportunity to raise his bid on the six bids he submitted in the first round. This new list of bids is posted on everybody's monitor -- and the process continues until no one wishes to raise his bid further.

Suppose that at this terminal stage, the highest bids on each individual licenses is $5M, and

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[25] A similar "stopping rule", using a constant percentage increment over the highest standing bid on each license, has been proposed by Pacific Bell and Nevada Bell in their comments to the FCC.

any manner bidders see fit. It has been argued that bidders with budget constraints may be at a disadvantage in a combinatorial auction. To see how the argument goes, consider the following simple example. Suppose that there are only three licenses, labelled A, B, C and three bidders. Suppose further that bidder 1 has only $10M to bid. Suppose that at the end of the first round, the bids are as follows (an asterisk denotes a winning bid):

Bid	A	B	C	A, B
bidder 1	$10M	-	-	-
bidder 2	-	$5M	-	-
bidder 3	-	-	$6M *	$16M *

Given these bids, bidder 1 realizes that he can't win license A since bidder 3's combination of A and B defeated the sum of bidder 1's bid on A and bidder 2's bid on B. Bidder 1 therefore decides to bid $10M on license C. However, if bids can only be raised (including non-winning bids), then we could end up with the following situation:

Bid	A	B	C	A, B
bidder 1	$10M *	-	$10M *	-
bidder 2	-	$7M *	-	-
bidder 3	-	-	$6M	$16M

That is, bidder 2 has raised his bid on B, which together with bidder 1's (old) bid on A, defeats bidder 3's bid on the combination of A and B. But, since bidder 1 has only $10M, his budget constraint is

spectrum auctions also raise a number of interesting theoretical issues such as the optimal design of auctions of multiple-units (especially in the presence of interrelated valuations), the optimality of combinatorial auctions, coalition formation to participate in auctions and pre-auction bargaining.

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PCS Auction Design Conference

John O. Ledyard

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1/27/94

2/14/94

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Outline

What is hard about the FCC problem?

Performance Criteria

Applied Mechanism Design

Issues

FCC's Problem

What is hard about this?

Issue: Can simple market processes coordinate the allocation of hundreds of heterogeneous items? (Milgrom-Roberts Chapters 3 and 4)

Easy if: Substitutes and convexity

homogeneous (Sim = Seq)

heterogeneity and independence (Sim > Seq)

Harder if:

Complements and packaging gains (returns to scale)

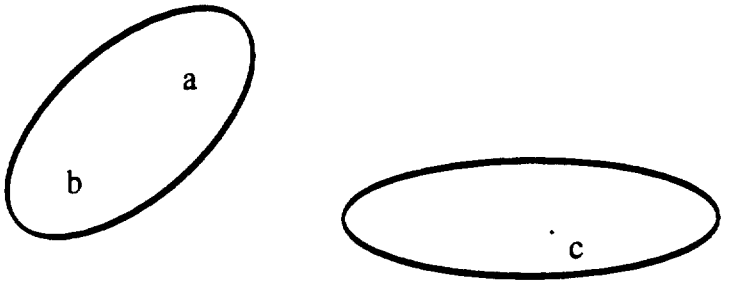
(see p. 3)

Most Hard if (also):

Coordination and fitting problems (non-convexities)

(see p. 4 and 5)

The Packaging Problem



	abc	ab	bc	ac	a	b	c
1	250	200*	100	110	60	50	50
2	255	150	110	105	55	60	50
3	250	175	125	125	50	50	75*

$V_{abc}=V_{ab}+V_c$ $\quad V_{bc}=V_b+V_c$ $\quad V_{ac}=V_a+V_c$

Equilibrium prices satisfy:

$55 \le P_a \le 150$ $\qquad 175 \le P_a + P_b \le 200$

$60 \le P_b \le 140$ $\qquad 255 \le P_a + P_b + P_c \le 275$

$50 \le P_c \le 75$

<u>Problem</u>: (a) <u>1 is exposed</u> $P_a + P_b \ge 175 > V_a + V_b$

(b) <u>Sequence matters</u> $P_a + P_b + P_c > 175 + 75$

<u>Solution</u>: Sell only packages ab and c simultaneously

Equilibrium prices $\quad 175 \le P_{ab} \le 200 \quad 255 \le P_{ab} + P_c$.

$50 \le P_c \le 75$

<u>Problem</u>: Who decides? How can you be sure?