

Preventing Collusion between Firms in Auctions

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1. Introduction

Collusion among bidders in auctions is a serious concern for those interested in designing allocation procedures to allocate public assets whether the goal of the process is efficiency or revenue maximization. In either case, bidders acting collusively can seriously impair an auctioneer's ability to accomplish their goal. There have been a wide variety of examples of collusion discussed in the economic literature including collusive bidding for school milk contracts (Pesendorfer (2000)), cattle auctions (Phillips, Menkhous and Coatney (2001)), timber auctions (Baldwin, Marshall and Richard. (1997)) and of course spectrum auctions which will be the focus of this study. We will present a brief survey of recent literature on collusion problems in mostly ascending auctions and then go on to discuss the Federal Communications Commission's experience in dealing with collusion in their auctions as a case study on how the lessons from this literature can be applied.

We will be discussing both ascending and sealed bid auction formats and the incentives for collusion embedded in each, but the focus will be on ascending auctions. As ascending auctions are the primary focus of the literature on collusion in auctions due to the fact that ascending auctions are more susceptible to "in-auction" collusion than are sealed bid auctions. The term in-auction collusion is used to refer to collusion that can emerge and be enforced inside a single auction. While sealed bid auctions are less susceptible to in-auction collusion they are still susceptible to forms of collusion stemming from interactions between the bidders outside of the auction itself. Similarly, our focus will be on multiple unit auctions rather than single unit auctions as collusion is more likely in the former than the latter for similar reasons.

Ascending auctions have become quite popular as mechanisms for allocating public resources as clearly demonstrated by their widespread use in spectrum license allocations in many countries around the world. The primary reasons for adoption in most cases is

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that they are generally thought to deliver highly efficient allocations and it seems quite simple for most bidders to figure out how to bid in them. An example of this reasoning is found in Binmore and Klemperer (2002) in which they note exactly these reasons in describing why the U.K. decided to adopt this format for their UMTS auction. Ascending auctions are thought to be easy to bid in because when there is a single unit of the good available for auction, the bidders know what the object is worth to themselves and the clock or Japanese version of the ascending auction is used, it is a well known result that the dominant strategy of the game for each bidder is to simply stay in the auction until the price reaches the level of what the bidder believes the object is worth to them and then drop out¹. Equilibrium strategies in multiple unit auctions are more difficult to derive but an extrapolation of the single unit strategy called “straightforward” bidding, is thought to be a reasonable and simple way bidders might approach bidding in such auctions. This strategy involves bidders bidding on the objects that would yield the most surplus to the bidder given the current prices so long as the prices are less than their value for the objects. Such a strategy is easy to learn and follow and it has been shown in Demange, Gale and Sotomayor (1986) and Milgrom (2000), that if bidders were to follow such simple strategies, it would lead to approximately efficient outcomes.

If bidders always did engage in straightforward bidding, these results would provide a strong foundation upon which to argue for the use of ascending auctions. Bidders, however, do not always follow this strategy. As we will discuss below, there are a number of alternative strategies bidders can and do pursue in multi-item ascending auctions that can lead to the bidders achieving a greater level of expected utility while leaving the auctioneer with less revenue and perhaps the social planner with less efficiency than if the bidders had bid straightforwardly. These strategies represent various approaches to bidders colluding among themselves to end up with an outcome they prefer to the competitive outcome. In situations in which such collusion seems likely, it is definitely important for an auctioneer to understand how and why collusion can impact their auction.

Toward this end, the next section will review some of the recent theoretical, experimental and empirical literature to see what types of collusive strategies exist in these auctions, how likely they are to be played as well as how one might design auctions to either minimize the possibility of collusion or to minimize its impact. The third section of the paper will discuss a case study of the FCC’s auction program to see what types of collusion have been experienced in their auctions, how the FCC has dealt with them and how the FCC has altered its rules over time in an attempt to minimize future collusion. We use the FCC as a case study for this purpose because it is an ongoing auction program that has evolved its approach to dealing with collusion over time in response to specific instances of attempted collusion. These examples and the public nature of the discussion

¹ The Japanese or clock version of the ascending auction involves the auctioneer using a continuous clock to slowly raise the price with all bidders who are currently “in” indicating by, for example, standing up in the room. As the price rises, bidders can choose to irrevocably exit the auction by sitting. The winner is the last bidder standing and they pay the price on the clock when the last bidder dropped out. The bidding strategy for the non-clock version of the ascending auction in which bidders are allowed to submit bids to top a standing high bidder is a little more complex but shares some of the same general properties and can be found in Isaac, Salmon and Zillante (2002).

around them make this an excellent environment in which to study the auction design problems arising from collusion. It is also the case that the FCC's experiences with collusion have inspired much of the recent theoretical and empirical literature on collusion and so in discussing these papers it is a natural follow-up to discuss their impact on the FCC's program.

2. Review of Literature on Collusion

2.1 Strategies for Collusion

There have been a large number of papers developing the types of collusive strategies inherent in multiple unit ascending auctions. One of the more important forms of collusion that can exist in either multi-unit or single unit repeated auctions was formally introduced in Robinson (1985), though of course had been discussed previously, in which the author develops models of bidder cartels or rings in auctions. A bidder cartel is a group of bidders that decide to bid as a single entity rather than multiple bidders. If we assume that there are n bidders involved in an auction and $k \leq n$ of them are involved in a cartel then the cartel works by having the cartel member with the highest value for the item in that particular auction bidding as they would in a normal auction while the others in the ring submit non-competitive bids or stay out entirely. This will usually allow the cartel member to win the item at a lower price than if they had to bid against the other members of their cartel. Robinson (1985) shows that such cartels are stable in ascending auctions but unstable in sealed bid first price auctions without repeated interaction. Stability in this case means that all members of the cartel achieve higher expected utilities by remaining a member of the cartel rather than attempting to compete against it.

The reason cartels are stable in ascending auctions is that, at least in the single unit private values setting, a bidder will always be willing to bid up to their value. Since all other bidders in the cartel would lose the auction anyway to the member with the highest value, they do just as well not bidding competitively. In a sealed bid first price auction, however, bidders submit bids lower than their value and the fewer number of bidders they believe they are facing the farther below their value they bid. For example, if we assume a standard single unit auction with private values such that bidder values are uniformly distributed on the range \$0 to \$100, we let n represent the number of bidders in the auction and v_i the value of winning to bidder i , the symmetric equilibrium bid function is $b(v_i) = v_i(n-1)/n$. For a two bidder auction, this means a bidder bids half of their value while for a three bidder auction, a bidder bids 2/3 of their value. The potential benefit of participating in the ring should be obvious as bidding against one rival and winning will be much more profitable than bidding against two.

Since the designated cartel member is bidding below their value though, another cartel member has an incentive to bid competitively against them. Consider two cartel members, A and B, with values of \$80 and \$60. If there is only one non-cartel member involved in the auction and the cartel worked as it should, then A would bid \$40 in the auction thinking he faces only a single competitor. B however, can look at this situation, see that A will be bidding \$40 and realize they can bid \$41 and make a profit if they beat the non-cartel member. B's ability to do this relies on having clear knowledge of A's

value but in order for A to be given the priority in the cartel to bid in the auction, B would have had to be informed of it. In anticipation of this cheating by B, A would have to bid enough to win against B, which would ultimately make the cartel of little value. Thus the incentive of cartel members to “cheat” in this manner means that such a ring may break down without repeated interaction. Note that in an ascending auction, bidder A will be willing to bid up to \$80 which means that B could never win (without making a loss) by bidding competitively. Therefore B has no incentive to do so and the cartel remains stable.

Cartel or explicit collusion like this usually involves formal communication and agreements between firms. Examples of it are studied in Pesendorfer (2000) and Baldwin, Marshall and Richard (1997). Collusion that results from repeated interaction is not typically studied as an explicit auction design problem as it is based upon the same principles of collusion that appear in the general literature concerning collusion among firms and must be dealt with in that manner rather than as an auction design issue.

The types of collusion that can be addressed by auction design were first discussed in Vickrey’s seminal paper on auction theory when he explicitly notes that the multiple unit versions of ascending or second price auctions include very different incentives than what are found in the single unit versions:

“It is not possible to consider a buyer wanting up to two units as merely an aggregation of two single-unit buyers: combining the two buyers into one introduces a built-in collusion and community of interest, and the bid offered for the second unit will be influenced by the possible effect of this bid on the price to be paid for the first, even under the first-rejected-bid method.” (Vickrey (1961) p. 27)

This idea is what has come to be known as “strategic demand reduction” in more recent papers, such as Weber (1997) and Ausubel and Cramton (2002). It is important to distinguish between two forms of demand reduction. The first is not a form of collusion yet its impact on the outcome of an auction is quite similar. The second form of demand reduction involves tacit or explicit coordination by firms to settle upon lower prices than would be reached without such agreements.

We can explain both types of demand reduction phenomena through a simple framework. Consider an auction environment in which there are 2 bidders and 2 items. In the first situation we will assume that one bidder is interested in winning both items, while the second bidder is interested in winning either of the two items but not both. In the second situation, the second bidder will be interested in winning both. Their values for the items are as in table 2.1.

	Bidder A	Bidder B
Item 1	\$100	\$80
Item 2	\$100	\$80
Both	\$200	\$80 or \$160

Table 2.1

To analyze this example we need to develop two fundamental concepts. The first is the idea of an equilibrium of an auction. We will use the game theoretic concept of Nash equilibrium, which defines an equilibrium as a set of strategies such that no bidder could improve their outcome through unilateral deviation. We will also use the term efficiency, which refers to the amount of the possible value to society that has been achieved by an allocation. If the bidder or bidders who value the items most win the items², then the most efficient or 100% efficient outcome has been achieved. If the items end up being assigned to other bidders then a less efficient outcome will be achieved.

Considering either case of the preferences bidder B has for winning both items, if the participate in a simultaneous ascending auction, the efficient competitive outcome is for bidder A to win both items paying \$80 for each item resulting in total revenue to the seller of \$160, total surplus of \$40 to bidder A and \$0 for bidder B. This is the outcome that would be approximately achieved if bidders followed the straightforward bidding strategy described previously as bidder B would always be willing to bid on item 1 or 2 whenever the price is below \$80 and would therefore drive up the prices of both to that level before dropping out.

The non-collusive sort of demand reduction could occur in the situation in which bidder B is only interested in a single item. In that case, once bidder B has placed a bid of \$1 on item 2, bidder A could place a bid of \$1 on item 1 and cease bidding. Bidder B has no interest in bidding further as he is currently winning one item at a substantial profit and that is all he wanted. If bidder A continues by bidding back on item 2, B will then bid back and continue doing so until the competitive outcome is reached. If bidder A stops bidding, or reduces his demand to a single object, then he ends up with a surplus of \$99 rather than a surplus of \$40. While this leads to substantially less revenue than the competitive outcome, this should not be termed as collusive as this requires no coordination or cooperation among bidders. This simply involves one firm reducing the number of items they are bidding on to reduce the price on the items that they win.

Demand reduction outcomes in the second case where bidder B is interested in both items can, however, be considered as collusive. It is possible to achieve the exact same outcome as before in which bidder A wins item 1 for a price of \$1 and bidder B wins 2 for a price of \$1. Again, both bidders prefer this outcome to the competitive one, as bidder A would have a surplus of \$99 and bidder B a surplus of \$79 compared to \$40 and \$0 respectively.

The important distinction between the two cases is based on what is required for this outcome to be supported as an equilibrium of the ascending auction. To construct an equilibrium that leads to this outcome we need to define strategies for each bidder that deliver it and show that neither bidder would prefer to deviate from them. The strategy for bidder A in this case would involve placing a bid of \$1 on item 1 and then committing to bid according to their non-collusive straightforward strategy of bidding until they reach their value if bidder B ever places a bid on 1. This is known as a “trigger” strategy as

² This analysis of course ignores the situations described in Janssen and Moldovanu(2003). The analysis could be extended to do so, but it is useful to begin with this simpler initial setting.

bidder A is promising to behave cooperatively unless bidder B does not and the first instance of non-cooperative play by bidder B triggers immediate punishment from bidder A. If bidder B adopts a similar “trigger” strategy in regard to item 2, then neither bidder would choose to deviate by bidding on the other’s item. Deviation from these strategies would involve something like bidder A choosing to bid on item 2. If he did that, bidder B would punish him by bidding up to his value of \$80 on both items. Bidder A would win both items but the outcome would be the non-collusive outcome already described in which bidder 1’s surplus is \$40. This is significantly lower than his surplus from not deviating, \$99. The same can be verified for bidder B. Thus these strategies constitute a Nash equilibrium of the game. The key element that allows this collusive outcome to be supported as an equilibrium is the ability for one bidder to punish the other bidder if they try to cheat from the collusive agreement. This agreement need not be explicit and could well be just tacitly observed and agreed to by both bidders. Such agreements or trigger strategies were not necessary in the case in which bidder B was only interested in a single item, but they are necessary when he is and it is the presence of these agreements, even when they are only tacitly observed, that makes the latter sort of demand reduction equilibria collusive in nature even though they are equilibria of non-cooperative games.

Using this same example, we can examine an important difference between ascending and sealed bid auctions. If we think instead of a first price sealed bid auction for both of these items simultaneously, then this demand reduction equilibrium disappears. If the bidders were to try to strike an agreement before the auction, either explicitly or tacitly, to only bid \$1 on their respective items, this agreement will be unenforceable during the auction as both have an incentive to deviate from it. If bidder B goes ahead and bids a price of \$1 on item 2 and nothing on 1, then bidder A can bid \$1 on 1 and \$2 on 2 and significantly improve the outcome for himself. Once bidder B realizes that A has cheated from their agreement, he has no recourse to punishment as he would in the ascending auction. Without this punishment capability to enforce the collusive agreement, it should no longer be effective.

This example should not, however, be taken as an indication that collusion is not possible in sealed bid auctions. If the bidders expect to be competing in a series of auctions or even in some repeated interaction outside of the auction environment, they can adopt strategies that involve punishing a deviator in future auctions or business dealings. The key to supporting collusive equilibria as possible outcomes of an auction is the ability of the bidders to punish someone who deviates from a collusive agreement and such opportunities can arise in any situation involving repeated interaction among firms. This is an application of what is known as the “folk theorem” among game theorists³. This is a general class of theorems which state that collusion can occur in games which are repeated an infinite or unknown number of times assuming players possess sufficient patience. The strategies that support collusion in these cases will take the form of a collusive agreement with punishment strategies used to enforce the agreement should

³ A deeper explanation of the idea of folk theorems for repeated games can be found in most game theory textbooks such as Osborne and Rubinstein (1994) for high level development or Watson (2002) for a simpler explanation. The particular type of folk theorem applied here was first developed in Fudenberg and Maskin (1986).

anyone deviate from the agreed upon course of action. With such strategies in place, no one would choose to deviate and collusion will be stable.

This allows us to make one very important point which is that in a situation involving firms that are generally collusive in nature, i.e. they tend to collude on most of their dealings, they will of course collude in any auction they are involved in. Anything an auction designer proposes to do inside the auction to eliminate collusion will lead to little success. This type of intrinsic collusion among a group of bidders will almost certainly also involve the explicit structure discussed above and again must be dealt with as a standard anti-trust issue, not as an auction design issue. Collusion can therefore exist under either auction format, but the ascending auction will be significantly more susceptible to it as the agreements can be made and enforced tacitly inside of a single auction.

There are a variety of papers such as Engelbrecht-Wiggans and Kahn (1999) and Brusco and Lopomo (1999) that develop other collusive strategies leading to collusion inside of a single auction that are quite similar to the collusive demand reduction example just discussed. Ausubel and Schwartz (1999) and Engelbrecht-Wiggans and Kahn (1999) make the situation for ascending auctions look particularly grim as they show that the collusive strategy is in fact the only strategy that proves to be a subgame perfect Nash equilibrium of an ascending auction⁴. Anton and Yao (1992), Brusco and Lopomo (1999), Ausubel and Schwartz (1999) and Grimm, Riedel and Wolfstetter (2001) describe similar collusive equilibria in which bidders signal collusive splits of the objects in the auction early and come to a sort of a negotiated agreement about how to divide up the objects in the auction most profitably. These papers paint a very dismal picture of ascending auctions by showing that the collusive equilibria are very damaging to the auction and that it is very reasonable to expect that bidders will be able to agree upon them.

A deeper look at the issue displays some key reasons why the picture for ascending auctions is not likely to be quite so bad in practice as in the theory. Most of the very pessimistic results about bidder collusion in these papers are derived from very simple two bidder models. In Ausubel and Schwartz (1999), the authors reframe an ascending auction as a bargaining game in which the two bidders are attempting to bargain over how to split up the items in the auction. They find that the unique subgame perfect Nash equilibrium of the game involves the bidders splitting the items between themselves at prices well below the competitive level. In a two bidder game, it seems entirely reasonable that bidders would be able to come to such an accommodation relatively easily. The problem comes from attempting to extrapolate such results to cases involving more than two bidders. As is found in most empirical or experimental studies of collusion or provision of public goods in non-auction contexts, the difference between a situation involving two agents trying to collude and one involving $n > 2$ agents is very significant as described in more detail in Isaac and Reynolds (2002). In two agent situations, the agents

⁴A subgame perfect Nash equilibrium is a stronger version of a Nash equilibrium that places additional restrictions on off-equilibrium path behavior for sequential move games of this sort. It is generally considered to be the most reasonable equilibrium concept to be used in these types of games.

can typically collude but this becomes more difficult and less likely as the number of agents grow even just to four or five.

There are both theoretical and practical reasons for the difficulty encountered by more than two agents colluding in auctions. Intuitively one can understand the issue by first imagining two people bargaining over how to achieve an amicable split versus three or more. Even in a standard bargaining situation where bidders can freely communicate, the difficulty will be increased. This is so because as the number of parties increases, so too is the possibility that 2 or more of them will have mutually exclusive interests that cannot both be satisfied. Also, the practical details involving forming an agreement between more and more parties become increasingly complex even in situations where an agreement is possible. Now imagine that all parties have to communicate through potentially difficult to interpret signals such as bids in an auction. Since effective collusion requires that all bidders be able to interpret the signals correctly, the more bidders are involved, the greater chance that at least one is unable to understand the signals being sent by the others. While it is certainly still possible for larger numbers of bidders to collude, it will be substantially more difficult.

The technical support for the decrease in collusion as the number of bidders increases is contained in Brusco and Lopomo (1999). It contains the standard two bidder results indicating that collusion is a serious problem as is found in other papers, but then extends the analysis to more bidders. They find that the possibility for collusive outcomes diminishes as the number of bidders rises relative to the number of items. The reason is similar to what was explained above. As the number of bidders grows, the possibility of the bidders finding amicable splits diminishes. Brusco and Lopomo go even further to show that the presence of significant externalities or synergies across items also diminishes the prospects for collusive outcomes. The intuition behind these results can be explained by examining two different situations. In situation A, imagine two bidders in a spectrum auction, one whose business plan requires obtaining all licenses on the western side of the US to operate a PCS business and would like the east coast licenses as well, but does not see those licenses as vital. The other firm has the inverse preferences, which means it wants to operate primarily in the eastern side of the country. In situation B, consider adding a third firm who has a business plan for the center of the country requiring half of the licenses from the east and west regions in order to be viable. In situation A, a collusive outcome will almost certainly emerge with the bidders dividing the country in half and agreeing not to bid on each others region. In situation B, no bidder will be willing to demand reduce below the half of the country they require and without side payments there is no way to split up the licenses in a way that would be agreeable to all three. In this case, bidding might continue until the east and west bidders have outstripped the willingness to pay of the middle bidder and only then would those two bidders engage in a demand reduction strategy to not bid on the other's half. By then, though, the prices of the licenses would be much higher than would result in situation A, diminishing the harm resulting from any collusion that emerges.

There is both experimental and empirical evidence to support the Brusco and Lopomo(1999) results. Kwasnica and Sherstyuk (2002) test these predictions through

conducting experimental auctions involving both small and large numbers of bidders and varying sizes of complementarities across items. They find that increasing the number of bidders and/or the presence of large complementarities across items reduces collusion as predicted in Brusco and Lopomo (1999). They also find an interesting side result due to the fact that their experiments involved a series of auctions, which is that moderate complementarities lead to winner rotation schemes being used more often as a collusion device by the bidders. Of course winner rotation schemes only work for repeated auctions as they involve cartel-like behavior in which bidders with low values in a particular period refrain from bidding while those with higher values bid and then trading off when their positions are reversed. In a single shot auction, such strategies could not emerge.

A careful study of many different spectrum auctions including those from the US, Canada and Australia will reveal many cases of such behavior, but Klemperer (2002b) contains a very clear explanation of a sequence of events from the German 3G spectrum auction to demonstrate that such behavior also occurs in field auctions. In this case, one of the firms in the auction, T-Mobil, appeared unable to interpret or unwilling to agree to the demand reduction signals being sent by another bidder, Mannesman. This inability to interpret signals or unwillingness to agree to the split lead T-Mobil to drive up the prices by 2.5 billion Euros before achieving the same allocation Mannesman initially signaled at a much lower price. This example is particularly interesting since earlier in the same paper and in Grimm, Riedel and Wolfstetter (2002) those exact same two firms are described as having come to a very rapid accommodation in an earlier 1999 German DCS-1800 spectrum auction. In Klemperer (2002b) the reason indicated for the breakdown in collusion is a result of T-Mobil just not understanding the way a collusive signal would be sent in the second auction, and in fact appears to criticize the advisors of T-Mobil for this failure to collude. It is worthwhile to note that the 1999 auction involved just two credible bidders while in the later 3G auction six were still in the auction at the time the original collusive signal was sent. Exactly why the collusive outcome was not realized in the second case is uncertain, but what is not in doubt is that the 3G auction with a large number of bidders resulted in greater than expected revenue while the earlier auction with only two credible bidders resulted in a quick collusive agreement and lower than expected revenue.

The indication from these results is that while collusion can be a problem in ascending auctions, and indeed a devastating one in particular cases, theory and empirical evidence tell us that it is primarily a problem of small numbers of bidders. Small numbers of bidders will tend to find it relatively easy to signal collusive outcomes to other bidders and come to quick accommodations. Larger numbers of bidders, bidders whose interests overlap more and/or involve more complementarities will be significantly less likely to effectively collude. This tension between smaller versus larger numbers of bidders is mostly absent from the majority of the theoretical analyses of collusion and accounts for the overwhelmingly negative results the literature contains. It is therefore quite important to examine the results from Brusco and Lopomo (1999) and Kwasnica and Sherstyuk (2002) to see the degree to which these problems exist when more than two bidders are involved. This argument, however, is in no way intended to minimize the definite problem with collusion that exists in ascending auctions with a small number of bidders

whose interests are relatively mutually exclusive. In such cases, an auctioneer who ignores the possibility of collusion does so at the risk of achieving a very poor outcome.

2.2 Proposed Solutions

The proposals for how to solve or minimize problems coming from collusion all involve different ways of trying to modify the design of the auction to either limit the possibility of bidders colluding or to limit the harm from the collusion if it is going to exist. It is important to realize that all of these proposals are designed to work against in-auction collusion. This type of collusion will only be an issue in auctions involving multiple units when bidders are allowed to win more than one item and are interested in doing so. In single unit auctions or auctions in which bidders can win only single items, the only type of collusion that can exist is of the general market collusion that we have already pointed out can not be dealt with through the design of an auction.

There have been several fundamental changes to the design of an ascending auction that have been proposed at various times to deal with the problem of collusion. The most basic proposal is to abandon the ascending auction in favor of a sealed bid design, which, as described previously, is less susceptible to in-auction collusion. The reason it is less susceptible is that a sealed bid auction removes the ability of bidders to punish other bidders inside of the auction for deviating from some proposed collusive split. One might see this as the implicit recommendation in Robinson (1985) and it is also suggested in Engelbrecht-Wiggans and Kahn (1998) who go further to suggest that in a multiple unit auctions, the objects might be best auctioned in sequential sealed bid auctions.

An alternative to getting rid of the ascending auction format entirely would be to have an auction that begins as an ascending auction and then at some point switches to a final sealed bid round. A simple version of this was proposed in Cramton and Schwartz (2000), but Klemperer (2002a) proposes a more sophisticated version of this approach calling it the Anglo-Dutch hybrid auction. The way such a design would work is that if there are k objects in the auction and $N > k+1$ bidders in the auction when it begins, the auction starts as an ascending auction. This continues so long as there is significant excess demand for the objects, but when the number of bidders drops down to $k+1$ then the ascending portion of the auction is ended and the remaining bidders participate in a sealed bid round to conclude the auction. The proposed benefits of this design is that it eliminates the possibility of punishment strategies and therefore destroys any of the collusive equilibria we discussed previously while preserving many of the advantages of ascending auctions.

There is another version of this idea of a final sealed bid round in Ausubel and Milgrom (2001). They propose a final round of proxy bidding be added to the end of an ascending auction or even using a proxy bid auction in place of an ascending auction. Under their proposal, instead of submitting bids, the bidders would send in a value function to the auctioneer and bidding would be done by a proxy bidding agent in an ascending auction that would place bids according to the straightforward bidding strategy. The reason for this proposal is that it has been shown that if bidders were to bid according to such a

strategy, then the efficient outcome would be achieved. This design is an attempt to force them to. In a single unit auction context, this is equivalent to e-Bay's proxy bidder design and should be expected to work quite well. Implementing such a design in a multiple unit context appears more problematic and will be discussed in more detail in section 3.

Albano, Germano and Lovo (2001) present a different idea for how to remove collusive equilibria in ascending auctions which involves using a Japanese or clock version of the auction instead of the non-clock versions more commonly used. The difference is that in the clock or Japanese version, prices rise at the discretion of the auctioneer and bidders are only able to agree to pay the price or drop out. In the non-clock auction, bidders submit specific bids as they choose. The results in Albano, Germano and Lovo (2001) show that using the Japanese version of the auction does eliminate certain types of signaling equilibria because bidders are no longer able to send signals with their bids, but demand reduction equilibria will still exist. The result of not allowing bidders to submit specific bids is to make collusion more difficult for bidders but not eliminate the possibility completely.

Still another novel change to the ascending auction can be found in Ausubel (2002). This paper describes an ascending auction design for multiple homogenous items in which bidders can "clinch" items as the auction progresses when the demand reaches a point at which it becomes clear that they will win at least one item. When that occurs, the price of that item becomes fixed but the auction continues for the other items. The result is that continuing to bid on other items cannot increase the price of clinched items. This effectively eliminates the incentive to engage in demand reduction.

There have been several experimental studies conducted aimed at investigating this auction design and they are summarized in Sherstyuk (2000) along with other experimental studies of collusion in auctions. The different studies have taken quite different approaches to evaluating the mechanism and their results indicate that the performance of the mechanism depends crucially on the environment and the implementation. In Kagel and Levin (2001) and Kagel, Kinross and Levin (2001), human bidders were placed into auctions of this type bidding against computer bidders that were programmed to play the equilibrium strategy. The results of the evaluation show that the auction design performs well in comparison to a uniform-price auction in terms of eliminating demand reduction and improving efficiency but occasionally yields less revenue than expected. Grimm and Engelmann (2001) evaluate Ausubel's dynamic Vickrey auction against five other formats with each auction involving two objects being auctioned between two human bidders with a demand for two units each. Their findings show again that the dynamic Vickrey auction produced higher efficiency and less demand reduction than the other mechanisms evaluated.

A perhaps more telling examination is found in Manelli, Sefron and Wilner (2000) in which the authors compare Ausubel's dynamic Vickrey auction to the standard Vickrey auction in a more complicated environment involving three items and three bidders, each of whom is interested in winning only two units. The study reports some unexpected behavior in the dynamic Vickrey auction in which the bidders would bid quite

aggressively by bidding on all three objects even though they would receive no value from winning the third item. Subjects would engage in bidding on all three objects until they had clinched the two objects they wanted which typically lead to inefficient outcomes. This strategic gaming of the Ausbel mechanism is certainly not part of the equilibrium strategy and may not even always be beneficial, but the authors report that its use by the subjects was quite robust to variations in the environment which could indicate that such strategies will be persistent or at a minimum bidders would need significant experience with the mechanism before they learn to bid according to the “right” strategy. In the short term, such aggressive dis-equilibrium bidding could lead to inefficient outcomes. The results from all of these experimental studies suggests that in simple environments, the Asubel dynamic Vickrey auction may work as intended, but in larger and more complex environments it may run into difficulties.

In addition to these large changes to the mechanism, there have been several proposals to slightly modify the rules of specific ascending auctions. One of the more common proposals is to allow only anonymous listings of bids in round results. In most current ascending auctions used for spectrum license auctions, the identities of those who placed the current standing high bids and even all past non-winning bids are available for all to see. Under this proposal, those identities would be hidden. The effect of such a change would be to make it impossible for one bidder to tell if another bidder has deviated from some collusive arrangement. They might see that some bidder has bid on a license they are interested in, but they will not know if it is the bidder they had the arrangement with or another and thus will not know to punish. Without the ability to monitor each other’s behavior, both parties to any collusive agreement have the incentive to deviate from the agreement. This suggestion has been made in several FCC proceedings and also in Cramton and Schwartz (2000) and Klemperer (2002a).

Another common suggestion is to raise reserve prices. If bidders are going to be able to agree to collusive splits early in the auction and revenue is a concern of the auctioneer, then using high reserve prices can minimize the harm from those agreements. This too is quite a common suggestion and can be found in Graham and Marshall (1985) Cramton and Schwartz (2000) and Klemperer (2002a). This proposed “fix”, however, has a very serious potential downside. As noted, the problem of collusion is primarily one of small numbers of bidders. If reserve prices are set too high, this may discourage potential bidders from entering and actually lead to collusion being more likely to occur. This remedy must therefore be used with great care.

Most of the standard approaches to combating collusion we have discussed have been designed to find ways to limit the ability of bidders in an auction to punish a deviator. There is another way to break up collusive equilibria of this sort, as suggested by Brusco and Lopomo (1999): additional bidders. If the auctioneer attracts more bidders to an auction, there will be less of a possibility that the bidders could agree on a split of the items that is mutually agreeable without using side payments. In the ascending version of the auction, bidders will tend to bid competitively until the values of enough bidders have been surpassed such that the remaining bidders can agree to collusive splits. The

remaining bidders may still be engaging in demand reduction, but the position of the auctioneer has been made significantly stronger by the addition of the additional bidders.

One issue to note with this though is that the additional bidders must be willing and active participants. Some have suggested that problems in some of the European UMTS auctions have occurred as a result of some bidders assuming they would be likely to lose the auction given the relative strengths of the other participants and choosing to bow out of the auction early or even not entering at all. The presence of such weak bidders is certainly not helpful. What is helpful is the existence of additional bidders who believe they have a legitimate chance of winning the auction even against a competitor deemed stronger. This suggests that pro-competitive measures such as giving smaller bidders bidding credits which allow them to compete against larger firms may also work against collusion.

3. Case study of FCC experience with combating collusion in spectrum auctions

There are two facts about the history of collusion in the FCC's spectrum auctions that explain why this is an important case study to consider. First, there have been a large number of different instances of bidders attempting to collude in FCC auctions. Second, these attempts have been largely unsuccessful and to date no one has been able to identify more than a negligible loss in revenue in these auctions resulting from collusion.⁵ The reason for this lack of successful collusion is due in part to the FCC's attempts to minimize collusion, but these attempts have been made far more successful by the large number of competitors that are usually involved in each auction. We will begin this case study by cataloging some of the more common or well known types of collusion that have been attempted in FCC auctions and then go on to explain how the rules of the auctions have evolved to deal with these issues. Before reading this case study it will likely be helpful to review the rules of FCC auctions, which are explained in detail in Salmon (2003).

3.1 Types of collusion in FCC auctions

There have been many forms of collusive strategies that have been attempted over the history of the 30+ spectrum auctions conducted by the FCC. All have shared the same basic structure discussed in section 2. That is, they have involved attempts to settle upon demand reduction equilibria supported by punishment strategies. The interesting part of these attempts is the varied approaches bidders have used to communicate such intentions to other bidders.

⁵ The possible exception to this is the DEF block PCS auction. This auction saw the highest level of collusive activity in any FCC auction and there is reason to believe that this led to lower than optimal prices.

The most basic attempts at collusion observed have taken the form of simple punishment strategies. These involve situations such as bidder A who is interested in license 1, bidding on license 2, one they may well not be interested in, in an attempt to convince bidder B, who does want 2, to cease bidding on license 1. This is sometimes referred to as “retaliatory bidding” and instances of such behavior are quite common throughout the FCC’s auctions. The difficult part of using a strategy such as this to signal another bidder to coordinate on the collusive outcome is finding a way to make the other bidder aware of what the signal means.

Perhaps the most creative and well-known approach to solving this communication problem has come to be known as “bid signaling with trailing digits,” which was used during the FCC’s early PCS auctions. At that time, bidders were allowed to enter in their own bid amounts so long as they were greater than some specified minimum. Since the prices of these licenses were in the millions and hundreds of millions of dollars, the last three digits in the bids were of no real consequence. The licenses themselves in these auctions were identified by a two or three digit code identifying the geographic location of the license. Imagine a situation in which bidder A is interested in license 242 while bidder B is interested in licenses 105 and 242. If bidder A wants to signal bidder B to stay away from license 242, he might submit a bid on license 105 of \$5,000,242. The last three or “trailing digits” are then used to refer back to the license bidder A wants B to cease bidding on. Using such trailing digits, bidders could send coded messages back and forth to try to settle upon a collusive outcome.

One problem with even the trailing digits approach is that some bidders might not look closely enough at a rival’s bid to notice them. This prompted some bidders to make their intentions even more obvious using strategic withdrawals. In an attempt to alleviate the exposure problem in their auctions⁶ the FCC allows bidders to withdraw standing high bids in the auction. When a bidder withdraws their standing high bid on a license, the new minimum accepted bid becomes the amount of the previous high bid on the object. In the early auctions, withdrawals were submitted after a round of bidding had concluded and standing high bidders declared. In the same scenario as above, assume that bidder B has a bid of \$4,500,000 on license 105. Bidder A could submit a bid of \$5,000,242 for license 105 and then withdraw it in the same round. Such a sequence would not only call attention to the bid but also constitutes a more explicit offer to bidder B since they can simply resubmit their previous bid of \$4,500,000 to regain the standing high bid on license 105. Such a withdrawal serves as a very clear signal of bidder A’s intent.

Without these two mechanisms, signaling collusive intent can be more difficult but it can still be done using retaliatory bidding, which requires a little more effort on the part of the bidders to communicate intent. As an example of one such attempt, in auction #18,

⁶ See Salmon (2003), the general FCC case study contained in this volume, for more information on the exposure problem. The general idea of the exposure problem refers to a problem that can occur when a bidder needs a group of say five licenses for their business plan such that if they only win four they are worth little or nothing to the firm. In that case, the bidder can be “exposed” to a significant loss if they bid on the package intending to win the entire group and then another bidder bids more on one of the licenses than this bidder is willing to pay. The bidder could end the auction having promised to pay a large sum of money for four licenses that are now of little value to him.

the 220 MHz auction, there were 3 nationwide licenses, denoted as K, L and M blocks, in addition to a large number of smaller regional licenses. It was well known that one particular bidder, we will refer to as bidder 1, had to win one of these three licenses but only wanted one. There were four other bidders interested in these licenses as well with two or three of those being interested in more than one license. Bidder 1 tried on repeated occasions to signal a collusive equilibrium by following a set pattern of bidding. They bid on license M in one round and then in the next they would bid on all three licenses, K, L and M. In the following period, they would re-bid on license M again, regardless of whether or not they already held the high bid on that license. They continued this pattern so long as one of the other bidders bid on license M⁷. This was a very clear retaliatory signal being sent that bidder 1 would refrain from bidding on the other two licenses if the other bidders stopped bidding on license M. The outcome of this auction is that the auction progressed with bidder 1 bidding according to the described strategy while the other bidders bid more or less evenly across the three nationwide licenses for 15 rounds, apparently ignoring the collusive offer being made. One bidder dropped out in round 8 while two of the other three dropped out of the competition simultaneously after round 15. At that point bidder 1 stopped bidding as did the remaining nationwide bidder. Bidder 1 ended up winning license M and the remaining bidder won the other two.

It seems quite clear that this was an attempt by bidder 1 to collude with other bidders. The interesting question is whether or not the outcome that emerged was a collusive outcome or a competitive outcome. Based upon the evidence, it seems more likely to have been a competitive rather than a collusive outcome. Since the last two bidders dropped out of the auction at the eventual price level, it seems likely that the prices were more than they were willing to pay rather than that they were agreeing to demand reduce. The remaining bidder could have demand reduced for collusive reasons from three licenses to two, but that seems unlikely as well. One thing about the outcome is certain though; by following this strategy, bidder 1 was driving up the price on license M faster than the prices of the other two items. Consequently, they ended up paying approximately 20-27% more for the license they won above the price the other two bidders paid for identical items.⁸ This example serves as an example of a rather clever signaling approach that can be used even in the absence of trailing digits and strategic withdrawals while also showing why such collusion attempts are not necessarily effective. Competing bidders are not always willing to go along with the collusive offer being made by another and pursuing a collusive strategy and failing can be quite costly.

3.2 FCC attempts to deal with collusion

The FCC has had some fairly simple anti-collusion rules in place since the auctions began. Their basic requirement is found in Section 1.2105(c)(1) of the Commission's rules and says:

⁷ It was possible for multiple bidders to bid on license M in one round with bidder 1 maintaining the high bid. This is because most of the bids were made at the minimum increment and the FCC's rules state that the bidder who bids first is made the standing high bidder.

⁸ \$3.9 million compared to \$3.2 and 3.0 million.

After the short-form application filing deadline, all applicants are prohibited from cooperating, collaborating, discussing or disclosing in any manner the substance of their bids or bidding strategies, or discussing or negotiating settlement agreements, with other applicants until after the down payment deadline, unless such applicants are members of a bidding consortium or other joint bidding arrangement identified on the bidder's short-form application pursuant to § 1.2105(a)(2)(viii).

The interpretation of this is that bidders can talk among themselves, and form whatever cooperative arrangements they choose to prior to the start of the auction process, which is considered to be when the bidders submit their applications to be bidders. These pre-auction discussions, however, must satisfy two conditions. The first is that any cooperative agreements formed must be disclosed in the application stage. Second, the agreements must not violate any relevant anti-trust laws dealing with collusion between firms. So long as these conditions are satisfied, bidders can talk as much as they want before the applications are submitted, but once that occurs bidders are not allowed to communicate about the auction.

It is interesting to note that this rule allows for the formation of bidder cartels or rings prior to the start of the auction. At first glance, this might seem to be an odd characteristic of an anti-collusion rule. The reasoning behind it is that it would be difficult if not impossible to forbid any such discussions and alliances among firms prior to the start of the auction. What the rule does, however, is make sure that any agreements that are made are publicly viewable which ensures that they can be more easily reviewed in light of standard anti-trust laws. In the previous section we already discussed that using an auction design to fight any such endemic collusion or concentration of market power in a market will be ineffective. This rule allows for the easier enforcement of standard regulations to combat collusion and concentration of market power.

This prohibition on communication during an auction was one of the reasons bidders were forced to send signals through their bids instead of talking directly. These signals are also technically violations of the anti-collusion rule, but the violation is not as clear and legally actionable. There have been only two cases in which the Justice Department/FCC has prosecuted bidders for violating the anti-collusion rule. One violation was based upon bid signaling while the other was based on direct communication between two bidders.

In the course of the DEF block PCS auction, High Plains Wireless accused a competitor, Mercury PCS, of using trailing digits to try to signal a warning for High Plains to cease bidding on a particular license. Mercury's main initial defense was that they believed that bid signaling with trailing digits was a common practice and therefore did not violate the FCC's anti-collusion rules. After an extensive investigation by the FCC and the Justice Department, this case was resolved when Mercury agreed to settle with a consent decree. In general terms, the company had to agree to little more than that they would not engage in similar actions in future auctions. Unfortunately, this was not a strong message sent to

future bidders about the consequences of such behavior. The reasons the Justice Department settled the case in this manner were never made public, but it appears to be due to the perceived difficulties in convincing a jury that such signaling was collusive in nature and to the likely low level of provable damage from the incident.

Parallel to the Department of Justice investigation, High Plains had filed a lawsuit against the FCC protesting the award of licenses to Mercury. This lawsuit led to a very long series of appeals with the most recent decision (January 11, 2002) coming from the US District of Columbia Circuit Court of Appeals. High Plains was challenging the award on several grounds, all of which the court dismissed. On the specific charge that the award of licenses should be rescinded due to Mercury's violation of the anti-collusion rule, the court ruled that since the language of the rule had not specifically mentioned and forbidden this sort of bid signaling and retaliatory bidding in general, the FCC was not violating its authority to award the licenses to Mercury.

The second case of bidder collusion occurred in the same auction and involved one bidder, US West, actually calling another bidder on the telephone, Western PCS, during the auction. The purported intent of the call was to "apologize" for a mistakenly placed bid on a license Western had the high bid on. Even if the intent was benign, this still constituted a direct breach of the auction anti-collusion rules. The communication was reported by Western PCS and the outcome was a fine in the amount of \$1.2 million levied against US West, although they were able to reduce the fine down to \$800,000 through subsequent negotiations. Western PCS also ended up paying a smaller fine due to the fact that they waited until well after the auction concluded to report the incident.

In the original FCC auction design there were few design features included that were intended to mitigate collusion beyond this general prohibition on communication. Since those first auctions, many rule changes have been proposed but only two have been implemented while a third is in the final stages of implementation. As a means of eliminating the possibility of bid signaling, the FCC has changed over to a system of increment bidding. In this system, instead of bidders typing in the specific amounts they wish to bid, they can simply choose to bid some multiple of the minimum increment over the previous standing high bid. If the standing high bid is \$5,000 and the minimum increment is \$500, then bidders are allowed to bid by choosing an integer x in the range 1-9 and their new bid will be $\$5000 + x * \500 . This makes it impossible for someone to use trailing digits to signal any collusive offer.

Similarly, the FCC has limited the number of withdrawals bidders can place. In the PCS auctions, DEF block in particular, bidders were submitting a large number of withdrawals throughout the auction as signaling devices. Not long after this auction, bidders were reduced to being able to submit withdrawals in only two rounds during the auction. That is, any bidder can choose two rounds in the auction in which to submit withdrawals but those two rounds can be different for every bidder. This makes withdrawals relatively more expensive to use as signaling devices and has virtually eliminated their use in such strategies.

3.3 Alternative Rules that Have Been Considered by the FCC

The FCC has considered a number of other possible rule changes to further reduce the possibility of collusion in their auctions. Most have been rejected. It is useful though to go through some of the more common proposals and explain why the FCC has rejected them. It is important to keep in mind that just because these proposals were rejected for the FCC's case does not mean that they are necessarily bad ideas, just that in the FCC's determination they are not appropriate to adopt for their situation. Therefore this section will attempt to describe where, when and why some of these proposals should or should not be adopted using the FCC's case as a background example.

Perhaps the most common rule change suggested is the move to anonymous bidding and/or to reduce the amount of information published during each round of the auction. The current approach in the FCC's auctions is to publish every bid submitted at the end of every round with the identity of the bidder. Some propose just publishing the highest bid with the associated bidder while others go so far as to suggest that the high bid only should be published without reference to the bidder that submitted it. The reasoning behind such a proposal was discussed above.

There are two main reasons the FCC has not adopted this proposal. One is something of a philosophical commitment to making the auctions as transparent as possible. This is thought to increase the trust among the bidders that the FCC is conducting the auction in a fair and legitimate manner. If bidders believe the auctioneer to be untrustworthy, this can adversely affect the outcome in many ways ranging from potential bidders choosing not to participate to actual bidders altering their bidding behavior in unforeseen ways that could lower revenue and/or efficiency. Full publication of all information represents an attempt to foster that trust.

In many of the FCC's auctions there is a second and more solid economic argument for publishing the information. For many of the services, the value a bidder has for a license may legitimately depend on which other bidders are bidding on the adjacent licenses. One reason for such preferences might be to ensure technological compatibility between providers in a certain region so that they could settle upon roaming agreements later on. Publishing bidder identities can then be very important to obtaining an efficient outcome from the auction. The FCC has continued to publish identities based on the belief that the efficiency enhancing aspects of the information outweigh its potential to be used for collusive purposes. One can argue that bidders are using the information to engage in "good collusion" as they are using it to coordinate on the efficient allocation. In cases such as this in which coordination among bidders is necessary to achieve an efficient allocation an auctioneer should be careful to balance their desire to eliminate "bad" collusion so that they do not also eliminate the possibility for "good" collusion.

It is important to realize that the situation of interrelated values described here goes beyond the standard view of affiliated values as developed in Milgrom and Weber (1982) and therefore the value of information revelation goes beyond the standard notion of the

linkage principle. Value affiliation refers to the idea that if the value one bidder has for a Boston license is high then this means the values other bidders will have for Boston are also likely to be high and the linkage principle suggests that in such cases, information revelation in an ascending auction can increase revenue. While it seems believable that values in spectrum auctions are affiliated in the Milgrom and Weber sense, the relationship noted above is quite different. The preferences described above involve complementarities between bidders and across licenses. In other words, the value a bidder has for winning the Boston license may depend on the identity of the bidder who wins the New York license. For situations in which such preferences exist, publishing the identities of standing high bidders is necessary for achieving efficient outcomes. For other situations in which such cross bidder linkages do not exist, the economic reason for publishing information will not be applicable and may indicate that anonymous bidding is a viable rule to counter possible collusion.

Another proposal that has been made on many occasions and in many different forms is to end the auction with a final sealed bid round. Again, the reasoning behind this has been discussed above. Theoretically this sounds like an easy fix, but there are a very large number of problems with it depending on how it is implemented. One possible implementation approach is just to declare that the auction will last x rounds as an ascending auction and round $x+1$ will be a sealed bid round. This implementation leads to a strong incentive for the bidders to engage in parking behavior. Parking refers to a bidder bidding on licenses they have little or no interest in to draw attention away from the licenses they are interested in. Such behavior already occurs in the FCC's auctions but the uncertain end point gives the bidders an increasing incentive to move away from this strategy as the auction moves on. If they know there is a defined endpoint, there is no reason to stop parking until then. If that occurs, then all of the information revelation that is the reason behind using the ascending format is eliminated as no useful information is revealed until the sealed bid round and by then it can not be taken advantage of. A final sealed bid round then is quite likely to have a significantly negative effect on efficiency and perhaps revenue although it would breakup the collusive equilibria.

An alternative would be to implement an unknown switchover point based on a rule derived from excess demand as in Klemperer's Anglo-Dutch auction, though this specific proposal has not been made to the FCC. This idea is superior but when an auction has perhaps 400 market areas it would be difficult to determine how to implement any such variable switchover rule. In an auction with a small number of roughly homogeneous items such as the case in most European 3G or UMTS auctions for which it was really proposed, this design might have worked quite well. In auctions with a large number of heterogeneous objects and markets, it is uncertain how to properly implement such a design.

The proxy bidding suggestion contained in Ausubel and Milgrom (2001) and discussed above has similar implementation problems for large auctions. One of the most significant problems would be constructing an interface through which bidders could send in such a value function. Since values in these auctions are very complex and interdependent, for a proxy auction to have a chance at reaching an efficient outcome,

such interdependencies must be accounted for in the system. More problematic still, bidders would have to actually be able to quantify their values for all combinations of items, which is something they typically cannot do when asked in such a manner. It would also likely take a fair amount of technical sophistication by the bidders to be able to figure out how to program their values into the system, as a table just listing all combinations of licenses is unfeasible for large numbers of items. These are all very difficult tasks and there is little reason to suspect the problems could be overcome for complex auctions. Unless these problems are solved, this approach again is likely to lead to inefficient outcomes and to bidders being faced with very serious exposure problems. In much simpler scenarios such as when values are not related across bidders and/or interdependent across items as well as when the number of items is small, such an approach might work just as it does for e-Bay. In the FCC's case and other complex environments, this should not be expected to be a workable solution.

A final proposal that attempts to deal with collusive behavior that was not mentioned in the previous section involves adopting a combinatorial auction design. In such a design, bidders would be able to send in a single bid that would be an "all or nothing" bid on a group or package of items. This is in contrast to the FCC's current system in which bidders must send in one bid per item and they could well end up getting only a few out of the group the package they are interested in. The primary motivation behind switching to such a design is discussed in Salmon (2003), which is to reduce the exposure problem bidders face. A side benefit is that it can also reduce the incentive to demand reduce.

Imagine a situation in which there are two bidders bidding on two items for which their values are those in the table 3.1. These values indicate that bidder B wants either 1 or 2 but not both while bidder A wants both. The non-collusive outcome of a standard ascending auction would involve bidder B always being willing to place a bid on either 1 or 2 so long as the price were less than \$80. This would result in bidder A winning both items for a price of \$80 each, resulting in a total cost of \$160 and surplus of \$40. If, however, he were to reduce his demand to only a single item he could end up with a much larger surplus, \$99, with both bidders just bidding a price of \$1 on alternate items. This is essentially the same example discussed earlier.

	Bidder A	Bidder B
Item 1	100	80
Item 2	100	80
Both	200	80

Table 3.1

In a combinatorial auction, this demand reduction strategy is no longer an equilibrium. Winner determination in a combinatorial auction is performed by finding the set of mutually exclusive bids that yield the highest revenue. For example, if bidder A submitted a package bid on 1 and 2 of \$20, in order for bidder B to submit a bid for 1 that would win, it would have to be at least \$21. What this means is that in order for bidder A

to win both items, he only has to submit a package bid for both that is higher than bidder B would be willing to bid for either item individually.

Since the highest bid B is willing to submit for either 1 or 2 individually is \$80, the equilibrium in this case would involve bidder A placing a package bid of \$80+ ϵ on both items. Bidder B would not be willing to bid more and bidder A would end up with a surplus of \$120. Since bidder A's surplus of \$120 is greater in this outcome than under the collusive outcome, the collusive outcome will no longer be an equilibrium of this game. This shows an example of a general phenomenon that the cases in which demand reduction equilibria exist are significantly fewer in combinatorial auctions. We should note that this does lead to less revenue than the competitive outcome in the non-combinatorial design but it seems unlikely that the competitive outcome is the one that would emerge in the non-combinatorial case.

We can note further that if bidder B possessed additive values for both items, that is, if his value for the package were \$160 instead of \$80, there would now be a demand reduction equilibrium. So combinatorial bidding does have some advantages in removing certain types of collusive equilibria but it will not remove all of them and may make those easier for the bidders to settle on. As a collusion fighting device, a combinatorial mechanism alone is insufficient, but its other benefits may lead to it being a desirable mechanism in cases involving significant cross license complementarities.

Conclusion

It should be clear that collusion in auctions can represent a serious obstacle to an auctioneer raising significant revenue or ensuring an efficient allocation. Finding ways to combat collusion in the rules of an auction is therefore a very important task for a designer. It is unfortunately not always an easy problem to solve and it is definitely not a problem that either the academic or applied auction design literature has developed a complete solution for. It is, however, possible to learn from past mistakes and from the academic literature to identify some principles of good collusion prevention in auction design.

The first principle is that if the pool of bidders that will be participating in an auction interact repeatedly outside of the auction and tend to collude in those dealings, there is little an auctioneer can do to prevent collusion inside the auction. Such situations are beyond the domain of auction design and one must approach them from a policy standpoint the same as any other case involving collusion among firms.

If collusion is not quite so endemic to the bidder population, the auctioneer has several tools available for limiting the possibility of in-auction collusion developing. The first step to dealing with collusion involves understanding the environmental characteristics that make it more likely to occur. These include:

1. Auctions involving multiple items in which bidders are allowed and interested to win more than a single item. This would include repeated single unit auctions for related goods.
2. A small number of bidders relative to the number of objects for sale.
3. Bidders with preferences that are diverse in terms of the items they are mainly interested in and possess a low degree of complementarity across items.

In situations that do not meet these criteria, it is significantly less likely that bidders would end up colluding. Consequently an auctioneer may be able to design an auction with less concern for collusion fighting allowing them to concentrate on other aspects. If these criteria are met, an auction designer must be very careful in designing an appropriate mechanism to fight collusion. The point is that the needs of fighting collusion in an auction design must be balanced against revenue and efficiency concerns. Over-designing an auction to fight collusion in some cases may be counter-productive as in doing so you may sacrifice other valuable qualities of the auction. For example, running a sealed bid auction to fight collusion in a complex case involving interdependent where collusion should be expected to be unlikely may well sacrifice efficiency and or revenue. That may not be a good trade-off. In a situation in which collusion should be more likely, however, the collusion fighting properties of the sealed bid auction may dominate and make running the sealed bid auction worthwhile.

There were many solutions discussed above that seem up to the task of minimizing collusion in auctions for small numbers of relatively homogenous goods. For example, using a properly designed first price sealed bid auction in place of an ascending auction is perfectly appropriate in simple environments of this sort. If the environment is a little more complex and the auctioneer decides that there are some benefits to the ascending process, concealing the identities of the bidders during an auction would allow the retention of much of the positive value discovery properties of the ascending auction without allowing the use of effective punishment strategies to support collusive equilibria.

These simple collusion fighting techniques may not be suitable for use in more complex environments that involve such things as value linkages across items and bidders where they would impair the ability of non-collusive bidders to achieve an efficient competitive outcome. Other approaches involving the encouragement and perhaps even subsidization of marginal bidders to enter the auction, combinatorial auctions and so forth may be required. It is these situations that pose a true challenge to the auction designer and there is more still to learn about the best techniques for cases such as these.

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