THE VULNERABILITY OF AUCTIONS TO BIDDER COLLUSION*

Robert C. Marshall and Leslie M. Marx

Working Paper
July 18, 2008

Abstract

Previous work has addressed the relative vulnerability of different auction schemes to collusive bidding. The common wisdom is that ascending-bid and second-price auctions are highly susceptible to collusion. We show that the details of ascending-bid and second price auctions, including bidder registration procedures and procedures for information revelation during the auction, can be designed to completely inhibit, or unintentionally facilitate, certain types of collusion. If auctions are designed without acknowledging the possibility of collusion then the design will ignore key features that impact the potential success of colluding bidders.

*The authors thank the Human Capital Foundation (http://www.hcfoundation.ru) for support. We thank Pino Lopomo, Peng Sun, Larry Katz (the editor), and five anonymous referees for helpful comments. We are indebted to Barry Ickes, Andrei Karavaev, Alexey Kuchaev, Vladimir Kreyndel, Alexey Pomanskiy, Mark Roberts, Georgy Trofimov, and Andrey Vavilov for numerous discussions regarding the Russian oil and gas lease auctions. Andrei Karavaev also provided skillful research assistance.

I. Introduction

Bidder collusion is a pervasive problem (Pesendorfer 2000) and is an emphasis of competition enforcement. A General Accounting Office Report in 1990 noted that from 1982 to 1988, over half of the criminal restraint of trade cases filed by the U.S. Department of Justice's Antitrust Division involved auction markets.[1]

The economics literature views ascending-bid and second-price auctions as similarly susceptible to bidder collusion because they are strategically equivalent ("logically isomorphic" in Vickrey's [1961] language).[2] At a second-price auction, a cartel could have its highest-valuing member bid its value while all other cartel members bid some amount below the auctioneer's reserve price. Similarly, this same cartel at an ascending-bid auction could have its highest-valuing member remain active up to its value while all other cartel members do not bid beyond the auctioneer's reserve price. In each case, the highest-valuing cartel member acts just as it would have had the bidding been non-cooperative, so other cartel members have no incentive to bid against it (Marshall and Meurer 2004).

Despite the view that opportunities for collusion may be similar in ascending-bid and second-price auctions, in this paper we show that the two auction formats can differ in terms of their susceptibility to collusion. We show that ascending-bid and second-price auctions can be designed to be robust to certain types of collusion.

Whether an auction is designed to be robust to collusion or not can have a large impact on auction revenue. Most other design issues are focused on relatively small margins around the second-highest valuation. In contrast, by inhibiting collusion the designer can be confident that the second-highest valuation (or something relatively close to it) is what the seller receives as opposed to, say, the fifth, six, or tenth highest valuation, which might be the outcome from effective collusion.

In this paper, we consider the effects of various auction rules on the ability of bidders to collude. As we show, aspects of an auction that are inconsequential for non-cooperative behavior may be material when bidders collude. As an illustration of this point, several years ago the U.S. Federal Communications Commission

[1] "GAO Report: Changes in Antitrust Enforcement Policies and Activities," GAO/GGD-91-2, October 1990, available at http://archive.gao.gov/d22t8/142779.pdf.

[2] The economics profession has generally credited Vickrey (1961) with being the first to propose the second-price auction format (McAfee and McMillan 1987; Milgrom 1989; Rothkopf, Teisberg, and Kahn 1990; Lucking-Reiley 2000); however, there are examples of the second-price auction being used in practice long before Vickrey's paper (Moldovanu and Tietzel 1998; Lucking-Reiley 2000).

(FCC) conducted auctions for spectrum licenses where the bids were large in dollar magnitude, but where there was no constraint on the exact amounts that could be submitted.[3] When bids are in the hundreds of millions, no non-cooperative bidder is too concerned about the last three digits of its bid, so FCC auction designers not focused on deterring collusion did not anticipate problems with the design. However, bidders took little time to realize that the last three digits offered the opportunity for anti-competitive signalling.[4] In the standard model with non-collusive bidders, there is no strategic value from the last three digits of a bid; however, once the assumption of non-collusive bidders is relaxed, such details become important.

We focus on two components of an auction's design that can be important for the susceptibility of the auction to collusion. First, we show that the information that is disclosed during an ascending-bid auction can affect its susceptibility to collusion. A common theme in the auction literature assuming affiliated values is that revenue will be enhanced by designing an auction scheme that reveals as much information as possible during the auction (McAfee and McMillan 1987; Milgrom 2004a). In addition, there may be good economic reasons for greater information disclosure in certain applications.[5] However, these arguments for revealing information presume that collusion is not an issue. We show that the revelation of information during an ascending-bid auction can facilitate collusion. But we also show that some minor changes in the rules of the auction scheme, coupled with careful thought about the information revealed at the time bidders register, can change that result completely, leaving the ascending-bid auction immune to certain types of bidder collusion.

Second, we show that the information disclosed about the identities of participating bidders can affect an auction's susceptibility to collusion.

Often a bidding cartel will organize itself so that payments are only required from

[3]For discussions of FCC auctions, including the susceptibility of some FCC auctions to collusion, see McMillan (1994), McAfee and McMillan (1996), Weber (1997), Klemperer (1998, 2000, 2002), Cramton and Schwartz (2000, 2002), Kwasnica and Sherstyuk (2001), Brusco and Lopomo (2002), and Milgrom (2004b). For an analysis of inefficiencies induced by FCC auction design choices, see Bajari and Fox (2007).

[4]As described in Weber (1997), this kind of signalling occurred at the FCC's PCS A & B Block Spectrum Auction (FCC Auction 4).

[5]For example, in multi-object auctions such as the FCC's spectrum license auctions, revealing information on bidder identities prior to the auction and on the identities of current high bidders during the auction might provide information about the technological standards that are likely to be adopted, which are relevant for roaming possibilities and the cost of mobile units because of economies of scale (Marx 2006). In such cases, revealing information can potentially improve the efficiency of the auction.

a cartel member who wins the object, with non-winning cartel members receiving payments from the cartel.[6] This type of cartel organization is facilitated when auctioneers release detailed information about the identities of the registered bidders. By withholding information about the identities of the registered bidders, the auction designer potentially can create opportunities for the winning cartel member to circumvent payments to its co-conspirators.[7] The cartel will observe these opportunities ex ante and either have to alter its preferred mechanism, or give up on collusion entirely. Thus, anti-collusive auction design can make collusion more difficult and less palatable to a typical bidding cartel.

To give an example of how bidders have manipulated the bidder registration process to their advantage, consider the Russian oil and gas lease auctions of the past few years.[8] In these auctions, at least two registered bidders are required for the auction to proceed. Three empirical regularities in the data are worth noting. First, of the auctions with more than two bidders, there often appears to be vigorous competition. Second, in the large plurality of auctions that have only two bidders, many end after the submission of only one bid. Third, many of the bidders that participate in the two-bidder auctions never win any oil or gas leases in our data. In summary, many of the two-bidder auctions appears to be one-bidder auctions where the single bidder has registered twice or arranged for an agent to register in order to satisfy the requirement that there be at least two registered bidders.

[6] This is a commonly observed characteristic of bidding cartels. See, e.g., U.S. v. Ronald Pook (No. 87-274, 1988 U.S. Dist. LEXIS 3398; E.D. Pa. April 18, 1988); U.S. v. Seville Industrial Machinery Corp. (696 F.Supp. 986; D.N.J. 1988); District of Columbia v. George Basiliko (No. 91-2518, 1992 U.S. Dist. LEXIS 1260; D.C. February 10, 1992); and NY et al. v. Feldman et al. (No. 01-cv-6691, S.D.N.Y.).

[7] As an example of a cartel member not making its agreed-to payment to its co-conspirators, see U.S. v. Portac, Inc. (869 F.2d 1288; 1989 U.S. App. LEXIS 2816). As described in that case, three companies conspired to rig bids at a government timber auction known as the "Up and Adam" timber sale held on March 22, 1985. The companies, Portac, Inc., Hoh River Timber Inc., and Astoria Plywood Corp. agreed that Astoria would win the auction, with Portac and Hoh River suppressing their bids, and they agreed that Hoh River would get the Hemlock and Portac would get a share of the Douglas Fir. The sale was indeed won by Astoria, but as stated in the case, "The agreed division of logs from the Up and Adam Sale never came to pass." In the end, it was the head of Hoh River, who did not receive his agreed-to cartel transfer, who became the government's prime witness at trial.

The auction format used at the Up and Adam Sale facilitated collusion in that it released sufficient information to the bidders that the cartel knew it would be able to observe whether Astoria won and so whether, according to their agreement, was supposed to make a transfer to Hoh River. We show that auction formats that withhold information can be less vulnerable to collusion.

[8] For more details, see the online appendix associated with this paper.

We incorporate the possibility for this type of manipulation into our model by explicitly allowing bidders to register multiple bidder IDs. Also, similar to the Russian oil and gas lease auctions, we consider the possibility that the registration process does not provide complete information about the identities of the registered bidders, making it difficult for bidders to detect duplicate registrations by other bidders.

A number of lessons for auction designers emerge from our analysis. First, designers should consider limiting how much information is released on the number and identities of registered bidders. Second, designers of ascending-bid auctions should consider limiting the information released during the course of the auction. Third, if registration information can be limited, but circumstances dictate that information on the identity of the current high bidder cannot be suppressed in an ascending-bid format, then a second-price auction may be more robust to collusion than an ascending-bid auction.

Of course, limiting the amount of auction information that is released to the public can potentially increase the scope for corruption by the auctioneer. However, in light of auction automation in recent years, there are many auction environments where opportunities for auctioneer corruption can be minimized by automating the auction process. For example, we are unaware of any concerns regarding auctioneer corruption at FCC spectrum license auctions, where automation has replaced human discretion in bid taking.

Our results suggest that the steps described above make one-shot auctions more robust to collusion. One-shot auctions arise in a variety of contexts, and in many bid rigging cases the illegal behavior described involves only a single auction or procurement.[9] The literature on collusion at repeated auctions shows that if a fixed set of bidders participates in an infinite sequence of similar auctions, with bidders' values drawn from the same distributions at each auction, then they may be able to improve upon their non-cooperative payoffs by forming an all-inclusive cartel if they are sufficiently patient (and, for some results, if they have access to a public randomization device).[10] In practice, collusion at auctions originates with two different kinds of car-

[9]Examples include U.S. v. Metropolitan Enterprises, Inc. (728 F.2d 444, 1984); U.S. v. A-A-A Elec. Co., Inc. (788 F.2d 242, 4th Cir. 1986); U.S. v. W.F. Brinkley & Son Construction Company, Inc. (783 F.2d 1157, 4th Cir. 1986); and Finnegan v. Campeau Corp. (722 F.Supp. 1114, S.D.N.Y. 1989).

[10]See Fudenberg, Levine, and Maskin (1994); Aoyagi (2003); Hörner and Jamison (2004); Skrzypacz and Hopenhayn (2004); and Blume and Heidhues (2006 and 2008). In some cases, even for large discount factors, a history-dependent strategy cannot deter deviations in the absence of equilibrium-

tels. Large international market share cartels, like the citric acid cartel of the 1990s,[11] rig bids at procurement auctions, but the extensive repeated interaction of the cartel members on a range of issues beyond bid rigging, along with their focus on a market share agreement, is likely to make limiting registration and auction information a relatively ineffective tool to thwart their attempts to suppress interfirm competition. However, there are other cartels whose sole focus (or nearly so) is on bid rigging. Collusion at the FCC auctions as well as the kinds of bid rigging seen in U.S. v. Seville, U.S. v. Ron Pook, and NY v. Feldman are examples. In these three cases, the cartels were not all-inclusive and had fluid member participation. All cartel transfers were completed at the end of each auction. Repetition was not needed for the ring to capture the full collusive surplus. In these cases, reduced information revelation is likely to have the biggest impact on thwarting collusion. And, the heterogeneity of the ring membership at any auction as well as the heterogeneity of the objects being sold at different auctions makes the use of repetition to overcome an anti-collusive auction design quite difficult.

The paper proceeds as follows. Section II describes the model. Results are in Section III, including implications of our findings for collusion deterrence. A summary of the main results is contained in Section IV. Section V consider extensions. Section VI provides concluding discussion.

II. Model

We are interested in bidding cartels that operate in single-object auction environments, where the bidding is only in terms of the price and where the auctioneer is non-strategic except for setting a fixed reserve price r.[12] We use the standard independent private values (IPV) formulation. Bidder i's value is assumed to be drawn from distribution F_i with density f_i and support $[\underline{v}, \bar{v}]$, where $\underline{v} \geq 0$.[13] All bidders

path punishment phases (Matsushima 2004).

[11] European Commission Decision of 5 December 2001, Case No COMP/E-1/36 604 — Citric acid (2002/742/EC).

[12] We assume no resale, but for a discussion of resale in our model, see the working paper version of this paper, Marshall and Marx (2008). See Garratt, Tröger, and Zheng (2007) on the susceptibility of the English auction to collusion when resale is allowed.

[13] The heterogeneous independent private values framework has been analyzed by Marshall et al. (1994), Lebrun (1999, 2006), Maskin and Riley (2000), and Bajari (2001). Assuming all distributions have a common interval support simplifies the analysis because, for example, we avoid environments in which only certain bidders could possibly have a value above the reserve price.

are risk neutral.

We model auctions as involving a registration process and a bidding process in which only registered bidders may bid. We assume there are $n \geq 2$ auction participants (as opposed to the number of registered bidders, which could be different), and that participants $\{1, ..., k\}$ are eligible to participate in a cartel, where $2 \leq k \leq n$. We assume that the identities of the k cartel participants are common knowledge within the cartel, but that the total number of auction participants n may not be known to cartel members. Specifically, we assume that either it is known by all that the cartel is all-inclusive, or that it is known by all that the the cartel might not be all-inclusive, in which case we assume cartel members have a common belief distribution over the number of non-cartel bidders, where the distribution is assumed to have unbounded support $\{0, 1, 2, ...\}$.

We focus on ascending-bid and second-price auction formats, which we describe below.

II.A. Bidding Formats

II.A.1. Ascending-Bid Auctions

A variety of ascending-bid environments are used in practice and in theory. In this paper, we focus on four that are distinguished by whether or not reentry is possible and whether or not the bidder IDs of the active bidders are revealed. We describe these four variations below. In all cases, we assume that if bidders are identified during the auction it is only through their bidder IDs, not the underlying identities behind those bidder IDs.

In many modeling environments, the ascending-bid auction is borrowed from Milgrom and Weber (1982). In that variant, no reentry is possible. Once a bidder ID withdraws from the bidding it cannot reenter. In addition, the number of active bidders is publicly displayed, but the bidder IDs for the active bidders are not revealed. Following Milgrom and Weber (1982), we refer to this variant as the "Japanese English Auction without identities" or "JEA without identities." As a variant of the JEA, one could also have the bidder IDs of the currently active bidders revealed during the auction. We refer to this as a "JEA with identities."

In other ascending-bid formats, reentry is costless and always possible, as is typically the case at many oral ascending-bid auctions (Izmalkov 2002). In these formats,

it may be possible for bidders to observe the bidder ID of the current high bidder. We will refer to this as the "Standard English Auction with identities" or "SEA with identities." As a variant of the SEA, bidders might not observe the bidder ID of the current high bidder, for example if Internet-based or telephone bids are allowed or if the bidders are able to disguise the fact that they are bidding. We refer to this as an "SEA without identities." For example, in some oral ascending-bid livestock auctions, although the identity of the winner is revealed after the auction concludes, the identities of the active bidders and current high bidder are obscured through the use of "ring masters" who accept bids from bidders seated in their assigned areas and transmit those bids to the auctioneer.

We assume that any information that is revealed during the bidding process is in terms of the bidder IDs, not their underlying identities.

We assume that in an SEA, the auctioneer always signals when the bid ascent has stopped and allows some brief period for bidding before closing the auction.

In the ascending-bid formats, the amount of the current high bid is observed by all bidders. In particular, the price paid by the winner is observed by all the bidders. The winning bidder must be able to observe that it has won and losing bidders must be able to observe that they did not win. In a JEA with identities or an SEA with identities, the bidder ID of the winner is revealed through the auction process. In the JEA without identities and the SEA without identities, the bidder ID of the winner may or may not be revealed to all the bidders. In what follows, we will specify whether the bidder ID of the winner is revealed where necessary.

In addition, for studying collusion at ascending-bid auctions it may also be important to specify how bid increments are determined; however, we abstract from this by assuming a continuous price ascent in all of the auction formats we consider.[14]

II.A.2. Second-Price Auctions

We consider a standard second-price auction in which bidders simultaneously submit bids, with the high bidder winning the object and paying the amount of the second-highest bid or the reserve price, whichever is higher. As with the ascending-bid auction formats, at the conclusion of the auction, the winning bidder must be able to observe that it has won and how much it must pay, and losing bidders must be able to observe that they did not win. In contrast to an ascending-bid auction,

[14] See Avery (2002) on strategic jump bidding at ascending-bid auctions.

in a second-price auction, the price paid may only be observed by the winning bidder. However, in what follows, to maintain comparability between second-price and ascending-bid auctions, we assume that at second-price auctions the price paid is observed by all bidders. In what follows, we will specify where necessary whether the bidder ID of the winner is revealed.

II.B. Registration Regimes

For any of the ascending-bid or second-price auction formats, we assume that before the auction bidders participate in a registration process in which each bidder chooses how many bidder IDs to request and is randomly assigned that number of bidder IDs from an infinite set $\mathcal{D}$. Each bidder ID in $\mathcal{D}$ is assigned to at most one bidder. Thus, for each $i \in \{1, ..., n\}$, bidder i has a set D_i of bidder IDs for which it is the underlying identity. We assume bidder i controls the bidding of all bidder IDs in D_i.

In practice, multiple registrations may be accomplished through formal or informal agreements with another entity, perhaps specifying the terms of resale following success at the auction.

We define three possible registration regimes:

1. *transparent registration* – Prior to the auction, the auctioneer announces the set of all assigned bidder IDs, $D \equiv \cup_{i=1}^{n} D_i$, and their underlying identities, i.e., the auctioneer announces the list $\{(i, d) \mid i \in \{1, ..., n\},\ d \in D_i\}$.
2. *semi-transparent registration* – Prior to the auction, the auctioneer announces the set of all assigned bidder IDs, $D \equiv \cup_{i=1}^{n} D_i$, but does not reveal their underlying identities.
3. *non-transparent registration* – The auctioneer does not reveal the set of assigned bidder IDs nor any information linking bidder IDs with their underlying identities.

These registration regimes are summarized in Table I.

We assume that any information revealed by the auctioneer must be accurate, although the auctioneer may choose not to reveal certain information.

Under transparent registration, bidders know which auction participant is associated with every bidder ID. Thus, if one registrant has more than one bidder ID, that is revealed to all the bidders. Under semi-transparent registration, an all-inclusive cartel can assure itself that no cartel member has multiple bidder IDs if there are ex-

actly k bidder IDs, with each bidder ID claimed by one of the cartel members. Under non-transparent registration, bidders do not even know the set of assigned bidder IDs prior to the auction.

II.C. Timing

We take as given the bidding format (SEA with identities, SEA without identities, JEA with identities, JEA without identities, or second price) and the registration regime (transparent, semi-transparent, or non-transparent) and consider the ability of a cartel to operate successfully.

The timing and description of the stages is as follows:

1. *Cartel formation*: A cartel mechanism is announced (there is commitment to the mechanism). Potential cartel members observe the mechanism and join if and only if their expected payoff from participation in the mechanism is greater than their expected payoff from non-cooperative play. Cartel members observe whether all potential cartel members join or not.[15] If all potential cartel members join, then the cartel mechanism operates and otherwise it does not, in which case all bidders participate in the auction non-cooperatively.[16]
2. *Values*: Bidders learn their values.
3. *Cartel mechanism*: If the cartel mechanism is operating, cartel members participate in the cartel mechanism. The formal definition of the cartel mechanism is given in the appendix, but we can describe the cartel mechanism as follows: Each cartel member makes a report to a "center," which is a standard Myerson (1983) incentiveless mechanism agent. Based on these reports, the center makes non-binding registration and bid recommendations privately to each cartel member and announces the transfer payments to be required after the auction as a function of the reports and observed outcomes. We require that the center's budget be balanced in expectation. The bid recommendations can be functions of information released as part of

[15] As described below, we assume non-cartel bidders use the non-weakly-dominated strategy of bidding their values, so it is not necessary that they observe the cartel mechanism or whether all potential cartel members join.

[16] This is a common assumption in the auction literature. The assumption affects the statement of the individual rationality constraint, but is not necessary for the results of this paper. An alternative assumption is that refusal by one potential cartel member to join implies that the remaining potential cartel members form a cartel of size $k-1$; however, given that we focus on ascending-bid and second-price auctions, the non-weakly-dominated bidding strategy of a potential cartel member that does not join is not affected by whether a cartel of the other $k-1$ forms or not.

the registration and bidding processes as long as the information is available at the time the bid must be submitted. We restrict attention to mechanisms that satisfy incentive compatibility and obedience conditions so that it is a best reply for all cartel members to truthfully report their values to the center and to follow the registration and bid recommendations of the center.

4. *Registration process*: Bidders participate in a registration process.

5. *Release of registration-related information*: The auctioneer releases registration-related information as specified by the registration regime.

6. *Claiming of bidder IDs*: Under semi-transparent or non-transparent registration, bidders may claim to have a particular bidder ID, although this is not verifiable. If a cartel member claims a particular bidder ID, then the cartel may use that information. For example, if cartel member i claims bidder ID d, and if the cartel mechanism requires that a cartel member make a payment to the cartel if it wins the object, then the payment can be collected from cartel member i if bidder ID d wins the auction. Bidders cannot credibly communicate that a particular bidder ID is *not* associated with it.

7. *Bidding process*: Registered bidders participate in the bidding process, with non-cartel bidders using the non-weakly-dominated strategy of bidding their values.[17]

8. *Cartel transfers*: Any within-cartel transfer payments required by the mechanism are made.[18] We assume the cartel can compel cartel members to make their required payments.

III. Results

As a benchmark, we begin by defining the first-best collusive outcomes.

For second-price and ascending-bid auctions, the first-best collusive outcome is for the highest-valuing cartel member to win the object whenever its value exceeds that of the highest-valuing outside bidder and to pay the maximum of the reserve price and the highest outside value. In the context of a second-price auction, this is

[17] We assume non-colluding bidders follow non-weakly-dominated strategies, but cartel members are not so constrained. This assumption is also made in Robinson (1985); Graham and Marshall (1987); and Mailath and Zemsky (1991). The assumption is consistent with observed behavior in U.S. v. Ronald Pook; U.S. v. Seville; and District of Columbia v. George Basiliko.

[18] As in Graham, Marshall, and Richard (1990) and Asker (2007), differential transfer payments are possible to account for heterogeneity among cartel members.

achieved, for example, when the highest-valuing cartel member bids its value and all other cartel members bid below the reserve or do not bid.

In the context of a JEA, the first-best collusive outcome is achieved when the highest-valuing cartel member remains active up to its value and all other cartel members exit at a price less than the highest-valuing cartel member's value and at a price no greater than the price at which the highest-valuing outside bidder exits. In an SEA, the first-best collusive outcome is achieved when the highest-valuing cartel member bids up to its value and non-highest-valuing cartel members do not bid or if the non-highest-valuing cartel members follow the rule of not bidding when the highest-valuing cartel member is the current high bidder and not bidding when an outside bidder is the current high bidder until the highest-valuing cartel member has had an opportunity to bid.

III.A. No Restrictions On Payments

If we allow payments from all cartel members, regardless of whether they win the auction, then a bidding cartel can suppress all within-cartel competition at a second-price or ascending-bid auction using the mechanism of Mailath and Zemsky (1991) or Marshall and Marx (2007). The mechanism of Mailath and Zemsky is ex-post budget balanced, but may require payments from multiple cartel members, including those instructed not to bid at the auction.

The mechanism of Marshall and Marx is ex-ante budget balanced, but only requires a payment from the highest-reporting cartel member. In that mechanism, the highest-reporting cartel member pays the center an amount equal to the expected surplus that a bidder with value equal to the second-highest report would receive if it were to bid at the auction against the outside bidders, and the expected value of this payment is distributed among all the cartel members so that the mechanism satisfies ex-ante budget balance.[19] It is an equilibrium for all cartel members to report their

[19]Specifically, in the mechanism of Marshall and Marx (2007), if r is the reserve price, $\tilde{v}_{(1)}^{out}$ is the highest value among the bidders outside the cartel (zero if the cartel is all-inclusive), and $s_{(2)}$ is the second-highest report from a cartel member, then the highest-reporting cartel member pays the center

$$E_{\tilde{v}_{(1)}^{out}}\left(\left(s_{(2)}-\max\{r,\tilde{v}_{(1)}^{out}\}\right)1_{s_{(2)}\geq\max\{r,\tilde{v}_{(1)}^{out}\}}\right)-p,$$

where p is $1/k^{\text{th}}$ of the ex-ante expected payment by the high-valuing cartel member, and all other cartel members receive payment p. The mechanism then recommends that the highest-reporting cartel member bid its report at a second-price auction or bid up to its report at an ascending-bid

values truthfully and follow the bid recommendations of the center. To see this, note that we can view cartel members as competing in a second-price auction for the right to be the sole cartel member to attend the auction. The usual second-price logic implies that it is a best reply for cartel members to report truthfully to the mechanism. Once the mechanism has identified the highest-valuing cartel member, cartel members have no incentive to deviate from the recommended bids. In addition, one can easily show that individual rationality is satisfied strictly.

Because the mechanisms of Mailath and Zemsky (1991) and Marshall and Marx (2007) do not rely on any information from the auction itself, they are not affected by the details of the auctions rules, including registration and bidding procedures. Thus, we have the following benchmark result.

Proposition 1 *When a cartel is unrestricted in its ability to collect payments from cartel members, the first-best collusive outcome can be achieved at any second-price or ascending-bid auction, regardless of registration transparency and regardless of auction details.*

Proof. The results follow from either Mailath and Zemsky (1991) or Marshall and Marx (2007). Our distributional assumptions are stronger than those in Mailath and Zemsky, who allow bidders' value distributions to have different supports, and although Marshall and Marx place additional restrictions on the densities f_i, these additional assumptions are not necessary for their results for second-price auctions. Q.E.D.

III.B. Payments Only From Winners

The mechanisms of Mailath and Zemsky (1991) and Marshall and Marx (2007) allow first-best collusion at a second-price or ascending-bid auction regardless of whether the identity of the winner or price paid is revealed. However, a cartel might prefer a mechanism that only requires a payment from the highest-valuing cartel member when that cartel member wins the object at the auction. This is particularly relevant for procurement auctions where cartel members may wish to fund transfer payments from auction proceeds or use subcontracting arrangements with other cartel members. The cartel may also prefer payments only from winners if the liquidity

auction, with all other cartel members bidding some amount below the reserve price.

required to make the payment will come from the object being sold. In many prosecuted bidding cartels, only the winner made payments to the cartel.[20] In a number of bidding cartels using post-auction knockouts, only the cartel member ultimately receiving the object made payments to the cartel.[21]

If the auctioneer or auction process reveals the identity of the winner, then a bidding cartel can condition transfer payments on that information. The mechanism of Graham and Marshall (1987) allows a bidding cartel to suppress all within-cartel competition while only requiring a payment from a cartel member if that cartel member wins the auction. In this mechanism, cartel members make reports to the center and the center recommends that non-highest-reporting cartel members bid below the reserve price at the auction, while the highest-reporting cartel member bids its report at a second-price auction or up to its report at an ascending-bid auction. If the cartel member wins the auction, it pays the center nothing if the auction price is greater than the second-highest report from the cartel. If the second-highest cartel report exceeds the price paid at the auction, then the winning cartel bidder pays the center the difference between the second-highest report and the price at the auction. Specifically, if the cartel members submit reports $s_1 \geq s_2 \geq ... \geq s_k$, a cartel member that wins the auction at price p must pay the center $\max\{0, s_2 - p\}$. Ex ante budget balance is achieved by having the center make a payment to each cartel member equal to $1/k$ times the expected revenue to the center as a result of payments by winning cartel members.

Given this payment rule, a cartel member has no incentive to over report because if doing so makes the difference between the cartel member's report being highest and not, then it means that the second-highest report is greater than the cartel member's value, and then the payment rule guarantees that the cartel member will have to pay an amount greater than its value if it wins the object. Similarly, there is no incentive to under report because if doing so makes the difference between the cartel member's report being highest and not, then since the highest-reporting cartel member bids truthfully at the auction, the deviating cartel member obtains no collusive gain.

[20] Examples include: the collectable stamp cartel described in Asker (2007); U.S. v. A-A-A Elec. Co., Inc. (788 F.2d 242; 4th Cir. 1986), where A-A-A did not make payments to its co-conspirators until after receiving final payment from the buyer; U.S. v. Metropolitan Enterprises, Inc. (728 F.2d 444, 1984); and U.S. v. Inryco, Inc. (642 F.2d 290, 1981), where subcontracting arrangements were used to transfer payments between cartel members.

[21] Examples include those prosecuted in U.S. v. Seville Industrial Machinery Corp., U.S. v. Ronald Pook, and District of Columbia v. George Basiliko.

We assume that any results of the bidding process that are made available to the bidders are done so only using the bidder IDs, not the underlying identities behind those bidder IDs. Thus, when we say that a cartel can only collect payments from a cartel member that wins the auction, we mean that in semi-transparent and non-transparent registration regimes, the cartel can only collect payments from a cartel member if that cartel member claims a bidder ID d during the "claiming of bidder IDs" phase *and* bidder ID d is observed to win the auction.

Proposition 2 *When a cartel can only collect payments from a cartel member that wins the auction, the first-best collusive outcome can be achieved at any second-price or ascending-bid auction that has transparent registration and that reveals the winning bidder ID.*

Proof. In this environment (transparent registration and the auctioneer reveals the winning bidder ID), the cartel can identify whether a particular cartel member has won the auction. In an ascending-bid auction, bidders observe the price paid as part of the bidding process, and in a second-price auction we assume the auctioneer reveals the price paid. Thus, the cartel can use the mechanism of Graham and Marshall (1987) to achieve the first-best collusive outcome. Although Graham and Marshall assume symmetric bidders, Graham, Marshall, and Richard (1990) show that their collusive mechanism continues to be incentive compatible and individually rational in our environment with potentially asymmetric bidders. Q.E.D.

Proposition 2 shows that under transparent registration, a restriction that the cartel only collect a payment from a cartel member who wins does not affect the profitability of collusion if the identity of the winner is revealed. However, if information suppression by the auctioneer, shill bidding, multiple registrations, subcontracting, or other arrangements interfere with the ability of cartel members to learn the true identity of the winner, then the result changes.

Proposition 3 *When a cartel can only collect payments from a cartel member that wins the auction, the first-best collusive outcome cannot be achieved at a second-price auction or ascending-bid auction without identities (JEA or SEA) that has non-transparent registration (even if the auctioneer reveals the winning bidder ID).*

Proof. Assume a second-price auction with non-transparent registration, and consider a collusive mechanism that achieves the first-best collusive outcome and that only collects payments from a cartel member that wins the auction. Relying on the Revelation Principle, assume the mechanism is incentive compatible both in terms of the truthful revelation of values and obedience to the mechanism's recommended registration and bidding behavior (Myerson 1985). To achieve the first-best collusive outcome, the highest-valuing cartel member must bid its value and non-highest-valuing cartel members must bid below the reserve price or not bid. (If the cartel is all-inclusive, then the first-best collusive outcome can also be achieved by having the highest-valuing cartel member bid above its value.) If the cartel does not require any payments from cartel members, then a cartel member with value greater than the reserve price can profitably deviate by reporting a value equal to the upper support of the value distribution and then bidding its value at the auction. In this case, since we assume all bidders have a common upper support of their value distributions, all other cartel members would be instructed by the cartel to bid below the reserve price or not bid, and so the deviation would increase the deviating cartel member's payoff whenever its value was greater than those of the outside bidders but not the highest in the cartel. Thus, with positive probability the collusive mechanism must require a payment from a cartel member that wins the auction.

But if a cartel member has a positive expected payment to the cartel in the event that it wins the auction, and no payment if it does not win, then a cartel member can profitably deviate by reporting a value equal to the upper support of the its value distribution *and* also registering a bidder ID that it does not reveal to the cartel (with non-transparent registration, no inference is possible by the cartel regarding multiple registrations by its members). The deviating cartel member can use that bidder ID to bid its value at the auction, while bidding zero with any other bidder IDs it has. The deviation allows the deviating cartel member to avoid having to make a payment to the cartel and is profitable whenever the cartel member's value is greater than those of the outside bidders.

Because the JEA without identities and SEA without identities provide no information during the auction process that can be used to identify the current high bidder, the proof for those auction formats proceeds as in the case of a second-price auction. Q.E.D.

Proposition 3 shows that rules exist for second-price auctions and ascending-bid auctions without identities that prevent a cartel from achieving the first-best collusive outcome using a mechanism that only collects payments from a cartel member that wins the auction. When cartel members can register bidders whose underlying identities cannot be traced to them, cartel members prefer to use such a bidder to avoid having to make a payment to the center in the event that they win. Thus, first-best collusion cannot be sustained. In particular, with non-transparent registration, the mechanism of Graham and Marshall (1987) no longer works because the highest-valuing cartel member can use a bidder ID that is not recognized by the cartel and thereby avoid having to make a payment to the cartel. In the environment of Proposition 3, correlating devices with no transfers are the only available mechanisms for collusion in a one-shot environment. Although the cartel cannot achieve the first-best collusive outcome, the cartel mechanism can still play the role of an equilibrium selection device if there are multiple equilibria and can allow the cartel to implement correlated equilibrium.[22]

Comparing Propositions 2 and 3, we see that there may be an incentive for a cartel to convert non-transparent registration to transparent registration if possible. For example, at the FCC's Nationwide Narrowband (PCS) Auction (FCC Auction 1), the FCC's intention was to hold an ascending-bid auction with identities, but with non-transparent registration. However, bidders were able to observe movements in and out of bidding booths and connect those with the timing of the posting of bids to figure out which bidder IDs were associated with which auction participants.

The following proposition considers semi-transparent registration. With a non-all-inclusive cartel, the proposition's result depends on whether non-cartel bidders, i.e., bidders that are truly independent non-cartel bidders, can and do identify themselves and claim their bidder IDs in a credible way. When a cartel member claims a bidder ID, they commit to making any payments required based on the observed bidding behavior of that bidder ID, but when a non-cartel member claims a bidder ID, that information is only useful to the cartel if it represents a credible statement that the

[22]If within-cartel payments can only be required from a cartel member who wins the auction, and if the auction process does not reveal the underlying identity of the winner, then a cartel member winning the auction has no incentive to pay (absent repeated-game incentives). Thus, if the auction process does not reveal the underlying identity of the winner, a cartel at a second-price auction must rely on correlated equilibria with no transfers among cartel members. For more discussion of this case, see the working paper version of this paper, Marshall and Marx (2008). For the development of this type of mechanism in an environment with resale, see Garratt, Tröger, and Zheng (2007).

claimed bidder ID is not actually the bidder ID associated with one of the cartel members, so the credibility of the claim becomes important.

Proposition 4 *When a cartel can only collect payments from a cartel member that wins the auction, the first-best collusive outcome cannot be achieved at a second-price auction or ascending-bid auction without identities (JEA or SEA) that has semi-transparent registration and that reveals the winning bidder ID unless the cartel is all-inclusive or the cartel is not all-inclusive and all non-cartel participants identify themselves and claim their bidder IDs in a credible way.*

Proof. If the cartel is all-inclusive or the cartel is not all-inclusive and all non-cartel participants identify themselves and claim their bidder IDs in a credible way, then the cartel can achieve the first-best collusive outcome by recommending reversion to non-cooperative bidding with no transfers unless it is observed that all bidder IDs are claimed by a cartel member or outside bidder. If all bidder IDs are claimed, then bidding and transfers are defined as in Graham and Marshall (1987). In this environment, a cartel member cannot profitably deviate by registering a bidder ID that it does not claim in an attempt to avoid having to make a payment to the cartel because that deviation would result in an unclaimed bidder ID and, thus, reversion to non-cooperative bidding. However, if the cartel is not all-inclusive and non-cartel participants either cannot or do not credibly identify themselves and credibly claim their bidder IDs, then as in the proof of Proposition 3, the first-best collusive outcome cannot be achieved because any mechanism achieving the first-best collusive outcome is vulnerable to deviations in which a cartel member registers a second bidder ID that it does not claim but that it uses to submit its bid.

Because the JEA without identities and SEA without identities provide no information during the auction process that can be used to identify the current high bidder, the proof for those auction formats proceeds as in the case of a second-price auction. Q.E.D.

Comparing the results of Propositions 2, 3, and 4 for second-price auctions, we have the following result.

Corollary 1 *At a second-price auction or ascending-bid auction without identities, transparent registration can be pro-collusive relative to semi-transparent registration, which can be pro-collusive relative to non-transparent registration.*

A second-price or ascending-bid format that releases detailed information about the registered bidders prior to the auction can be pro-collusive because it can allow a cartel to police attempts by cartel members to set up alternative bidder identities that might allow them to disrupt the ability of the collusive mechanism to collect payments from a winning cartel member.

Corollary 1 suggests that subcontracting and resale agreements arranged prior to an auction might be anti-collusive if they establish a second identity under which a cartel member can bid without being recognized as the underlying identity. However, such arrangements can be pro-collusive in other contexts, such as if subcontracting can be used to implement transfer payments among cartel members (Kovacic, et al., 2006).

In contrast to the above results, at an ascending-bid auction with identities the presence of bidders whose underlying identities cannot be observed need not eliminate the possibility of first-best collusion. In some environments, we can construct a collusive mechanism, which we refer to as a "responsive to outside bidders" or "ROB" mechanism, that employs the payment scheme of Graham and Marshall (1987) but requires active bidding by non-highest-valuing cartel members and thereby restores the possibility of first-best collusion at ascending-bid auctions when registration is not transparent.

In the case of a JEA with identities, the ROB mechanism instructs the cartel members to claim their bidder IDs and instructs non-highest-valuing cartel members to stay active up to their values or until the last bidder that is not identifiable as a cartel member exits, whichever comes first. Under this mechanism, if a cartel member attempts to win the object using an unclaimed identity to avoid making a payment to the cartel, the other cartel members remain active up to their values and there is no collusive gain.

In the case of an SEA with identities, the ROB mechanism once again instructs the highest-valuing cartel member to reveal its bidder ID to the other cartel members, and it instructs the non-highest-valuing cartel members to bid if the price is less than their values and the auctioneer has signaled that the auction is about to close and the current high bidder is not identifiable as the highest-valuing cartel member. The highest-valuing cartel member is instructed to bid promptly whenever it is not the current high bidder and the price is less than its value. Again, under this mechanism, if the highest-valuing cartel member attempts to win through a disguised identity

to avoid making payments to the cartel, the collusive gain is lost because the other cartel members bid up to their values.

Under the ROB mechanism, cartel members bid up to their values as long as they perceive competition from bidder IDs not claimed by the cartel, and this deters deviations based on disguised identities.

Proposition 5 *When a cartel can only collect payments from a cartel member that wins the auction, the first-best collusive outcome can be achieved at a JEA with identities or an SEA with identities, even with semi-transparent or non-transparent registration.*

As shown in Proposition 5, the cartel's ability to eliminate cartel members' use of disguised identities as a profitable strategy at ascending-bid auctions does not depend on whether reentry is possible—effective cartel strategies exist for both the JEA with identities and the SEA with identities, namely the ROB mechanism. As this argument shows, in both a JEA and SEA with identities, auction rules may permit cartel strategies that prevent disguised identities from being used by cartel members to cheat on the cartel. In such environments, these ascending-bid auctions are more susceptible to collusion than a second-price auction.

Corollary 2 *The susceptibility of ascending-bid auctions to collusion depends on whether the auctions are with or without identities but not on whether reentry is allowed (SEA allows reentry and JEA does not).*

Proposition 5 contrasts with Propositions 3 and 4 and shows that in some environments ascending-bid auctions are more susceptible to collusion than second-price auctions.

Corollary 3 *With non-transparent registration and in some cases with semi-transparent registration, ascending-bid auctions with identities are more susceptible to collusion than second-price auctions.*

Because the economics literature on bidder collusion has typically focused on transparent registration, the result of Corollary 3 is in stark contrast with some existing results. For example, Graham and Marshall (1987, p.1234) state: "Models of single-object second-price and English auctions have been proposed in which cooperative behavior is permitted and in which the auctioneer is allowed to respond

strategically to such behavior. ... Therefore, the revenue equivalence result for the second-price and English auctions within the IPV context extends to cooperative behavior." As Corollary 3 shows, the revenue equivalence result does not extend to cooperative behavior in environments with non-transparent or semi-transparent registration.

III.C. Implications For Bid Data

In the ROB mechanism described in the previous section, at a JEA one would expect to observe cartel members exiting the auction at the same time as the last outside bidder. Traces of this simultaneous exit might be detected in bid data. For example, a paper submitted to the FCC in 2007 by Gregory Rose alleges that in FCC Auction 66 for Advanced Wireless Services, there was a mass simultaneous exit of incumbent wireless providers at the point when Wireless DBS LLC, a joint venture of the two leading satellite TV companies and a potential new competitor to the existing wireless providers, exited the bidding for the large F Block spectrum licenses.[23] Although there are many possible explanations for the bidding behavior at FCC Auction 66, this example demonstrates that such bidding behavior potentially can be detected through a retrospective analysis of the data.

IV. Summary of Results

Our results show that one auction format may be more or less susceptible to collusion depending on the details of the auction rules and environment as well as the strength of the cartel, in particular the cartel's ability to collect payments from its members. The difference between the second-price and ascending-bid auction formats arises when the cartel restricts attention to mechanisms in which only the winner pays and when the use of disguised identities is possible. Differences within ascending-bid formats depend on the informational environment, i.e., whether or not it is an ascending-bid auction with information or without information, but not the ability to reenter or not, i.e., collusive opportunities are the same at a JEA and an SEA as long as both are with information or both are without information.

[23] Gregory Rose, "How Incumbents Blocked New Entrants in the AWS-1 Auction: Lessons for the Future," FCC Docket No. 06-150, Filed on behalf of Public Interest Spectrum Coalition by Media Access Project, April 23, 2007.

Our results are summarized in Table II. As shown by the last column of the table, in an environment with transparent registration, the auction formats we consider are all equally susceptible to collusion. But reading down the other columns, we see that for other registration regimes, auction design decisions can affect the susceptibility of the auction to collusion. Reading across the rows, we see that for a given auction format, the registration regime can affect the susceptibility of the auction to collusion. Finally, in some cases comparisons "along the diagonal" in the table may be relevant. For example, if a given auction format necessitates a particular registration regime, then the relevant comparisons involve changes in both the auction format and the registration regime.

The results shown in Table II that are based on Proposition 1 are supported by the collusive mechanism of Marshall and Marx (2007), which involves transfer payments that do not depend on the outcome of the auction and may be required of a cartel member that does not win the auction. The results based on Proposition 2 are supported by the collusive mechanism of Graham and Marshall (1987), which involves a transfer payment only from a cartel member that wins the auction. The other two "yes" results in Table II, which are based on Proposition 5, are supported by the ROB collusive mechanism described in Section III.B., which requires that all cartel members participate in the auction and bid in a way that does not reduce the collusive gain, but does prevent bidders IDs not recognized as belonging to a cartel member from being able to win the auction at a price less than the values of the cartel members. The negative results in Table II, which reference Propositions 3 and 4, are novel results in that the literature on bidder collusion typically views ascending-bid and second-price auctions as susceptible to collusion, a view which we show follows from the literature's focus on transparent registration.

V. Extensions

Below we consider two extensions. Section V.A considers the case in which no within-cartel transfers are allowed, and Section V.B considers the case in which resale is possible.

V.A. Mechanisms with No Payments

If ring payments can only be required from a ring member who wins the auction, and if the auction process does not reveal the bidder ID of the winner, then a ring member winning the auction has no incentive to pay (absent repeated-game incentives). Thus, if the auction process does not reveal the winning bidder ID, a cartel at a second-price auction must rely on correlated equilibria with no transfers among ring members.

Proposition 6 *At a second-price auction, if a cartel cannot collect payments from ring members, the first-best collusive outcome cannot be achieved.*

Proof. In order to achieve the first-best collusive outcome, non-highest-valuing ring members must bid below the reserve price or not bid. Suppose the existence of an incentive compatible mechanism that recommends that non-highest-valuing ring members bid below the reserve price, and suppose no transfers. Given this mechanism, a ring member with a value above the reserve price strictly prefers to report the maximum possible value rather than truthfully report its value, and then bid its value at the auction. In this case, if the deviating ring member's value is greater than the values of the outside bidders but less than the value of the highest-valuing other ring member, then the deviation is profitable, and in all other cases, the deviation has no effect on the ring member's payoff. Q.E.D.

Proposition 6 provides a contrast with Proposition 2, which says the first-best collusive outcome can be achieved when the auctioneer reveals winning bidder ID, and implies that at a second-price auction, if a cartel can only collect payments from a ring member that wins the auction, then an auctioneer can reduce the profitability of collusion by not revealing the winning bidder ID.

When a cartel cannot collect payments from ring members, Proposition 6 implies that the first-best collusive outcome cannot be achieved, but it may still be possible for the ring members to profit from collusion. Without the ability to arrange transfer payments, the center can only play the role of a correlating device, but as we now show, this can be sufficient to achieve a collusive gain.

In what follows we explore the extent to which collusive gains are possible in the absence of transfers by presenting two examples in which collusive gains are possible at a second-price auction even without transfer payments.

Consider a second-price auction with homogeneous bidders and $n = k = 2$ so that there is an all-inclusive ring with two bidders. The bidders can increase their expected payoffs above non-cooperative play using a correlating device that randomly (with equal probabilities) assigns one of the ring members to bid zero and the other to bid the upper support of the value distribution. Ring members need not make reports, and it is incentive compatible for ring members to bid according to the recommendations of the center.

Under this correlating device, expected bidder surplus is $\int_0^{\bar{v}} v dF(v) = \int_0^{\bar{v}} (1 - F(v))dv$, but expected bidder surplus in the non-cooperative equilibrium (in non-weakly dominated strategies) of the second-price auction is $\int_0^{\bar{v}} F(v)(1 - F(v))dv$, which is strictly less.

Furthermore, under the correlating device, a bidder with value v has expected surplus $\frac{1}{2}v$, but under non-cooperative play, a bidder with value v has expected surplus $\int_0^v (v - b)dF(b) = \int_0^v F(b)db$. If $\frac{1}{2}v > \int_0^v F(b)db$ for all $v > 0$, as with the uniform distribution, bidders with positive values strictly prefer participation in the correlating device even at the interim stage when they know their values.

The outcome under this correlating device is inefficient. In some environments, other correlating devices can be used to reduce the inefficiency and increase expected bidder surplus. For example, with $n = k = 2$ if $v_i \in \{1, 4, 7\}$, with equal probability on each value, and if bids are restricted to the integers $\{0, 1, 2, ..., 7\}$, then the correlating device that randomly assigns one bidder to bid zero and the other to bid 7 generates expected bidder surplus of 4, expected revenue of zero, and total surplus of 4. But under an optimal correlating device (the optimal correlating device need not be unique), expected bidder surplus is higher and expected revenue is higher.[24] The values for expected bidder surplus, expected revenue, and expected total surplus are given in Table III. The increase in both expected bidder surplus and expected revenue is possible because the optimal correlated equilibrium does better than the fully random correlating device in terms of efficiency, and both bidders and the auctioneer capture some of that efficiency gain.

As shown in Table III, the expected total surplus from the optimal correlating device remains below that of the non-cooperative outcome, which is efficient, but it is higher than that of the correlating device that randomly assigns bidders to bid

[24] An optimal correlating device, which can be calculated using linear programming techniques, is described by $\Pr(b_1, b_2 \mid r_1, r_2)$ defined as follows:

either zero or seven. The bidders increase their expected surplus by using the optimal correlating device rather than the correlating device that randomly assigns bidders to bid either zero or seven.

V.B. Mechanisms with resale

The results above assume no resale. Thus, for results predicated on the ring being unable to collect payments from a ring members unless that ring member wins the auction, achieving the first-best collusive outcome requires that the highest-valuing ring member actively bid at the auction. The highest-valuing ring member must bid its value at a second-price auction or remain active up to its value at an ascending-bid auction. We show in Proposition 3 that with non-transparent registration, the first-best collusive outcome cannot be achieved because the highest-valuing ring member has an incentive to register multiple times and use a bidder ID not recognized by the cartel to bid at the auction, thereby avoiding having to make a payment to the cartel.

We can relax our restriction that cartel can only collect payments from a ring member that wins the auction to say instead that the cartel can only collect payments from a ring member that receives that object. Then the first-best collusive outcome could still be achieved if a bidder other than the highest-valuing ring member bid at the auction, as long as the collusive mechanism ultimately allocated the object to the highest-valuing ring member. In this case, the possibility of first-best collusion is restored if the ring has access to a disinterested party that can be used to submit a bid equal to the value of the highest-valuing ring member. In this case, the result of

r_1	r_2	b_1	b_2	$\Pr(b_1,b_2\|r_1,r_2)$
1	1	0	7	0.5
1	1	7	0	0.5
1	4	0	1	0.5
1	4	1	7	0.5
1	7	0	2	0.5
1	7	1	7	0.5
4	1	1	0	0.5
4	1	7	1	0.5
4	4	1	7	0.5
4	4	7	1	0.5
4	7	1	7	0.5
4	7	7	1	0.5
7	1	2	0	0.5
7	1	7	1	0.5
7	4	1	7	0.5
7	4	7	1	0.5
7	7	1	7	0.5
7	7	7	1	0.5

One can check that this mechanism is incentive compatible both in terms of truthful reporting to the mechanism and following the bid recommendation of the mechanism.

Proposition 3 is reversed. Instead, the first-best can be achieved. Specifically, the ring can use the mechanism of Graham and Marshall (1987) with the modification that the highest-reporting ring member is told not to bid, and instead the disinterested party is told to bid an amount equal to the report of the highest-reporting ring member. Then the object is transferred to the highest-reporting ring member at a resale price equal to the purchase price at the auction, and the highest-reporting ring member makes transfer payments as defined in Graham and Marshall (1987).

Of course, this type of mechanism is vulnerable to collusion between the highest-valuing ring member and the party bidding for the cartel at the auction. Furthermore, if the disinterested party is not truly disinterested, the mechanism is vulnerable to the use of a disguised bidder ID by that party.

VI. Discussion

Many results in the auction literature that hold for second-price auctions also hold for ascending-bid auctions, and vice versa. However, the results of this paper show that there is a difference between ascending-bid and second-price auctions insofar as their susceptibility to collusion. Specifically, a cartel operating at an ascending-bid auction need not be disrupted by non-transparent registration, but we show that under certain conditions non-transparent registration forces a cartel at a second-price auction to revert to non-collusive play.

The results of this paper suggest that both the design of an auction and the actions of auctioneers can affect the profitability of collusion. Auction designs and auctioneer actions that reduce the profitability of collusion can be expected to inhibit collusion. Prior to an auction, steps can be taken to facilitate the use of disguised identities by potential cartel members, such as using non-transparent registration. During ascending-bid auctions, information on the identities of the active bidders and the current high bidder can be suppressed. After an auction, if possible, the auctioneer can keep the identity of the winner anonymous. Also after an auction, bid data can be reviewed for evidence of simultaneous exit that might be suggestive of cartel behavior.

Although reduced information disclosure has potential benefits in terms of inhibiting collusion, these gains must be balanced against the costs in terms of potentially increasing the scope for corruption by the auctioneer and potential costs in terms of

decreased efficiency in environments with externalities (see footnote 5). With regard to the increased potential for auctioneer corruption, many auctions that were historically conducted by human bid takers can now be run with computer automated procedures. This incremental design change greatly mitigates possibilities for auctioneer corruption and thereby makes our recommendations implementable without confronting a substantial tradeoff.

"Transparency in bidding" has been touted by the federal government. As we show in this paper, pre-auction transparency in the form of transparent registration, and real-time transparency in the form of revelation of the identities of the active bidders in a JEA and the identity of the current high bidder in an SEA, increase susceptibility to collusion. Thus, pre-auction and real-time transparency can be pro-collusive. If the primary motivation for "transparency in bidding" is concern about the possibility of corruption by the auctioneer, then post-auction transparency, where auction results are made public after the conclusion of the auction, may provide sufficient information to monitor the auction process without being as pro-collusive as pre-auction or real-time transparency.

Additional benefits associated with suppressing information on the identities of active bidders and current high bidders are possible in simultaneous multiple object auctions. For example, in the FCC's spectrum license auctions information on the identities of bidders can potentially facilitate retaliatory bidding, signalling, gaming of the auction's activity rule, and other attempts to deter or foreclose entry into markets (Brusco and Lopomo 2002; Reitsma, et al., 2002; Marx 2006). Recently the FCC announced that in some cases it would modify its simultaneous multiple round auction (a multi-object variant of an English auction) so that bidders could no longer observe which bidder had submitted which bids. The FCC argued that this change would make its auctions less susceptible to collusion, a conclusion that is supported by the analysis of this paper.

Penn State University
Duke University

Appendix

In this appendix, we define a collusive mechanism for a second-price auction when no registration-related information is revealed. The definition can be adapted for other auction formats and registration regimes.

We focus on incentive compatible, ex-ante budget balanced, strictly individually rational collusive mechanisms.

Assume bidder i draws its values from distribution F_i with interval support S, where S is common to all bidders.

Let $K \equiv \{1, ..., k\}$. To allow the possibility that cartel members can submit multiple bids, for $i \in K$, let cartel member i's bid b_i be a finite-dimensional vector. If the mechanism recommends that cartel member i submit bid vector b_i with dimension m_i, we interpret that as a recommendation that cartel member i should register m_i bidders with itself as the underlying identity and submit bids accordingly. Let B be the set of possible vectors of bid recommendations. For $i \in K$, let $\pi_i(v_i, b_1, ..., b_k)$ be cartel member i's expected payoff when its value is v_i, cartel members bid $b_1, ..., b_k$, and outside bidders bid their values, taking the expectation over the outside bidders' values (and the number of outside bidders if that is not known) and over any randomization in the auction mechanism, such as a random tie-breaking rule.

We define a collusive mechanism by (μ, p), where $\mu : S^k \to \Delta(B)$ is the distribution over recommended bids and $p_i : S^k \times I \to \mathbb{R}$ is the transfer payment required of cartel member i as a function of the reports made to the cartel center and the information I revealed as part of the auction process. It will also be useful to define the associated *expected* transfer payment for cartel member i given its report as $\tilde{p}_i : \mathbb{R} \to \mathbb{R}$. A collusive mechanism (μ, p) is incentive compatible if $\forall i \in K$, $\forall (v_i, v_i') \in S^2$, $\forall \psi_i : B_i \to B_i$,

$$\begin{aligned} & E_{v_{-i}}\left(\int_B \pi_i(v_i, b_i, b_{-i}) d\mu(b_1, ..., b_k \mid v_i, v_{-i})\right) - \tilde{p}_i(v_i) \\ \geq \; & E_{v_{-i}}\left(\int_B \pi_i(v_i, \psi_i(b_i), b_{-i}) d\mu(b_1, ..., b_k \mid v_i', v_{-i})\right) - \tilde{p}_i(v_i'). \end{aligned} \tag{1}$$

Condition (1) captures two types of incentive compatibility constraints. It ensures that cartel members report truthfully to the mechanism, and it also ensures that cartel members follow the recommendation of the center when they register and bid at the auction. (We interpret a ψ_i that maps an m_i-dimensional bid recommendation onto a bid vector with different dimension as capturing a deviation by the cartel member

in the number of bidders it registers with itself as the underlying identity.)

Cartel members use the information contained in their recommendation to update their beliefs about the recommendations made to the other cartel members and to determine their optimal registration and bidding behavior. In an incentive compatible mechanism, it is optimal for cartel members to obey the recommendation of the center given their posterior beliefs.

The mechanism is ex-ante budget balanced if $E_{v_1,...,v_k}\left(\sum_{i\in K}\tilde{p}_i(v_i)\right) = 0$, and participation in μ is strictly individually rational if $\forall i \in K$,

$$E_v\left(\int_B \pi_i(v_i, b_i, b_{-i})d\mu(b_1, ..., b_k \mid v_i, v_{-i}) - \tilde{p}_i(v_i)\right)$$

is greater than cartel member i's ex-ante expected payoff when all bidders play non-cooperatively.

References

Aoyagi, Masaki, "Bid Rotation and Collusion in Repeated Auctions," *Journal of Economic Theory,* 112 (2003), 79–105.

Asker, John, "A Study of the Internal Organisation of a Bidding Cartel," Working Paper, New York University, 2007.

Avery, Christopher, "Strategic Jump Bidding in English Auctions," in *Game Theory in the Tradition of Bob Wilson* (Berkeley, CA: Berkeley Electronic Press, 2002).

Bajari, Patrick, "Comparing Competition and Collusion: A Numerical Approach," *Economic Theory*, 18 (2001), 187–205.

Bajari, Patrick, and Jeremy T. Fox, "Measuring the Efficiency of an FCC Spectrum Auction," Working Paper, University of Minnesota, 2007.

Blume, Andreas, and Paul Heidhues, "Private Monitoring in Auctions," *Journal of Economic Theory,* 131 (2006), 179–211.

—, "Modeling Tacit Collusion in Auctions," *Journal of Institutional and Theoretical Economics,* 164 (2008), 163–184.

Brusco, Sandro, and Giuseppe Lopomo, "Collusion Via Signaling in Simultaneous Ascending Bid Auctions With Multiple Objects and Complementarities," *Review of Economic Studies,* 69 (2002), 407–436.

Cramton, Peter, and Jesse A. Schwartz, "Collusive Bidding: Lessons from the FCC Spectrum Auctions," *Journal of Regulatory Economics,* 17 (2000), 229–252.

—, "Collusive Bidding in the FCC Spectrum Auctions," *Contributions to Economic Analysis and Policy,* 1 (2002), Article 11.

Fudenberg, Drew, David Levine, and Eric Maskin, "The Folk Theorem with Imperfect Public Information," *Econometrica,* 62 (1994), 997–1040.

Garratt, Rod, Thomas Tröger, and Charles Z. Zheng, "Collusion via Resale," Working Paper, University of California at Santa Barbara, 2007.

Graham, Daniel A., and Robert C. Marshall, "Collusive Bidder Behavior at Single-Object Second Price and English Auctions," *Journal of Political Economy,* 95 (1987), 1217–1239.

Graham, Daniel A., Robert C. Marshall, and Jean-Francois Richard, "Differential Payments Within a Bidder Coalition and the Shapley Value," *American Economic Review*, 80 (1990), 493–510.

Hörner, Johannes, and Julian S. Jamison, "Collusion with (Almost) No Information," Working Paper, Northwestern University, 2004.

Izmalkov, Sergei, "English Auctions with Reentry," Working Paper, Pennsylvania State University, 2002.

Klemperer, Paul, "Auctions with Almost Common Values," *European Economic Review,* 42 (1998), 757–769.

—, "Why Every Economist Should Learn Some Auction Theory," in *Advances in Economics and Econometrics Invited Lectures to Eighth World Congress of the Econometric Society* (Cambridge, UK: Cambridge University Press, 2000).

—, "What Really Matters in Auction Design," *Journal of Economic Perspectives,* 16 (2002), 169–189.

Kovacic, William E., Robert C. Marshall, Leslie M. Marx, and Matthew E. Raiff, "Bidding Rings and the Design of Anti-Collusion Measures for Auctions and Procurements," in *Handbook of Procurement*, Nicola Dimitri, Gustavo Piga, and Giancarlo Spagnolo, eds. (Cambridge, UK: Cambridge University Press, 2006).

Kwasnica, Anthony M., and Katerina Sherstyuk, "Collusion via Signaling in Multiple Object Auctions with Complementarities: An Experimental Test," Working Paper, Penn State University, 2001.

Lebrun, Bernard, "First Price Auctions in the Asymmetric N Bidder Case," *International Economic Review*, 40 (1999), 125–142.

—, "Uniqueness of the equilibrium in first-price auctions," *Games and Economic Behavior,* 55 (2006), 131–151.

Lucking-Reiley, David, "Vickrey Auctions in Practice: From Nineteenth-Century Philately to Twenty-First-Century E-Commerce," *Journal of Economic Perspectives,* 14 (2000), 183–192.

Mailath, George, and Peter Zemsky, "Collusion in Second Price Auctions with Heterogeneous Bidders," *Games and Economic Behavior,* 3 (1991), 467–486.

Maskin, Eric S., and John G. Riley, "Asymmetric Auctions," *Review of Economic Studies,* 67 (2000), 413–438.

Marshall, Robert C., Michael J. Muerer, Jean-Francois Richard, and William Stromquist, "Numerical analysis of asymmetric first price auctions," *Games and Economic Behavior,* 7 (1994), 193–220.

Marshall, Robert C., and Leslie M. Marx, "Bidder Collusion," *Journal of Economic Theory,* 133 (2007), 374–402.

—, "The Vulnerability of Auctions to Bidder Collusion," Working Paper, Duke University, 2008.

Marshall, Robert C., and Michael J. Meurer, "Bidder Collusion and Antitrust Law: Refining the Analysis of Price Fixing to Account for the Special Features of Auction Markets," *Antitrust Law Journal,* 72 (2004), 83–118.

Marx, Leslie M., "Economics at the Federal Communications Commission," *Review of Industrial Organization,* 29 (2006), 349–368.

Matsushima, Hitoshi, "Repeated Games with Private Monitoring: Two Players," *Econometrica,* 72 (2004), 823–852.

McAfee, R. Preston, and John McMillan, "Auctions and Bidding," *Journal of Economic Literature,* 25 (1987), 699–738.

—, "Analyzing the Airwaves Auctions," *Journal of Economic Perspectives,* 10 (1996), 159–175.

McMillan, John, "Selling Spectrum Rights," *Journal of Economic Perspectives,* 8 (1994), 145–162.

Milgrom, Paul, "Auctions and Bidding: A Primer," *Journal of Economic Perspectives,* 3 (1989), 3–22.

—, *Putting Auction Theory to Work* (Cambridge, UK: Cambridge University Press, 2004a).

—, *Auction Theory for Privatization* (Cambridge, UK: Cambridge University Press, 2004b).

Milgrom, Paul R., and Robert J. Weber, "A Theory of Auctions and Competitive Bidding," *Econometrica,* 50 (1982), 1089–1122.

Moldovanu, Benny, and Manfred Tietzel, "Goethe's Second-Price Auction," *Journal of Political Economy,* 106 (1998), 854–859.

Myerson, Roger B., "Mechanism Design by an Informed Principal," *Econometrica,* 51 (1983), 1767–1797.

—, "Bayesian Equilibrium and Incentive Compatibility," in *Social Goals and Social Organization*, L. Hurwicz, D. Schmeidler, and H. Sonnenschein, eds. (Cambridge, UK: Cambridge University Press, 1985).

Pesendorfer, Martin, "A Study of Collusion in First-Price Auctions," *Review of Economic Studies,* 67 (2000), 381–411.

Reitsma, Paul S. A., Peter Stone, János A. Csirik, and Michael L. Littman, "Self-Enforcing Strategic Demand Reduction," in *Agent-Mediated Electronic Commerce IV. Designing Mechanisms and Systems,* Julian Padget, Onn Shehory, David Parkes, Norman Sadeh, and William E. Walsh, eds. (Berlin: Springer-Verlag, 2002).

Robinson, Marc S., "Collusion and the Choice of Auction," *RAND Journal of Economics,* 16 (1985), 141–145.

Rothkopf, Michael H., Thomas J. Teisberg, and Edward P. Kahn, "Why Are Vickrey Auctions Rare?," *Journal of Political Economy,* 98 (1990), 94–109.

Skrzypacz, Andrzej, and Hugo Hopenhayn, Tacit Collusion in Repeated Auctions, *Journal of Economic Theory,* 114 (2004), 153–169.

Vickrey, William, "Counterspeculation and Competitive Sealed Tenders," *Journal of Finance,* 16 (1961), 8–37.

Weber, Robert J., "Making More from Less: Strategic Demand Reduction in the FCC Spectrum Auctions," *Journal of Economics Management Strategy,* 6 (1997), 529–548.

Table I
Registration Regimes

	List of bidder IDs revealed	Bidder IDs linked to the underlying bidder
Transparent	Yes	Yes
Semi-transparent	Yes	No, but IDs can be claimed by the bidders
Non-transparent	No	No, but IDs can be claimed by the bidders

Table II
Summary of Results

	Can the first-best collusive outcome be achieved?		
	Non-transparent registration	Semi-transparent registration	Transparent registration
Unrestricted ability to collect payments			
	Yes (Prop. 1)	Yes (Prop. 1)	Yes (Prop. 1)
Restricted to payments only from winners			
Ascending with IDs (JEA or SEA)	Yes (Prop. 5)	Yes (Prop. 5)	Yes (Prop. 2)
Ascending without IDs* (JEA or SEA)	No (Prop. 3)	No (Prop. 4) (exceptions**)	Yes (Prop. 2)
Second price	No (Prop. 3)	No (Prop. 4) (exceptions**)	Yes (Prop. 2)

*Assume the auctioneer reveals the identity of the winner.

**Yes, if the cartel is all-inclusive or all outside bidders credibly identify themselves and claim their bidder IDs.