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Collusive Bidding: Lessons from the FCC Spectrum Auctions

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Abstract

The Federal Communications Commission (FCC) spectrum auctions use a simultaneous ascending auction design. Bidders bid on numerous communication licenses simultaneously, with bidding remaining open on all licenses until no bidder is willing to bid higher on any license. With full revelation of bidding information, simultaneous open bidding allows bidders to send messages to their rivals, telling them on which licenses to bid and which to avoid. These strategies can help bidders coordinate a division of the licenses, and enforce the proposed division by directed punishments. We examine solutions to mitigate collusive bidding in the spectrum auctions, and then apply these ideas to the design of daily electricity auctions.

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1 Introduction

The key innovation of the Federal Communications Commission (FCC) spectrum auctions is having an open auction for many licenses simultaneously. In other auctions commonly used, the auctions are open but for a single unit at a time, like an English auction at Sotheby's or Christie's, or are for many units simultaneously but are sealed-bid, like Treasury auctions. The FCC has good reason for conducting auctions that are both open and simultaneous.

The main reason is that in this way, bidders can build efficient aggregations of licenses. This efficiency is much more difficult to achieve in sequential auctions, where one market is sold, then the next, and the next and so on, since then a bidder who wants a certain collection of markets does not know what the prices will be in future auctions when calculating whether to win the present auction. Alternatively, when all licenses are sold simultaneously, a bidder can observe the tentative prices on all of the licenses, and so knows which aggregations are the best value.[1] In addition, if some licenses in the sequential auction become too high, a bidder may have to abandon key complementary licenses, and will not get the opportunity to build a substitute aggregation if some of the needed licenses are already sold. Sealed-bid simultaneous auctions also hinder bidders in building efficient aggregations. A bidder may not get critical markets it needs or may get more than it requires. The outcome is simply a crapshoot. Bidders cannot condition their bids on critical assignment and pricing information.

A second advantage of the simultaneous, open auction format the FCC adopted is that it provides information on the value of licenses to bidders. Digital wireless services are a new technology. Bidders are uncertain about build-out costs, penetration rates, prices, and market shares. The information revealed in an open auction can help bidders learn about these values. Since the auctions are simultaneous, this information is useful on all licenses, not just those that will be sold later.

A third benefit of the FCC's simultaneous ascending auction is full transparency. Bidders and other interested parties can verify that the rules are followed. If problems exist, they are found and resolved

[1] One question is whether the tentative price information is of sufficient quality. Cramton (1997), in a study of the early spectrum auctions, demonstrates that both price and assignment information improves throughout the auction. The tentative information is of sufficiently high quality early enough that bidders have the flexibility to make adjustments in response to the information.

before significant damage is done. Moreover, since secrecy is not an issue, costly protocols to preserve secret data are unnecessary.

Yet the FCC auctions—being simultaneous and open—facilitate tacit collusion. Since bidders can observe each other's bids, bidders can coordinate on a collusive agreement, and then enforce the agreement by punishing deviations. Until recently, bidders were able to broadcast their strategies with their bidding. For example, bidders could engage in "code bidding"—attaching market numbers in the trailing digits of their bids to tell another bidder where it would be punished if it continued its bidding on a certain license, or what license to back off of if it wanted to avoid further punishment.[2] Also, bidders could use an unlimited number of withdrawals to emphasize punishment bids. To do this, a bidder would bump a rival from a license, and then immediately withdraw the bid to indicate that it was not bidding on this market because it wanted to win the market, but to warn the rival that it could raise the price on this market as a punishment for the rival bidding elsewhere. Withdrawals may also be used to coordinate a cooperative split of the licenses. A bidder moves off or withdraws from the markets it least wants or anticipates the rival most wants as a quid pro quo for the rival to do likewise. This "lateral handoff" lets the bidders sort out who gets what without resorting to prices. To the extent these strategies, whether with withdrawals, code bids, or other forms of retaliation, are successful, revenues and efficiency can be compromised. Although revenue was not the FCC's top priority (efficiency was), it is nevertheless important for a government with distortionary taxes to raise as much money as possible from nondistortionary sources. Moreover, revenue and efficiency are closely linked in markets where resale is permitted (Ausubel and Cramton 1999).

Collusion can be mitigated in the simultaneous ascending auction by appropriately enhancing the particular rules of the auction. For example, limiting bids to three significant digits eliminates code bidding and makes bidding easier, since bidders do not have to waste resources determining what the trailing digits mean or finding clever messages to send to rivals. Still, reporting bidder identities allows retaliatory bids—punishments for violating collusive arrangements, since bidders can determine who to punish and on which licenses. Even if tacit agreements are not made, a bidder who holds many markets may be reluctant to bid aggressively on other markets for fear of retaliation.

This paper is policy oriented. The focus is on bidder conduct, rather than auction performance, since our data does not permit precise estimates of performance. Many of the conclusions we draw are

[2] Market numbers are two or three digits and bids are typically six figures or more, so a bid could contain at negligible cost the market number as its last few digits, prefaced by leading zeroes to make the trailing digits stand out.

speculative, drawn more on our experiences and examinations of the spectrum auctions than on formal theory (which is still developing for multiple-unit auctions). Our main objectives are:

- to examine the collusive bidding strategies that were used in the FCC spectrum auctions,
- to identify how these strategies depend on the auction rules,
- to explore how these rules might be enhanced to mitigate tacit collusion, and
- to show how the rule changes might affect auction performance aside from collusion.

The paper is organized as follows. In Section 2, we examine collusive bidding strategies in the FCC's simultaneous ascending auctions. We then discuss how the FCC changed its rules in response. Section 3 examines proposed rule changes—those adopted by the FCC and others not yet adopted—to see how they might mitigate tacit collusion, and to identify likely side effects. We only examine rule changes that do not drastically change the FCC's basic design, such changes as restrictions on bids and what information is reported after every round. Section 4 uses these results to inform the design of electricity markets, where the possibility of tacit collusion is an even greater concern. Section 5 concludes.

2 Collusive Bidding in the FCC Spectrum Auctions

The FCC held 16 auctions between July 1994 and July 1998, raising $22.9 billion dollars for the U.S. Treasury and assigning 5,893 licenses.[3] Table 1 presents a summary of these auctions. Of the 16 auctions, one was a sequence of oral outcry auctions, and two were for a single license. The remaining 13 auctions were simultaneous ascending auctions. In the last two auctions (Auctions 16 and 17), the FCC introduced a number of rule changes intended to reduce the bid signaling that was prominent in Auction 11, the DEF-block auction.

[3] Some of the licenses are paid for with installment payments over 10 years. The $22.9 billion figure includes the sum of these payments. Recently, some of the bidders in the C-block auction have defaulted on their payments. The $22.9 billion figure does not deduct any losses from defaults.

Table 1. Summary of FCC Spectrum Auctions

Auction Number[1]	Auction	Licensing Scheme[2]	Number of Licenses	Net High Bids ($M)	Date Opened	Date Closed	Number of Rounds
1	Nationwide Narrowband PCS	Nationwide	10	617	25-Jul-94	29-Jul-94	47
2	IVDS	MSA	594	214	28-Jul-94	29-Jul-94	Oral Outcry
3	Regional Narrowband PCS	Regional	30	393	26-Oct-94	8-Nov-94	105
4	A & B Block PCS	MTA	99	7,019	5-Dec-94	13-Mar-95	112
5	C Block PCS	MTA	493	9,198	18-Dec-95	6-May-96	184
6	MDS	BTA	493	216	14-Nov-95	28-Mar-96	181
7	900 MHz SMR	MTA	1,020	204	5-Dec-95	15-Apr-96	168
8	DBS (110 W)	Nationwide	1	683	24-Jan-96	25-Jan-96	19
9	DBS (148 W)	Partial	1	52	25-Jan-96	26-Jan-96	25
10	C Block PCS Reauction	BTA	18	905	3-Jul-96	16-Jul-96	25
11	D, E, & F Block PCS	BTA	1,479	2,517	26-Aug-96	14-Jan-97	276
12	Cellular Unserved	MSA/RSA	14	2	13-Jan-97	21-Jan-97	36
14	WCS	MEA/REAG	128	14	15-Apr-97	25-Apr-97	29
15	DARS	Nationwide	2	173	1-Apr-97	2-Apr-97	25
16	800 MHz SMR	EA	525	96	28-Oct-97	8-Dec-97	235
17	LMDS	BTA	986	579	18-Feb-98	25-Mar-98	128
	Total		5,893	22,881			

Source: FCC.

[1]Auction 13 (IVDS) postponed.

[2]MTA = Major Trading Area; BTA = Basic Trading Area; EA = Economic Area; MEA = Major Economic Area; REAG = Regional Economic Area Grouping; MSA = Metropolitan Statistical Area; RSA = Rural Service Area.

The difficulty with analyzing collusion in the spectrum auctions is distinguishing between noncooperative behavior that results from the bidders' unilateral incentives to reduce auction prices and the cooperative behavior where bidders use their bids to strike deals to allocate the licenses. What is known from the literature is that in sealed-bid uniform-price auctions bidders have the incentive to demand reduce. (Demand reduction is the tendency for bidders to reduce the quantity they bid on in order to keep prices low; see Ausubel and Cramton 1996). In a simple setting, Ausubel and Schwartz (1999) have shown how pronounced demand reduction can be in ascending uniform-price auctions. Because arbitrage opportunities tend to equalize the prices across different spectrum licenses, the FCC auctions also have a uniform-price nature, so that bidders have the incentive to understate their demands to keep prices low. However, because of the abundance of information reported by the FCC during the auction, bidders also have the incentive to coordinate this demand reduction, to ensure that specific licenses go to specific bidders. That is, with heterogeneous bidders and heterogeneous licenses, there will be a matching problem, and it is in the bidders' interest to efficiently allocate the licenses as best they can. Demand reduction in sealed-bid uniform-price auctions precludes the possibility of allocative efficiency (as proved in Ausubel and Cramton 1996); however, through signaling and bidding at low prices, bidders may be able to reduce the level of inefficiency associated with demand reduction.

Because it is difficult to disentangle the cooperative and noncooperative incentives that bidders have in the spectrum auctions, we will need a definition of collusion to inform our analysis. The usual definition of collusion is "any practice that a group of bidders uses to limit competition between themselves" (page 468 of Mailath and Zemsky, 1991). However, as outlined in the previous paragraph, the noncooperative incentive to demand reduce would fall under this definition of collusion. We, therefore, take as our *working definition* of collusion: Collusion occurs between two bidders if they have overlapping interests on several licenses and if these bidders agree to allocate these licenses such that each bidder wins a license for a price substantially (more than a bid increment) below what the other bidder is willing to pay. This working definition can be expanded to include more than two bidders. It should be noted that this definition does not coincide with legal definitions of collusion or how economists have traditionally viewed collusion in auctions. For single-unit auctions, other work has modeled collusion with a ring of bidders that meets outside of the actual auction game to decide how to cooperatively bid in the auction (see, for instance, Graham and Marshall 1997, Mailath and Zemsky 1991).[4] Our working definition does not require this extra stage game (the knockout auction), buts allows for collusive agreements to be negotiated through the bidding during the auction. In what follows, we will describe some of the techniques that bidders used to strike and enforce collusive agreements.

3.0 Bid Signaling and Retaliation

During the DEF auction for personal communication services (PCS), High Plains Wireless, a Texas company that bid on a small number of markets mostly in the Southwest, found that a rival, Mercury PCS was punishing it on Amarillo as a warning for High Plains to stop bidding on Lubbock. High Plains experimented with its bidding to ensure that it indeed was being punished; it then backed off of the Lubbock license that the rival had wanted, and, as a result, was no longer punished in Amarillo. High Plains then filed a complaint to the FCC arguing that Mercury had used illegal bidding practices to signal its strategy, violating the anti-collusion rules. The FCC had known since the first auction in July 1994 that bidders were using bids to signal each other about bidding strategies. Signals were used to tell a rival which markets it wanted, which markets a bidder was willing to sacrifice to get another market, which markets were not being bid on seriously, and generally how to split up markets between bidders. In round 229 of the auction, the FCC sent a notice warning bidders to review the anti-collusion rules.[5] This marked

[4] Baldwin, Marshall, and Richard (1997) provide a brief review of the theoretical and empirical work on collusion in auctions. See also Marshall and Meurer (1999) for a legal perspective; this paper also overviews much of the economic literature on collusion.

[5] Auction announcement, 11_229.01, www.fcc.gov:

> The Commission has received a formal complaint alleging that the practice of using bids to signal interest in other markets—specifically, by using the BTA [Basic Trading Area] number of the other market as the

the climax of what had been building from the very first FCC auction: the FCC coming to terms with the bid signaling and collusion that was possible under the original bidding rules.

We begin by describing the essential auction rules, and how they permit bidders to signal each other about their bidding intentions.[6] In each auction, the FCC sold a set of licenses for a particular slice of the spectrum. Different auctions sold different frequencies, which are used for different services, such as voice, paging, dispatch, satellite broadcasting, and data services. A license allows the holder to use a particular frequency in a particular geographic area in accordance with specific rules, such as power limits and protocols to reduce interference. Rather than sell each license separately, an entire set of licenses is auctioned simultaneously. This is known as a simultaneous ascending auction.[7] In this auction, there is a tentative price associated with each license: the standing high bid. Bidding progresses in rounds. In each round, bidders can raise the standing high bid on any license by at least the minimum bid increment, which is typically between 5 and 10 percent. As prices rise, bidders can see which licenses represent the best values. Bidders can switch to substitute licenses, and attempt to aggregate complementary licenses. For example, High Plains was seeking many licenses to provide services in several cities in Texas. At the end of every round, the FCC posts the bids each bidder made on each license, listing for each bid, the amount of the bid and who made the bid.

The auction ends when a round goes by in which no bidder improves the bid on any license; that is, no bidder is willing to bid higher. The high bidder on each license is awarded the license and committed to pay its high bid. The simultaneous stopping rule is important in that the bidding for each license stays open until bidding ceases on all licenses. This allows bidders to shift to substitute licenses that represent better values, at any time during the auction.

A bidder's eligibility to bid is determined by its upfront payment. The larger the upfront payment the greater the quantity of spectrum the bidder can bid on in any round of the auction. Typically, eligibility is measured in MHz-pop: the bandwidth of the license in megahertz times the number of people in the

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final three digits of the bid amount—is an improper disclosure of bidding strategy, and as such violates the anti-collusion rule. We have reached no determination on the merits of this argument. However, we invite all bidders to review the anti-collusion rule (47 C.F.R. Section 1.2105(c), which is reprinted at page 192 of the Bidder Information Package) and assess whether they are complying with the letter and spirit of the rule.

[6] The rules described here are those used in the simultaneous ascending auctions before Auction 16. For brevity we omit many details. The exact auction rules for each auction are available at www.fcc.gov. For a more detailed discussion of the rules see McMillan (1994), Cramton (1995, 1997), McAfee and McMillan (1996), and Milgrom (2000).

[7] This design was proposed by Paul Milgrom and Robert Wilson of Stanford University, and R. Preston McAfee of the University of Texas.

geographic area covered by the license. An activity rule requires each bidder to maintain a minimum level of activity in each round of the auction. Activity in a round is defined as placing a new bid on a license or being the standing high bidder on a license in the prior round. If a bidder fails to maintain the required level of activity in a round, its eligibility to bid in future rounds is reduced. This rule forces bidders to bid actively throughout the auction, and prevents bidders from holding back until late in the auction.

4.0.0 Code Bids, Reflexive Bids, and Retaliating Bids

Bids are in dollars. Since the bids are reported in their entirety, and since bids on all but the smallest markets are at least six digits, bidders can use the last few digits of a bid to encode messages. For example, in the AB auction (Auction 4), GTE frequently ended its bids with "483," which spells GTE on the telephone keypad. In the same auction, American Portable, a subsidiary of TDS, signaled interest in some markets by spelling "TDS" (837) in the last three digits. In the nationwide narrowband auction (Auction 1), one bidder ended its bid with the phone number of Congressman John Dingell, who introduced the legislation to auction spectrum. This type of behavior caught the attention of the FCC, but it was not viewed as compromising either efficiency or revenues.

However, in the DEF auction (Auction 11), some bidders were more aggressive in their use of the last few digits of their bids. In a particularly noticeable case mentioned in the introduction, Mercury PCS ended its bids with market numbers to signal its rival, High Plains Wireless, that it wanted it to move off of Lubbock, Texas or that it would be punished on Amarillo, Texas. Each market has a three digit market number (for example, 264 for Lubbock and 013 for Amarillo). After trading bids on block F of Lubbock for several rounds, with the price rising by 10% in each round, Mercury bumped High Plains in round 121 from Amarillo, a market on which High Plains had been the standing high bidder since round 68. This was Mercury's first bid on Amarillo during the auction. The bid served as a punishment to High Plains for bidding against Mercury on Lubbock, a punishment made clear since it contained as its last three digits "264," the market number for Lubbock. Mercury's bid on Amarillo said to High Plains, "I am bumping you from Amarillo, a market you have held since round 68, a market that I have shown no interest in whatsoever. To win Amarillo back you will have to bid higher by at least two bid increments more than your previous bid. I want you to back off of Lubbock, leaving it to me." To clarify that the Amarillo bid was a retaliation for High Plains bid on Lubbock, Mercury tagged its rebid in Lubbock with "013," Amarillo's market number. Tagging both the rebid in the market of interest and the punishment bid with the market numbers of the punishment market and market of interest, respectively, is called *reflexive bidding*.

What made this example exceptionally clear was that High Plains bid again on Lubbock in round 124, enticing Mercury to repeat its punishment with another bid ending in Lubbock's market number, and a rebid in Lubbock ending in Amarillo's market number. The second time, the punishment worked. High Plains placed no further bids on block F of Lubbock, and Mercury placed no further bids on Amarillo. However, since High Plains still wanted a block of Lubbock, it switched over to the D and E licenses and won the D block license with a $2.38 million bid. Its highest bid on Lubbock block F was $2.11 million. The $2.38 million bid on a D block license had a much higher cost to High Plains when one realizes that had it won the F-block, High Plains, as a preferenced bidder,[8] would have received a 25% bidding credit and an installment payment plan at attract rates worth an additional 25%. Hence, the net increase in cost of the D block bid was $2.38 - 0.5 \times 2.11 = \$1.32$ million. High Plains, during and after the auction, complained to the FCC about Mercury's practice. The complaints led to investigations by the FCC and the Department of Justice. The FCC tentatively fined Mercury $650,000 for making 13 code bids—bids ending in market numbers which might be construed as signals to rivals.[9]

Punishments for deviations from tacit agreements need not include market numbers to be clear. Imagine that Mercury ended its bids on Amarillo and Lubbock with "000" rather than with market numbers. As long as High Plains could deduce that Mercury's bids on Amarillo were a punishment, or *retaliation*, for High Plains' continued bidding on Lubbock, the message to back off of Lubbock would be clear. A high-stakes example of retaliation that did not use trailing digits occurred between NorthCoast and NextWave. These bidders were competing intermittently on block F of Boston early in the auction, before NorthCoast placed a bid on Boston in round 43. This bid remained the high bid until NextWave bumped NorthCoast in round 67. Then in the following round, NorthCoast retaliated by bumping NextWave from block F of San Francisco with a bid of over $5 million (NextWave had been the standing high bidder on San Francisco since round 28). In round 70, NextWave recaptured San Francisco for $5.8 million and NorthCoast recaptured Boston for $8.9 million. What made NorthCoast's retaliation clear was that it was NorthCoast's only bid on any block during the auction on San Francisco and that these two markets were the only two markets that NextWave and NorthCoast were trading bids on between rounds 67 and 70. Thus, a retaliation need not contain market numbers to be effective. However, code bidding is a more powerful collusive device, since it can be used to split up markets between two bidders that are competing for many markets.

[8] The FCC rules often gave designated bidders preferential treatment. We refer to these bidders as "preferenced bidders." The preferences were some combination of bidding credits, installment payments, and tax breaks. See Ayres and Cramton (1996) for an analysis and discussion of bidder preferences.

[9] *Notice of Apparent Liability for Forfeiture*, FCC 97-388, October 21, 1997.

A drastic kind of retaliation occurs when a bidder punishes a rival on many markets. Consider USWest who was trying to win block E of Salem, OR, but was facing competition from another bidder, MVI. USWest bumped MVI from Aberdeen, WA, Appleton, WI, Bremerton, WA, Duluth, MN, Green Bay, WI, Kalispell, MT, Madison, WI, Manitowoc, WI, Sheboygan, WI, and Spokane, WA, ending its bids with "395," Salem's market number. (When a bidder punishes another bidder on many markets, it is called *blanket* retaliation.) These punishments took place over many rounds because MVI was slow to back off of Salem, though after persistent signaling USWest did eventually drive out MVI. Strikingly, USWest placed 17 bids ending in "395" during this episode of signaling, showing how freely some of the bidders used code bidding.

The above examples provide some evidence that signaling was used effectively for collusive ends in the FCC spectrum auctions. But just how extensive was collusive bid signaling? We concentrate on the DEF auction, since it was the focus of the FCC and DOJ investigations. Moreover, because of the large number of licenses ($3 \times 493 = 1,479$) and the fact that it was less competitive than either the AB or C auctions, the opportunities for bid signaling loomed large. We begin by reviewing the evidence from Cramton and Schwartz (1999), hereafter CS.

CS find that bidders attempted to use code bids to win 23 licenses, but for only 12 licenses were these code bids successful. The definition of success is that the code bidder placed the winning bid on the license within five rounds of the latest code bid. Usually, as is the case with the USWest example above, code bids were used repeatedly to win a single license. Code bids were used as punishments, and sometimes code bids were used to signal which markets were being or would be punished should the rival not cease its competition. CS identify over 90 bids ending in market numbers that were part of a code bidding strategy.

CS find that over 50 bids were retaliating bids *that did not use trailing digits*. These retaliating bids were used in attempts to win 14 licenses, and were successful 7 times, meaning that the retaliator placed the winning bid on the contested market within five rounds of its retaliation. Using both econometric methods and simple assumptions,[10] CS estimate that the FCC lost between $6 million and $14 million in the contested markets due to code bidding and retaliation, with a majority of the loss coming from retaliations that did not use code bids. These are the direct losses that come from one bidder backing off of a license after having been punished on another license. Of course, the punishments also raised prices on those markets punished. CS estimate the gains due to punishments to be about $5.5 million. The net of

[10] Specifically, as a "reality check" of the econometric approach, CS calculate the lost revenues assuming bidding would have continued for between 2 and 4 rounds more, each time raising the price by 10%.

these two figures is at most $8.5 million (14 – 5.5), a miniscule figure in an auction which raised over $2 billion in net revenues.

The analysis above may suggest that clever bid signaling strategies were not effective in the DEF auction, and that the FCC need not worry about tacit collusion. We do not believe this to be the case. One must remember that the retaliation and code bidding that we observed are *deviations* from tacit agreements. When tacit agreements are reached without disagreement, then we will not observe deviations. Indeed, it is the cases without disagreement where one would expect prices to be the lowest. To assess this hypothesis, CS examine whether the six bidders (21Century, AT&T, Mercury, NorthCoast, OPCSE, and USWest) that frequently engaged in code bidding and retaliation won licenses at especially attractive prices. In price regressions, where we include an indicator variable for licenses won by these "retaliating bidders" the coefficient is negative and highly significant. The retaliating bidders paid prices that were significantly less than the other bidders. Given that these five bidders won 40% of the spectrum (measured by 1994 population), this suggests that our earlier estimate of lost revenues is a gross underestimate.

5.0.0 Signaling with Withdrawals

Bid withdrawals are another tool to broadcast bidding strategies. Before Auction 16, the FCC allowed an unlimited number of withdrawals. If a bidder withdrawals its high bid on a license, the FCC becomes the standing high bidder on the license, and the minimum bid on the license is set at the previous high bid. If the final bid is less than the withdrawn bid, the FCC charges a penalty to the withdrawing bidder equal to the difference between the withdrawn bid and the highest bid after the withdrawal, which typically is the final winning bid. The purpose of allowing withdrawals is to allow bidders to switch to alternative aggregations when prices on the initial aggregation rise too high. However, bidders soon saw that withdrawals could be used for bid signaling and other strategic purposes. [11]

Bidders can use the withdrawals as part of a punishment strategy. To do this, a bidder warns a rival by bumping the rival from a license, and then immediately withdrawing the bid to emphasize that it does not want the market. This is a warning, rather than a punishment, since the bumped bidder can rebid its prior high bid. As an example of a bidder using a withdrawal to warn another bidder, in round 84 of the DEF auction, NorthCoast bumped 21Century from block F of Albany, NY and then immediately withdrew its bid. Prior to this, NorthCoast and 21Century were competing on New Haven, CT and New London, CT. In round 84, 21Century recaptured Albany, and NorthCoast placed the winning bids on New Haven and New London.

In addition to withdrawals being part of a warning/punishment strategy, withdrawals can also be used more cooperatively. If two bidders are bidding against each other on several markets, they can use withdrawals to help reach an agreement on how to split up the markets between them. Since the bidders probably have different preferences over which of these markets are the most important, withdrawing from the licenses that they least want, or that they think the other bidder most wants, suggests to the other bidder a proposed split. One instance of this is in the AB auction. After round 97, WirelessCo withdrew its bids from Houston and Tampa, and then in round 98, placed a bid on San Francisco. Apparently, WirelessCo was proposing a swap with American Portable: San Francisco for Houston and Tampa.[12] Another high-stakes example of collusive withdrawals occurred in the DEF auction between USWest and Triad. These firms were competing on Big Spring, TX, Farmington, NM, Grand Junction, CO, Lubbock, TX, Prescott, AZ, Salt Lake City, UT, San Luis Obispo, CA, and St. George, UT. Through a series of withdrawals, USWest and Triad arranged how to allocate these markets, with USWest giving Triad Big Spring, Farmington, Lubbock, San Luis Obispo, and St. George, and Triad giving USWest the other licenses.[13] These bidders made 11 withdrawals in rounds 96-106 to facilitate these trades. What is so alarming about these incidences of withdrawals is that they were made at prices drastically below what the bidders were willing to pay for the licenses. For instance, Triad picked up San Luis Obispo for $155,000 in round 100 following USWest's withdrawal. Although USWest and Triad were able to agree on which markets to split up, other bidders could bid on these markets if the prices were attractive. This is what happened on San Luis Obispo. Another bidder, Unlimited, began trading bids with Triad later in the auction. Before dropping out of this market, Triad bid up to $838,000, over five times the price it was able to coordinate with USWest in round 100. Similarly on Lubbock, Triad picked up this market for $985,000 following USWest's withdrawal in round 99; however, Triad ended up bidding $2.4 million for Lubbock after competing with another bidder later in the auction. With sufficient competition, these coordinated market splits between two bidders are likely to unravel later in the auction when a third-party bidder enters the bidding. However, on Farmington, Grand Junction, and Prescott, Triad and USWest secured these markets by round 106, without facing further competition from other bidders.

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[11] For a detailed description on withdrawal strategies see Cramton (1997).

[12] See Cramton (1997) and Weber (1997).

[13] Other bidders later bid on some of these licenses. If there is sufficient competition, as in the C auction, these tacit agreements are unlikely to be successful.

In the DEF auction, withdrawals were much more common than in prior auctions. Most of these were part of parking strategies.[14] The examples discussed above, where withdrawals were used as warnings or as devices to signal how to assign licenses, were more the exception than the rule.

6.0 The FCC's Response to Bid Signaling and Other Rule Changes

The FCC was aware of the possibility of code bidding after the first auction in July 1994, but did nothing about it, because it appeared that the code bidding was of little importance. Then, in the DEF auction after a bidder made a formal complaint to the FCC, the news hit the press with front-page feature articles in the *Wall Street Journal* and elsewhere.[15] Bid signaling could be ignored no more. The FCC decided to take no chances, and in Auction 16 moved to "click-box bidding," in which bidders simply click on the licenses they wish to bid. All bids are exactly one increment above the standing high bid in this case, whereas prior to click-box bidding, bidders could bid any higher dollar amount.

After the DEF auction, other rule changes were made as well. Some of these changes were adopted to hinder signaling with code bids and withdrawals, but other rule changes were adopted to quicken the auction process. Rather than describe the rule-changes for each auction following the DEF auction, we describe the rules as of Auction 17, the *Local Multipoint Distribution Service* or *LMDS* auction, which occurred in February through March 1998. The FCC determined *minimum opening bids* for each license based on population coverage (a bidder who bids on a license that no bidder had bid on in prior rounds can only bid the minimum opening bid). Once some bidder had placed the minimum opening bid, bids in subsequent rounds were constrained to be 1-9 bid increments over the standing high bid.[16] Bid increments were between 5% and 15%, depending on the frequency of bids in prior rounds. Bidders could only place withdrawals in two rounds during the auction.[17]

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[14] Parking is a bid on a license—that the bidder does not intend to win—made to preserve enough eligibility so that the bidder can bid on its desired markets later in the auction. Parking is a means to circumvent the intent of the activity rule.

[15] For example, see David Bowemaster and Brock Meeks, "Justice Probes FCC's Wireless Auctions," MSNBC, May 5, 1997.

[16] Precisely, a bidder wishing to bid on a license must bid $X \in \{1, 2,\ldots, 9\}$. A bid of X on a license translated into bidding the prior standing high bid plus X bid increments. This eliminated code bidding, which occurred when a bidder could name the dollar amount of its bid.

[17] We refer the reader to the FCC web site: www.fcc.gov/wtb/auctions/collusio/collusio.html, which archives the FCC's dealings with collusion in the spectrum auctions.

7 Auction Design to Mitigate Collusion

In this section, we discuss ways the FCC auctions might be amended to curtail the possibility of collusion. We discuss rule changes that keep the basic ascending round structure. We consider changing the kinds of bids allowed, what information is revealed between rounds, withdrawal rules, and closing rules. Other more drastic changes, such as allowing combinatorial bids, are not discussed.[18] Often the rule changes that we discuss affect auction performance outside of collusion. For example, the change may impact how quickly the auction proceeds, or how easy it is for the FCC to implement. We give the pros and cons of rule changes intended to circumvent or reduce collusion.

8.0 Bid Restrictions

Before Auction 16, any bid at or above the minimum bid was allowed and reported in its entirety including the bidder identity. As documented above, this allowed for all kinds of signaling. Bidders attached market numbers in their retaliations to show rivals which markets they wanted, used market numbers to say which markets they would punish in if the rival did not cease competition in a particular market, used fancy signatures, spelled labels using the telephone keypad, and wasted much time determining what signals to send and interpreting what was sent by others. Probably many more signals were sent than were received, meaning that many bidders either ignored the signals or could not interpret them in the time between rounds.

The advantages of restricting bids, either to three significant digits, 1 bid increment (click-box bidding, as used in the SMR auction), or 1-9 bid increments (as used in the LMDS auction), are: (1) code bidding is eliminated; and (2) bidders do not waste resources figuring out how to send or interpret signals in the trailing digits.[19]

However, as we have emphasized, effective signaling through retaliation does not require trailing digits; it only requires that bidding identities be reported. We expect that eliminating code bidding will induce code bidders to switch to retaliating bids since the bidders already understand the strategies involved. Retaliating without using trailing digits weakens the clarity of the signals, and may make it more difficult for the parties to coordinate on an arrangement. However, eliminating code bids is smart from the perspective that it eliminates the unproductive task of determining what the trailing digits mean.

[18] On combinatorial bidding, see Bykowsky, et al. (2000), Charles River Associates and Market Design, Inc. (1997, 1998), and Rothkopf, et al. (1998).

[19] An additional advantage of 1–9 increments or click-box bidding is that bidders are prevented from the "fat-finger" error, where a bidder mistakenly adds extra digits to its bid. This occurred several times in the FCC's early auctions. With three-significant-digit bidding, the fat finger error is avoided by including appropriate warning messages in the auction system.

This task is difficult, because the vast majority of potential code bids mean nothing at all. Most are simply the random typing of a bidder to avoid ties. Others are not random, but equally meaningless. For example, in the DEF auction, AllTel ended many of its bids with round numbers, 21Century ended its bids with 21, Poka Lambro PCS used numeric patterns, repeated numbers, and palindromes of numbers.

9.0 Reporting Bidder Identities

A critical design decision is whether to report bidder identities. An alternative to full transparency is an anonymous auction, where only the bids are reported, and not who made them. The main issue is whether the bidders have a legitimate "need to know." Since the revelation of the identities increases the risk of collusion and can greatly complicate the bidders' strategies, the auctioneer must weigh these costs against the benefits of the extra information. Below we list and discuss the benefits and costs of reporting bidder identities.

Benefits of Reporting Bidder Identities

- Reporting the bidder identities makes the auction fully transparent. The FCC simply posts all information on the Internet. Bidders can more easily verify bids, and feel confident that the auction rules are being followed.

- Reporting bidder identities can induce higher auction revenues if a bidder's valuation for one license in a market depends on who will be the winner of the other licenses in the market or neighboring markets. A bidder might care what type of service its competitor provides. For example, for PCS, there are three competing technologies: Code Division Multiple Access (CDMA), Time Division Multiple Access (TDMA), and Global System of Mobile Communications (GSM). Bidder A might want to be the only GSM provider in Baltimore, and so will bid higher on Baltimore if it knows that the other likely winners in Baltimore do not intend to use GSM technology. On the other hand, knowing the identities of the other bidders may cause inefficiencies after the auction. Bidder A may prefer that bidder B wins Baltimore over bidder C if A and B both provide service in Philadelphia, and A and C do not have any multi-market contact. This is because bidder B has a greater incentive to cooperate in Baltimore, since B wants A to cooperate in Philadelphia.

- Bidders do not waste resources trying to figure out who is who.

Costs of Reporting Bidder Identities

- Reporting identities allows for retaliation. Even the threat of retaliation may seriously dampen bidding. A bidder that has a favorable price on a key market may be reluctant to bid on other markets

for fear that the bumped bidder will respond by raising its price in the key market. This is especially important in auctions with little competition, and was a major issue in the AB auction and the DEF auction. These were auctions for broadband PCS licenses with few bidders per license. The AB auction and the D and E blocks of the DEF auction both had on average 5 bidders for each pair of licenses over the entire auction. The F block of the DEF auction had 4 bidders per license. In contrast, the C block auction had 11 bidders per license. The possibility of low prices may make small bidders reluctant to place bids against large bidders for fear of retaliation.

- Reporting identities helps the bidders coordinate on a cooperative split of the licenses; that is, it aids in targeted demand reduction. If two bidders A and B are competing in markets X and Y, both may realize it is unwise to try to win both markets. A may back off of Y with the hopes that B backs off of X. This can be made clearer with strategic withdrawals.

- Bidders spend resources trying to encode or decode bid signals. These are the transactions costs of bid signaling. Every time a bidder is bumped it must determine whether it was retaliated against for its bidding elsewhere. In addition, savvy bidders may search where to punish to deter competition.

Another cost of revealing bidder identities is that revelation can discourage competitive bidding because some bidders avoid bidding against certain others. One reason for avoiding a bidder is because the bidder has a reputation for blanket retaliation or other types of aggressive bidding. Another reason to avoid a bidder is that if the bidder has deep financial resources, then there is little reason to believe that a license can be won if that bidder is interested in it. Note that these reasons are not mutually exclusive. If a bidder thinks that the other bidder has a large enough budget to win any license it wants, and there is some probability that the bidder protects the licenses it wants with retaliation, then to bid against this bidder risks a substantial cost—namely, raising the prices on the other licenses the bidder wants. Suppose there is one large bidder that wants many licenses in the auction. If it is possible to keep the prices low on the licenses this bidder will win, then this bidder may be willing to demand reduce. It sacrifices some licenses it values in order to keep its overall prices low. Thus, bidders have the incentive to avoid the large bidder, letting the large bidder win the licenses it wants at low prices.

Though our reasons why bidders avoid certain others are speculative, that this is a real phenomenon is not. In the DEF auction, AT&T won 223 licenses—more licenses than anyone else. These licenses covered 140 million people, over 50% more than any other bidder. To explore whether bidders avoided AT&T, we looked at all of the bids that occurred after round 10 on the D and E blocks in markets on

which AT&T was the high bidder.[20] We ask the question: Did bidders bump AT&T when AT&T was the high bidder on the less expensive of the two blocks? If bidders did not care about the identity of the high bidder, they would arbitrage the prices of the D and E blocks, and bid against AT&T if the other block was more expensive. This did not happen. When the other block was 15% more expensive (the bidding increments were 5% or 10% of the standing high bid in the DEF auction), bidders still bid on the other block 32% of the time rather than bid against AT&T on the less costly block. When the other block was 25% more expensive, bidders still avoided AT&T 31% of the time. Even when the price of the other block was 50% higher, bidders bid on the higher priced block 27% of the time.

As a comparison, we performed this same exercise to see if bidders systematically avoided smaller bidders in the same way. We chose five bidders who won between 9 and 14 licenses—ACCPCS, Comcast, Rivgam, PAccess, and Touch. We counted all of the bids made by other bidders when one of these five bidders was the standing high bidder on the D or the E block. When the other blocks were 15%, 25%, and 50% more expensive, bidders avoided these five bidders 20%, 18%, and 15% of the time, respectively. We summarize these results in Table 2.

Table 2. Do Bidders Avoid AT&T more than Small Bidders?

	AT&T	Five Small Bidders[1]	Test Statistic for Comparison of Means[2]
Other Block is 15% More Expensive			
Number of Bids on Other Block	194	28	
Number of Bids on Less Expensive Block	422	115	
Percent of Bids on Other Block	31.5%	19.6%	3.13
Other Block is 25% More Expensive			
Number of Bids on Other Block	140	16	
Number of Bids on Less Expensive Block	307	71	
Percent Bid on Other Block	31.3%	18.4%	2.75
Other Block is 50% More Expensive			
Number of Bids on Other Block	73	7	
Number of Bids on Less Expensive Block	203	41	
Percent Bid on Other Block	26.5%	14.6%	2.07

Notes:

[1]The five smaller bidders are ACCPCS, Comcast, Rivgam, PAccess, Touch, each of whom won between 9 and 14 licenses. AT&T won 223 licenses.

[2]Here, to get the test statistic, we assume that the decision to bid on the more expensive block follows a Bernoulli distribution. We then use the standard formula for comparison of means for two normally distributed random variables with unknown means and variances (Kmenta 1986, pp. 137 and 145). The test statistic is approximately

[20] AT&T, as a large bidder, was only eligible to bid on the D and E blocks in the DEF auction, since the FCC set aside the F-block licenses for small bidders.

normally distributed. The null hypothesis that the means are equal is rejected at the 5% level of significance in all three cases.

Bidders did not take full advantage of arbitrage opportunities in the DEF auction. On 202 of the 480 markets in which the low bid on the D and E blocks was more than $10,000, the price discrepancy between the two blocks was more than 15%. 131 of these markets exhibited a price discrepancy of more than 25%. 63 of these markets exhibited a price discrepancy of more than 50%. Just considering the 353 markets where the lower bid was more than $100,000, 120 had a price discrepancy of more than 15%, 66 of these had a price discrepancy of more than 25%, and 25 of these had a price discrepancy of more than 50%. Of these last 25 markets, AT&T was the winning bidder on the expensive license 5 times, and won the inexpensive license 11 times, including 3 markets that sold for more than $1 million. This is more evidence that bidders were reluctant to bid against certain bidders. Even when the price discrepancy was more than $½ million, bidders often preferred to bid against the other bidder than bid against AT&T.

For whatever reasons, smaller bidders were reluctant to bid against large bidders in the DEF auction. Not bidding vigorously against the larger bidders is the complement of demand reduction—small bidders making room in the auction for large bidders. This has consequences for what collusion can be accomplished in the auction, for if small bidders avoid the large bidders, then all that remains for the large bidders to do is work out which of them wins which licenses. Large bidders demand reduce because they prefer to win fewer licenses at a lower price. And small bidders demand reduce to avoid retaliation from large bidders.

The consequences of bidders avoiding the largest bidders may be great. Competition is diminished in the wireless communications industry. Auction revenues are compromised, since large bidders can win licenses without facing stiff competition. And large bidders can use their budgets to win more licenses, expanding their market presence.

In sum, an anonymous auction is desirable unless: (1) there is a strong efficiency reason why bidders have a “need to know,” and (2) it is anticipated that competition will be strong.

An intermediate position between full disclosure and the anonymous auction is to reveal bidder numbers, but not to release the mapping from bidder number to bidder identity. Then, a bidder will know it is being attacked by bidder “34,” but the bidder will not be told the identity of bidder “34.” This in fact was the rule that the FCC used in the nationwide narrowband auction (Auction 1). We see no reason for this intermediate position. It allows most of the collusive uses of bid signaling, and yet limits the information that may stimulate bidding. This rule was immediately abandoned by the FCC in favor of full

transparency in all subsequent auctions. As a practical matter, the bidders, especially the large bidders, were able to figure out who was who through a host of detective work (Cramton 1995).

In an anonymous auction, the auctioneer should hide the time stamp, which lists the precise time that a bid is placed. The reason for this is that bidders would be able to see patterns of bids by a bidder by looking at the bids with the same time stamp. In addition, one can imagine that bidders may attempt to send signals through the time stamp, such as submitting punishment bids in the last minute of the round. These signals would likely fall on deaf ears, but one must be careful not to underestimate what clever bidders can do in high stake auctions. It is hard to imagine that bidders have a legitimate need to know the time stamp.

10.0 Withdrawal Rules

Withdrawals may be necessary in a simultaneous ascending auction if synergies are strong and heterogeneous among bidders, and package bids are not allowed. However, as we have seen above, unlimited withdrawals may be used to facilitate collusion, as in lateral handoffs or warnings of retaliation. In Auctions 16 and 17, in response to the withdrawal signaling that went on in the DEF auction, the FCC restricted a bidder to making withdrawals in only two rounds. In effect, this allowed bidders to back out of up to two failed license aggregations.

Withdrawals were used as parking strategies, as part of retaliations, as a tool to suggest lateral handoffs, and to reduce withdrawal penalties. All of these strategies are contrary to what the FCC intended. We believe that the synergies in the FCC auctions through Auction 16 were sufficiently minor and/or consistent across bidders that bidders were able to assemble the market aggregations they wanted in most cases.[21] The two-round limit allows at least some flexibility in letting bidders back out of failed aggregations, and did not appear to be overly binding in auctions 16 and 17, when this rule was enacted.[22]

An alternative limitation on withdrawals is to make withdrawals irreversible, meaning that when a bidder withdraws, it cannot bid again on the license. A slight modification of an irreversible withdrawal rule is to allow the bidder to bid on its withdrawn license only if three rounds pass with no one else placing a bid on the license; this modification is to allow the bidder to win the license rather than letting the FCC win the license, requiring a reauction later. Though the irreversible withdrawal would greatly

[21] Ausubel, et al. (1997) and Moreton and Spiller (1998) provide support for this belief from the AB and C broadband PCS auctions.

[22] In Auction 16, of the 60 bidders who placed bids, only three bidders made withdrawals in two rounds, and only 10 bidders made any withdrawals. In Auction 17, of the 133 bidders in the auction, only nine bidders made withdrawals in two rounds, and only 21 bidders made any withdrawals.

hinder bidders to make warnings, as we described above, this scheme would still allow some punishments. As an example, a bidder could bump its rival from one market, then withdraw to emphasize that its bid was not intended as a serious bid, and then if the rival does not cooperate, bump it from another market, this time though without withdrawing the punishing bid. Irreversible withdrawals would limit parking strategies, since a bidder would need to find different markets to park on after if it withdrew its high bid.

On balance, we prefer the FCC's solution to the withdrawal problem—a bidder can withdraw in at most two rounds. The rule is simple to implement, allows a bidder to back out of two failed aggregations, and largely avoids the collusive use of withdrawals.

11.0 Using Reserve Prices to Upset Collusion

Reserve prices are often viewed as an instrument to fight collusion.[23] One of the difficulties is determining what the reserve prices should be. A natural approach would be for the FCC to try to estimate value, and then set the reserve price to be a fraction of this estimated value. In the DEF auction, the FCC had a good idea of license valuations from the prior broadband PCS auctions in which the A, B, and C blocks were sold. Even a small reserve price can have a big effect in upsetting collusion and demand reduction.

There are three advantages of reserve prices:

- Reserve prices can speed the auction along. Initial rounds at low prices are skipped. In the DEF auction, fewer than 17 markets had a winning bid for less than $10,000, yet bidders placed 2,732 bids of less than $10,000, 600 of these after round 10, 277 of these after round 50. Bidders wasted much time bidding at low prices.

- The incentive to collude is larger when prices are low relative bidder valuations. If prices are never low, then the expected benefits of collusion may be outweighed by the legal risks and the transaction costs of enforcing collusion. Without reserve prices, there may be many rounds of bidding at low prices, giving the bidders a longer time to coordinate on an tacit agreement. These rounds may be

[23] An alternative to reserve prices is minimum opening bids. The distinction is that with minimum opening bids the FCC has the ability to lower the minimum bid if no one bids on the license, whereas reserve prices are never changed. The difficulty with the added flexibility of minimum opening bids is that it gives bidders an extra incentive to hold back initially in order to get the prices to drop. Minimum opening bids may actually foster collusion by magnifying the incentive to hold back. Since the SMR 800 MHz auction, the FCC has used minimum opening bids. This, however, has not caused any problems, since the FCC has refrained from dropping the minimum bid. At least through Auction 16, the minimum opening bids have been equivalent to reserve prices, assuming that bidders correctly anticipated the FCC's reluctance to lower minimum bids.

essential to resolve disputes about which companies should get which licenses. Without these rounds, the bidders may learn too late what constitutes an acceptable split. Graham and Marshall (1987) have shown how the auctioneer can tailor the reserve price to optimally protect against the revenue loss from collusion in an ascending auction for a single unit. It is our contention that reserve prices play an even more important role in multi-unit ascending auctions. Reserve prices can prevent some collusive deals from being struck.

- Reserve prices, even if small, can upset demand reduction by large bidders, promoting efficiency and increasing revenues.

To illustrate the last point, we present the following example. To keep the example as simple as possible, we assume complete information, and consider a sealed-bid uniform price auction, which approximates the simultaneous ascending auction of identical items.[24] We show how a reserve price can upset demand reduction in the sealed-bid uniform price auction.

Suppose there are two identical items for sale to bidders A and B. Bidder A has a capacity for two units and bidder B has a capacity for one unit. Assume the auctioneer knows these capacities and only allows bidder B to bid for one unit, but allows bidder A to bid for two units (i.e., submit two bids). Suppose A values winning one unit at $160 and winning two units at $300, meaning if A pays $X and wins one unit her payoff is 160 – X or if A wins two units the payoff is 300 – X. If bidder B wins one unit and pays $X B's payoff is 75 – X. Assume these payoffs are commonly known to both bidders. In this sealed-bid uniform price auction, the auctioneer accepts the three bids and awards goods corresponding to the two highest bids, charging the highest-rejected bid for each unit. Assume that the reserve price is $0. If there is a tie between the second-highest bid and the lowest bid, the good is awarded randomly. The only weakly undominated strategy for bidder B is sincere bidding—B submits a bid for $75. Bidder A knows this, and sees that if it submits one bid for $160 and a second bid of $0, the clearing price will be $0, giving A a payoff of $160. Alternatively, if A wants to win two units it will have to place two bids for at least $75, giving a clearing price of $75 (B's rejected bid). This gives A a payoff of $150 (= 300 $-2\cdot 75$). Therefore, A prefers to submit only one positive bid. This is demand reduction. A reduces the amount it bids below its true valuation to make room for the other bidder and keep the price low. Therefore, the unique equilibrium outcome in weakly undominated strategies is for A and B to win 1 unit each at a price of $0.

To see how even a small reserve price can mitigate demand reduction, suppose the auctioneer imposes a $20 reserve price. Bidder B's unique weakly undominated strategy of bidding sincerely is

[24] The result extends to more realistic settings with incomplete information.

unchanged. However, now bidder A sees that winning one unit at $20 only gives it a payoff of $140 (= $160 – $20) but by placing bids for $160 and $140 ($140 is A's marginal value for winning a second unit), A wins two units, the clearing price is bidder B's rejected bid of $75, and A gets the payoff of $300 – 2($75) = $150. Therefore, A prefers to win two units, and the equilibrium outcome has A winning both units, and the total revenue is $150. Since the price is $75, considerably more than the $20 reserve price, one might conclude that the reserve price is not binding, and therefore unnecessary, but in fact, it is essential to mitigate bidder A's demand reduction.

12.0 Stimulating Competition with Preferences for Small Businesses

Stimulating competition may be the auctioneer's best defense against collusion and demand reduction. As Bulow and Klemperer (1996) demonstrate for single unit auctions with symmetric bidders, even one extra bidder is better than using an auction with an optimal reserve price. The example above shows how a reserve price can upset demand reduction, but an extra bidder can have a similar effect. One way to stimulate competition between large bidders and smaller bidders is by awarding smaller parties bidding credits, as was done in many of the FCC's auctions. The bidding credits tended to be bid away by competition among small bidders (Ayres and Cramton 1996). In the DEF auction, the F block license was set aside for the preferenced bidders, and the small bidders received no preferences on D and E. Competition may have been enhanced in the D and E blocks if small bidders received preferences on D and E. If the auctioneer's goal was to ensure that these smaller bidders acquired PCS licenses, then they could still set aside the F block licenses, protecting them from competition from the D and E block bidders. Allowing the preferenced bidders to maintain their preferences on D and E block licenses may have stimulated competition, and may have upset some of the collusive and demand reduced outcomes.

Indeed, code bidding or retaliatory bidding often was successful temporarily, but then upset when a third-party came into the market. The better the collusion is at keeping the prices low, the harder it is to discourage value seekers from stepping in.

13.0 Closing Rules

A variation on the simultaneous closing rule is to have a final round of sealed bids once the auction activity is low. Auction activity is measured as the population-weighted percentage of licenses receiving new high bids. The logic is that if there is one final round of bidding, bidders do not need to fear retaliation later in the auction, so they can bid sincerely in the final round. This can upset collusive arrangements. The problem is that late in the auction bidders may not have the eligibility to bid where they would like to. Late in the auction the collusion may have already worked. If the final round is placed

sometime when bidders do have sufficient eligibility to switch to other markets, then many of the benefits of price discovery, learning, and aggregation building are lost. Alternatively, in the final sealed-bid round, eligibility could be restored to initial levels, with the bidding limited to the top-two bidders on a license. But this alternative also has many of the problems of a sealed-bid auction.

Market-by-market closing is another option. Licenses would close individually after several rounds of inactivity. Once a license closed, it would be protected from retaliation, thus upsetting the ability to collude, which requires the possibility of punishment. The license-by-license closing is much less severe than the one-final-round option. Bidders have greater freedom to see that they have all of the licenses they need for their aggregation, and if these licenses close first, then a bidder is safe on these licenses. However, if late in the auction a bidder still has not secured all of the licenses it needs for its planned aggregation, it might get stuck with some of the other licenses that are closed. This is a necessary feature. However, if a bidder does not obtain the final license it needs for an aggregation, it may not be able to bid on a substitute aggregation if some of the key licenses have already closed. Market-by-market closing may create problems for many bidders. Again, it seems that this should not be used unless collusion is probable or if the other benefits (shortening the length of auction) is a main concern.

A better alternative to either market-by-market closing or one-final-round is to raise the bid increment toward the end of the auction. This has the benefits of the other options,[25] but since the size of the increment is used to limit bidding, the process avoids the large inefficiencies possible with the other approaches. If one bidder has a high value on a license relative to the standing high bid, the bidder can come back with a bid; whereas, market-by-market or one-final-bid may prevent this.

14 Applying These Ideas to Electricity Auctions

Many countries worldwide are in the process of restructuring their electricity industries. A key component is letting the suppliers and demanders of wholesale electricity compete in a day-ahead energy auction to provide and receive electricity in each hour of the next day. In such an auction, an important question is: What bidding information should be revealed to the bidders, and when and how should it be revealed? We describe two extreme approaches, and then discuss a middle ground that is more likely to be appropriate.

[25] The cost of punishment is much greater if the bid increments at the end of the auction are very large. If a retaliator punishes a rival, the rival is more likely to abandon the license rather than retake it. This will leave the retaliator sitting on a license it does not want, forcing it to withdraw if it is able to, and being liable for the withdrawal penalty equal to the large bid increment.

The energy auction typically is organized by the "independent system operator" (ISO), who is charged with running an efficient market. For any piece of information received or produced by the ISO, there are several options.

1. The ISO can reveal publicly the information (public information).
2. The ISO can reveal the information to all the bidders, but not the public.
3. The ISO can report the information to the specific bidder (bidder-specific information).
4. The ISO can report the information to no one (secret information).

We do not give option 2 a name, since it is an option that can be dispensed with immediately. Any information that is revealed to all the bidders should be made public. The reason is that if it is useful information to the bidders it is useful information to a *potential* bidder. Since the ISO cannot know the set of potential bidders, the information should be made public. However, the decision among options 1, 3, and 4 is less obvious.

At one extreme is a fully transparent process: reveal all bidding information to the public, as in the FCC spectrum auctions. Before the auction begins the FCC posts the set of eligible bidders, the extent of each bidder's eligibility, the bidder's identity, and the bidder's application form, which includes ownership and other financial information. During the auction, after each round of bidding, the FCC immediately posts all the bids for the round, the bidder that made each bid, and any changes in eligibility. As we have discussed, this approach has three main advantages. First, it gives participants (and potential participants) the maximum amount of information. The bidders then can use this information in preparing subsequent bids. The information reduces the bidders' uncertainty, which facilitates price discovery and improves efficiency. Moreover, it may increase auction revenues, since with less uncertainty the bidders can bid more aggressively, without fear of falling prey to the winner's curse.[26] Second, it simplifies implementation. The information simply is posted on the Internet. The FCC need not worry about maintaining or delivering bidder-specific information. Nor does the FCC need to be concerned with establishing secure methods of preserving secret or bidder-specific information. Third, it means that the process is fully transparent. This permits the bidders and any other interested party to check that the auction is being conducted in compliance with the stated rules. If problems are discovered, they can be fixed quickly, before any serious damage is done.

[26] The winner's curse is the tendency for naïve auction winners to lose money, because they fail to take account of the information contained in winning a competitive auction. To avoid the winner's curse, smart bidders shade their bids. The amount of shading depends in part on the amount of uncertainty the bidders face. See Milgrom and Weber (1982).

The difficulty with a fully transparent process as we have emphasized is that information is sometimes a two-edged sword. It can be used to facilitate collusion, as well as promote efficiency. Information about the bidder identity associated with each bid is especially vulnerable to collusive use. For example, a group of bidders can establish a collusive supply schedule, and then punish defections to the schedule. If bidder identities are known, then the punishment can be directed against the defector, by retaliating in particular hours or locations, so as to harm the defector the most. Alternatively, only a small subset of bidders may be party to the tacit agreement. For example, the three largest bidders may have a collusive understanding. In this case, to enforce the collusive agreement, it is important for the colluding bidders to know the bidder identities, so that deviations can be detected, and then punished.

At the other extreme is a policy of complete secrecy. The ISO makes no disclosure of any information, aside from what is absolutely necessary—each bidder would only be told its settlement information (prices and its quantities). This approach would mitigate tacit collusion to the greatest extent. However, it exposes the bidders to the greatest uncertainties, and this may introduce inefficiencies.

A middle ground is probably best. First, the secrecy of individual bids is essential for competition in this kind of market. The market is repeated daily and in many markets a few participants constitute the majority of supply. Such a setting is ripe for abuse if the parties are given the informational means. System-wide results should be public information: prices, total generation, total reserves, etc. This information is either needed by bidders for planning or can be inferred from settlement information. Hence, it should be made public. The next step would be to make the aggregate bid schedules public. Bidders surely would like to have this information in preparing bids for the next day. It represents an indication of what would be the consequences of changing the quantity bid. However, the information is not essential for competition. A supplier whose bid was rejected yesterday knows that it needs to improve its bid tomorrow (assuming tomorrow is like today). Knowing the price elasticity of supply (or demand) is not essential to the analysis. Unless a strong argument can be made that knowing the price elasticity improves efficiency, it would seem prudent to keep the aggregate schedules secret and only reveal prices and aggregate quantities publicly. We do not believe that such an argument can be made. Unlike in the spectrum auctions, which are a once-and-for-all event for many bidders, the electricity auctions are repeated daily. Thus, the recent history provides a good indication of the future. In the spectrum auctions, the case for information revelation is much stronger, since the price discovery process cannot rely on past transactions.

On balance, in a daily electricity market with few participants, the risk of collusion is sufficiently large to outweigh the efficiency gains of disclosing information beyond market prices and total quantities. This is especially the case in markets without robust demand-side bidding, where demand is completely

inelastic. However, the delayed release of certain information may be best. This is true for information that may have a collusive use if released immediately, but for which the collusive use decays over time. For example, the release of aggregate supply and demand curves with a three-month lag enables participants, regulators, and the public to better understand and improve the market. This policy of delayed-release has been adopted in California and is being considered by other ISOs as well. Regardless of the information policy, it is essential that there be an independent market surveillance committee that can access all bids, and report any abuses of market power.

15 Conclusion

The key innovation in the FCC spectrum auctions is that licenses are auctioned simultaneous in an open ascending process. This fully transparent design gives bidders a great deal of information, which facilitates arbitrage across substitute licenses and promotes the efficient aggregation of complementary licenses. However, with full revelation of bid information, simultaneous open bidding allows bidders to send messages to their rivals, telling them on which licenses to bid and which to avoid. These bidding strategies can help bidders coordinate a division of the licenses, and enforce the proposed division by directed punishments. If successful, such bidding undermines the price discovery process. Both revenues and efficiency are compromised.

Although the FCC's fully transparent auction design is vulnerable to collusive bidding, we find that only a small fraction of the bidders frequently used collusive strategies. These bidders were only sometimes successful at keeping prices low. Indeed, direct estimates of revenue losses from these practices are inconclusive. However, bidders that used these collusive bidding strategies paid significantly less, suggesting that the indirect revenue loss may be much larger. The FCC and others conducting similar auctions should think carefully about the tradeoff between more informed price discovery and the risk of collusive bidding.

The best resolution of this tradeoff depends on the particulars of the market. In once-and-for-all spectrum auctions in which competition is expected to be strong, then a fully transparent process may be best, provided simple restrictions, such as restricting bids to three significant digits, are in place to eliminate code bidding. In daily electricity auctions with a few large suppliers, then the gains from disclosure are outweighed by the risk of collusion, which is magnified by the daily repetition of the market. In other cases, a middle ground may be best. This would involve revealing all tentative price information, but concealing bidder identities. In an anonymous auction, the ability to identify and enforce collusive outcomes is greatly weakened, since the detection and punishment of deviations is difficult.

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