The Economics of Auctions and Bidder Collusion*

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1 Introduction

Auctions and procurements are pervasive mechanisms of exchange. Most government acquisitions are competitively procured.[1] In the private sector, a large number of commodities are sold by auctions, including items such as antiques, art, rugs, and used machinery. The assets of bankrupt businesses are typically liquidated by means of auction. The federal government is the biggest auctioneer in the country. Offshore oil leases as well as timber from national forests are sold by means of auction. The largest of all auctions are those for government securities. The Treasury sells over $4.7 trillion of marketable securities by means of auction every year to refinance debt and finance the deficit.[2]

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[1]The Federal Acquisition Regulations recommend competitive procurement – see Subpart 6.1—Full and Open Competition (available at https://www.acquisition.gov/far/current/html/FARTOCP06.html, accessed March 6, 2012). In fiscal year 2004, 61% of the U.S. government's purchases of "supplies and services" ($338 billion) were purchased through a competitive process ("competed"), and in fical year 2005, the percentage was 64% on a base of $365 billion (Report of the Acquisition Advisory Panel to the Office of Federal Procurement Policy and the United States Congress, January 2007 (available at https://www.acquisition.gov/comp/aap/finalaapreport.html, accessed March 6, 2012), Chapter 7, p.439).

[2]Website of the U.S. Department of the Treasury, Bureau of the Public Debt, http://www.publicdebt.treas.gov/whatwedo/what_we_do.htm (accessed March 6, 2012).

Auctions and procurements are popular despite their vulnerability to bidder collusion. A spate of cases in the 1980s as well as more recent cases serve as a reminder that the success of anti-collusive policies is limited in auction and procurement markets.[3]

In a posted price market, when sellers join together to fix prices, society suffers an efficiency loss from reduced output in the market. Output falls because the colluding firms raise the market price in a quest for monopoly profits. However, when bidders collude in an auction market, the efficiency effect is not so clear. As we show in the Article, there are circumstances in which bidder collusion might increase rather than decrease economic efficiency.

One reason efficiency results for bidder collusion can differ from those for posted price markets is that private information is significant in typical auction markets but not in typical posted price markets. In posted price markets transactions usually involve products with salient features that are easy to discern. In many bidding markets the transaction involves an informationally complex product that requires significant training and expertise to properly assess. Examples include offshore oil tracts and weapons contracts. Costly and dispersed information changes the nature of competition as compared to posted price markets. Horizontal agreements between bidders affect the distribution of information, which in turn affects the expected winning bid, the profits to the parties, and the incentives of the parties to gather information in advance of an auction or procurement. Thus, it seems reasonable that informational issues should play a prominent role in assessing the illegality of bidder collusion.

A second factor that distinguishes posted price from auction markets is the ability of the auctioneer to combat collusion. In posted price markets the victims of collusion are often small and powerless to stop it. In contrast, an auctioneer often has market

[3]See, Froeb (1989) – 81 percent of criminal cases under Sherman Section One from 1979 to 1988 were in auction markets. During that time period there were 245 bid-rigging or price fixing cases involving road construction, and 43 cases involving government procurement. See GAO Report (1990). Recent bid rigging cases pursued by the U.S. Department of Justice include cases involving Real Estate (2012, http://www.justice.gov/atr/public/press_releases/2012/280487.htm), Municipal Tax Liens (2012, http://www.justice.gov/atr/public/press_releases/2012/280451.pdf), Mineral Rights Leases (2012, http://www.justice.gov/atr/public/press_releases/2012/280273.pdf), Auto Parts (Denso) (2012, http://www.justice.gov/atr/cases/f280000/280002.pdf), Auto Parts (Yazaki) (2012, http://www.justice.gov/atr/cases/f280000/280050.pdf), Auto Parts (Furukawa) (2011, http://www.justice.gov/atr/public/press_releases/2011/275503.pdf), and Optical Disk Drives (2011, http://www.justice.gov/atr/public/press_releases/2011/278224.pdf). (All cites accessed March 6, 2012.)

power and can react strategically to bidder collusion. There is a possibility that the countervailing power of the auctioneer may mitigate the adverse effects of collusion. A parallel argument is used to justify labor unions – when employers have monopsony power the consequent deadweight loss can be reduced by allowing workers to organize and bargain as a unit.

In order to analyze the effect of bidder collusion on efficiency, in Section 2 of this Article we first discuss the basic theoretical structures through which one can think about bidder collusion.

In Section 2.1, we show that bidding rings at oral auctions are more resistant to cheating by cartel members than price-fixing agreements in other markets. Conventional wisdom holds that the greatest obstacle to collusion (besides illegality) is the incentive of colluders to cheat by cutting their prices below the cartel price.[4] Although this wisdom holds at a sealed bid auction, it fails to hold at an oral ascending bid auction. At a sealed bid auction the designated winning bidder in the ring, the member with the highest valuation, must shade his bid below his valuation. Because he pays what he bids, shading is the source of the collusive gain. This action leaves the designated winner vulnerable to a cheater who can submit a bid slightly above the collusive bid and win the item. To deter cheating, potential cheaters must each get a share of the collusive gain, which can make collusion problematic. At an oral auction the designated ring bidder follows the same strategy that he would as a non-cooperative bidder. Because there is no shading, he is not vulnerable to cheating. The gain to collusive bidding comes from the strategic behavior of co-conspirators who would have lost by acting as noncollusive bidders. These bidders can potentially affect the price paid by suppressing their bids at the auction.

Also in Section 2.1, we show that bidding rings at oral auctions are less affected by the problem of entry. Monopoly profits are likely to attract entrants who erode the profits and destabilize the cartel. OPEC's experience illustrates the normal situation. New suppliers have entered the petroleum market attracted by high collusive prices.[5] Entrants have captured some of OPEC's customers at prices near the collusive price. Over time OPEC's share of the market and ability to maintain high prices have declined. Entry into an oral auction in which a bidding ring is active is no more

[4]The susceptibility of cartels to secret price-cuts by members has played a prominent role in the analysis of cartel stability. See Stigler (1964).

[5]See Carlton and Perloff (1990, p.246) saying that in June 1985 "non-OPEC production is 33% higher than in 1979, undercutting OPEC's prices."

profitable than entry to an oral auction that has no collusion. A potential entrant knows that the ring will respond to entry. The representative of the ring at the auction will remain active against an outsider up to the highest valuation of any ring member. This is the same as noncooperative bidding. Consequently, an entrant can earn no profit in excess of what he could earn if all bidders acted noncooperatively.[6] The only hope for an entrant to share the gains from collusion is to join the ring. The stability of less than all inclusive collusion at certain kinds of auctions is one more reason why auctions are particularly vulnerable to collusion. This difference from posted price markets, where an excluded firm may be able to destabilize a cartel by undercutting the cartel's price and capturing a large market share, is relevant to the issue of antitrust injury.

In Section 2.2, we discuss how the ideas of Section 2.1, which are developed in the framework of a single-object auction, extend to the case where multiple units are offered simultaneously. In Section 2.3, we extend the results of the earlier sections, which are presented for an environment in which bidders know each other's valuation, to the case where bidders' valuations are their private information. In Section 3, we discuss the efficiency effects of bidder collusion, including the possible role of collusion in creating countervailing buyer power and in providing incentives for ex ante investments by bidders. In Section 4, we conclude.

2 Noncooperative bidding and bidder collusion

An auction is a mechanism of exchange whereby a seller, following a simple set of procedural rules, evaluates the simultaneous offers of potential buyers to determine a winner and payments for bidders to make. A procurement is the flip side of an auction – a buyer evaluates the simultaneous offers of potential sellers.[7] For simplicity, the following discussion will be presented in terms of auctions. Also, for simplicity, we initially assume the auctioneer does not take strategic actions, such as setting a

[6] This argument applies to a single object oral auction. It sometimes does not apply to multi-object oral auctions. A bidding ring might find it optimal to let an entrant win the first item brought up for sale so as to eliminate this source of competition on later items. In this scenario entry is successful only because the ring allows it.

[7] Procurements are typically more difficult to analyze than auctions. Except when buying a homogeneous commodity, sellers will not only specify a price in their bid but will also specify the product they plan to provide. The products might differ significantly between firms. Then t h e buyer will need to score each firm's bid in order to rank firms by the surplus they are offering.

reserve price.[8]

For the sale of a single item, there are four standard auction schemes. At the **English** or **oral ascending bid** auction bidders appear before the auctioneer and, through open outcry, raise the bid price until no bidder remains who is willing to pay a higher price. Then the item is sold to the highest bidder at the amount of their last bid. This scheme is used for liquidation auctions, the sale of timber by the Forest Service, the sale of art, antiques, rugs, industrial machinery and many other items. A variant has been used by the Federal Communications Commission for the sale of spectrum licenses.

At a **Dutch** or **oral descending bid** auction bidders appear before the auctioneer who starts by asking a very high price for the item. When no one "takes" the item she progressively drops the price. The first bidder to stop the price descent by open outcry wins the item for the price at which he stopped the bidding. This is a common mechanism used in western Europe for the sale of vegetables, flowers, and other foodstuff.

At a **first price sealed bid** auction bidders submit sealed bids to the auctioneer. The highest bidder wins the auction and pays the amount of his bid to the auctioneer. First price mechanisms are used for most procurements. The Forest Service and Bureau of Land Management use them on occasion for the sale of timber (most of the sales are by English auction). The Mineral Management Service uses them for the sale of off-shore oil lease tracts. The Dutch and first price auctions are strategically equivalent in certain modelling environments.[9] In subsequent analysis we focus only on the first price.

At a **second price** auction bidders submit sealed bids to the auctioneer. The highest bidder wins and pays the amount of the second highest bid. This mechanism is rarely used in practice. However, it is enormously important as an analytic device. In many modelling environments it is equivalent to the English auction. In both auctions, under reasonable assumptions, the price paid is equal to the second highest valuation among all bidders.

[8] Of course, in practice, auctioneers use reserve prices, entrance fees, phantom bidding techniques and supply restrictions to raise the price paid for the item they are selling. To include the auctioneer as a player in the description of the games involves stating additional contingencies in the transactions that add little to one's understanding of the central issues regarding bidder behavior. Later, we explicitly discuss the strategic measures that an auctioneer might take to fight collusion.

[9] See Vickrey (1961) as well as Milgrom and Weber (1982).

Multiple objects can be sold by schemes that are extensions of the single object first price and second price auctions. At a **discriminatory** auction bidders submit sealed bids that specify how many units of the commodity they are willing to buy at a specific price. These bids are aggregated by the auctioneer. The auctioneer determines the highest bid price at which the last item available will be sold (we call this price the "market clearing price"). Then all bidders bidding that amount or more are allocated items. Like a first price auction, they each pay the auctioneer the amount of their bids.[10]

At a **uniform price** auction bidders submit sealed bids that specify how many units of the commodity they are willing to buy at a specific price. These bids are aggregated by the auctioneer. She determines the highest bid price at which the last item available will be sold. Then all bidders bidding that amount or more are allocated items. They pay the auctioneer the amount of the market clearing price. In 1992, the U.S. Treasury switched from using discriminatory price to uniform price auctions for the sale of bonds.[11]

Most economic analysis of auctions is presented in models with incomplete information.[12] This means that bidders possess private information – at least one bidder knows something that another bidder does not know. Often the private information concerns a bidder's personal valuation of an item or, in the case of procurements, a bidder's performance cost.

A benchmark informational framework is called the independent private values (IPV) model. As the name implies, bidders obtain individual-specific values from some common underlying probability distribution. Knowledge of one's own valuation provides no useful information about what another bidder holds as a valuation (this is the independence). Each bidder's valuation is known only to them (this is the privacy).

Clearly this formulation does not encompass some fairly common auction settings. Consider the sale of offshore oil lease tracts. If the pool of reserves, the quality of the oil, and the cost of extraction were known to all bidders, then each bidder

[10] To complete the formal specification of these auction games we should specify what happens in the case of a tie. For a single object, a random allocation device (like a coin flip) determines the winner. For multiple objects, a "tie" occurs when the demand at the market clearing price exceeds the quantity available. Bidders at the market clearing price then receive items pro rata.

[11] See Lopomo et al. (2011) for additional examples of the various types of auctions.

[12] See Milgrom and Weber (1982), Riley and Samuelson (1981), Myerson (1981), McAfee and McMillan (1984).

would have the same valuation for the tract. In practice, this common underlying value is not known, but each individual bidder obtains private information about the salient unknown characteristics. The modelling framework in which bidders obtain conditionally independent signals about the true underlying value of the item being sold is called the common value (CV) model. A variant of the CV model allows for the possibility that some bidders have better information about the true value than other bidders.

There are probably no pure IPV or CV settings, but the models are extremely helpful in analyzing bidding behavior. The IPV model is used, for example, in procurement settings in which seller costs have a random and independent component. It is also used to analyze auctions for collectibles such as art or antiques. The CV model is used in procurement settings in which the common cost of performance is uncertain. It is also used to analyze auctions for many kinds of natural resources.

In the subsequent analysis we assume that bidders have complete information (no bidder holds private information) whenever we can. Although this is less realistic it makes the analysis much easier to follow. Some issues are essentially about private information.

2.1 Bidder collusion at a single object auction

We begin with the most basic modeling framework from the theory of auctions. A single non-divisible object is to be sold to one of several risk neutral bidders. First we explain noncooperative behavior at English and first price auctions. Second, we address the susceptibility of each auction scheme to bidder collusion. Third, we discuss the anti-collusive effect of entry by new bidders.

2.1.1 Noncooperative behavior

A remarkable result established independently by a number of authors in the early 1980s is called the Revenue Equivalence Theorem.[13] It holds that in the basic auction model with symmetric bidders, the first price and English auctions generate, on average, the same revenue for the seller. This result is surprising because the strategic behavior of bidders is so different at the two auctions. First consider an English auction. When should a bidder withdraw from the bidding? A bidder should withdraw

[13] See Myerson (1981), Riley and Samuelson (1981), and Milgrom and Weber (1982).

when the price reaches his valuation (presuming arbitrarily small bid increments). Any alternative behavior is less profitable. On the one hand, bidding in excess of his valuation is foolish because he may win at a price above his valuation. On the other hand, withdrawing below his valuation offers no benefit and may cause a bidder to lose an item he otherwise would have won. This logic is independent of the strategic behavior of any other bidder. In the language of game theory, it is a dominant strategy for bidders to remain active up to their valuations. The auctioneer's revenue from this auction is therefore equal to the magnitude of the second highest valuation.

What does strategic behavior look like for a first price auction? A specific example is helpful. Suppose there are five bidders who have valuations of 5, 4, 3, 2, and 1. Bidders know the valuations held by others as well as their own. Clearly, no bidder will bid his valuation for the item. If such a bid wins, it will leave the winner with no surplus from the auction because the winner pays the amount of his bid. So each bidder will have an incentive to bid some increment below his valuation. In deciding how much to shade his bid below his valuation a bidder optimally trades off the reduction in probability of winning from reducing his bid with the increase in surplus that comes from winning with a lower bid. In equilibrium, all bidders shade their bids below their valuations in a way that is mutually consistent – namely, no one wants to change their strategic behavior in light of how all others are behaving. In our ex ample, bidder 5 wins the first price auction with a bid of 4.[14] Thus the revenue is the same as at the English auction.

Although the two auctions produce the same expected revenue for the seller, the strategic behavior of the bidders is different. At the first price auction each bidder shades his bid. The surplus of the winner is strictly determined by the difference between his valuation and the amount of his bid. At the English auction each bidder

[14]The reader may wonder whether bidder 4 can take the item with a bid of 4 and whether bidder 5 should bid slightly above 4. This possibility is just a technical nuisance that we could deal with in several different ways. One way is to invoke the notion of trembling hand perfect equilibrium, which is a refinement of Nash equilibrium. A bid of 4 by bidder 4 always yields a profit of zero whether or not bidder 4 wins the item. A more sensible strategy is for bidder 4 to select a random bid slightly below 4 in the hope that bidder 5 mistakenly submits a bid (i.e. trembles) below 4. For the details of this argument see Hirshleifer & Riley supra note 16 at 374. The IPV counterpart to this example would have five bidders independently draw private valuations from the uniform distribution on the interval zero to six. Then each bidder would optimally submit a bid equal to (4/5) times their individual valuation realization. Of course, there is no guarantee that valuation realizations will be so accommodating as to produce 4 as the actual revenue. However, on average, the revenue will be 4.

remains active up to his valuation. The surplus of the winner is determined by the difference between his valuation and the valuation of the runner-up.

At the risk of seeming redundant, we emphasize the difference in the source of the winner's surplus for the two auctions. For the first price auction, the magnitude of the winner's surplus depends strictly on the actions and characteristics of the winner. For the English auction, the magnitude of the winner's surplus depends on the characteristics of the winner, and actions of another bidder, the runner-up. This is a critically important distinction for understanding the susceptibility of each auction scheme to collusion.

2.1.2 Collusion

Bid-rigging cases catalogue varied and subtle methods of collusion.[15] Colluding bidders specify rules of communication within the ring, bidding behavior, the ultimate allocation of commodities obtained by the ring among ring members, and any payments between members.[16] In contrast, we examine a rather austere model of collusion. We prefer an austere model because it focuses one's attention on factors crucial to ring stability.[17]

The stability of a bidding ring depends on at least three factors. Participation must be individually rational. In other words, bidders must voluntarily opt to be members of the ring (individual rationality constraint). Next, bidders cannot have an incentive to cheat. Specifically, the ring must be designed so that bidders do not pretend to participate in the ring and then disregard the directions of the ring, for example, by using surrogate bidders at the main auction. We call this the "no-cheat"

[15] See Marshall and Marx (2012, Chapter 9).

[16] A practical example would be a bid rotation scheme such as the electrical contractors conspiracy. (See Sultan (1974)). In that case bidders decided ex ante who would submit the winning bid at a given auction. There were no side payments. Another example is provided by collusion among antiques dealers. At the main auction no ring member bids against another ring member. If a member of the ring wins the item, then it is the property of the ring – ultimate ownership is determined in a secondary auction conducted by the ring after the main auction. The difference between the winning bid at the secondary auction and the main auction is divided as sidepayments in some predetermined manner among members of the ring. See United States v. Ronald Pook, 1988 U.S. Dist. Lexis 3398 (E.D.Pa. 1988).

[17] Microeconomic theory offers various models of mechanisms for bidder collusion. Mechanisms are discussed in: Graham and Marshall, (1987); Graham, Marshall, and Richard, (1990); Guth and Peleg, (1993); Mailath, and Zemsky, (1991); McAfee and McMillan, (1992); Tirole, (1992); Marshall, Meurer, and Richard, (1994); Marshall, Meurer, Richard, and Stromquist, (1994); Lopomo, Marshall, and Marx (2005), Marshall and Marx (2007, 2012); Lopomo, Marx, and Sun (2011).

constraint. Finally, bidders must be truthful in reporting private information to one another (incentive compatibility constraint). We discuss the first two constraints but not the third. Our initial modeling environments are ones of complete information so the question of how information revelation occurs within rings does not arise. When we turn to incomplete information, we suppose that truthful revelation occurs. When appropriate we will comment on the effect of the incentive compatibility constraint on collusion.

How might bidders at an English auction organize themselves to bid collusively? We continue with our five bidder example. Our first question is what groupings of bidders can effectively collude. Consider collusion between any number of bidders but where the ring does not contain both bidders 4 and 5. In this circumstance the ring cannot realize a gain to collusion. We refer to such rings as "ineffective." A ring that contains bidder 5 but not bidder 4 will pay 4 for the item. A bidding ring that does not contain bidder 5 will never prevail as a winner.

Next consider the minimally effective ring of two bidders – bidders 5 and 4. Collusion can operate as follows. Bidder 5 bids until he wins the item as long as the latest bid is less than or equal to 5.[18] Bidder 4 is silent. In exchange, bidder 4 receives a sidepayment from bidder 5. The individual rationality constraints are satisfied because bidders 4 and 5 both get a higher profit in the ring than from noncooperative bidding. Bidder 4 profits by the amount of the sidepayment. Bidder 5 profits by obtaining the item for a lower price, 3 instead of 4. But what about cheating? Remarkably, bidder 4 does not have any incentive to deviate. The logic stems from the strategic actions of bidder 5. Bidder 5 does nothing differently when colluding than when acting noncooperatively. Bidder 4 cannot win the item at a price less than 5, and so cannot profitably cheat. This logic applies to rings of any size for the English auction.

Continuing with our example we ask how collusion might be organized at a first price auction.[19] Again, a ring that does not consist of bidders 5 and 4 cannot possibly

[18] Bidder 5 would drop out of the auction if the bidding ever went above 5, but this cannot happen in equilibrium.

[19] In our example the bidders know the valuations of the other bidders. If they do not, then we cannot identify a collusive mechanism that produces a payoff in excess of non-cooperative behavior. Specifically, there is no such mechanism identified in the literature. However, a bounding argument has been numerically constructed which shows that the best possible payoff for a ring at a first price auction is never larger than the payoff to a ring at an English auction. See Marshall, Meurer, Richard and Stromquist (1994).

be profitable. Therefore, we consider the minimally effective ring of bidders 4 and 5. Clearly, there is a potential collusive gain. Bidder 4 could bid strictly less than 3 and then bidder 5 could win the item for a bid of 3.[20] This produces a collusive gain of one. But what compensation does bidder 4 require to submit a bid below 3? Suppose bidder 5 offers to pay bidder 4 an amount of .5 for bidder 4 to bid an amount less than 3. Then bidder 4 will face the following tradeoff – accept .5 and not win the object or act as if the sidepayment is acceptable but then bid slightly above 3 at the main auction. By beating bidder 5 with such a bid bidder 4 would obtain a payoff close to one, instead of just .5. So, what is the smallest sidepayment that will dissuade bidder 4 from cheating on the collusive agreement? Bidder 4 must be paid at least what he could obtain by cheating – a payment of 1. But such a payment means that bidder 5 does not benefit at all from the collusion – he pays 3 for the object, makes a sidepayment of 1 to bidder 4, and earns a surplus of 1. This is the same as what he could have achieved from noncooperative behavior. If organizing collusion is at all costly, or if there is any potential penalty associated with collusion, then bidder 5 will prefer noncooperative behavior to collusion.[21]

Surprisingly, there are still no gains to collusion for bidder 5 at a first price auction if the ring expands in size. In fact, the problem of deterring cheating becomes worse. Consider the ring with bidders 5, 4, and 3. It could potentially reduce the price paid for the item to 2. However, when bidder 5 bids 2 (or just above 2) bidders 4 and 3 will see the possibility of a profitable unilateral deviation from the collusive agreement. To dissuade bidder 3 from bidding in excess of 2 he must receive a payment of 1. Bidder 4 must receive a payment of 2. Note that bidder 5 strictly prefers noncooperative behavior to making these sidepayments. The reason is that the marginal cost associated with securing a reduction in the price paid from 4 to 3 is still 1 but the marginal cost of securing a reduction in the price paid from 3 to 2 is not 1 but 2. Both bidders 3 and 4 must be compensated in order not to deviate when the bid is suppressed from 3 to 2.

Collusion is not sustainable at a first price auction because it is too costly for the highest valuation bidder to create incentives that stop pivotal ring bidders from

[20] Actually bidder 5 would bid slightly above 3 to beat bidder 3. When this technical issue arises later in the Article, we will treat it the same way.

[21] The situation is no different if bidder 5 chooses another bid such as 3.5. Bidder 4 could earn .5 by cheating, and a sidepayment of .5 to prevent cheating would wipe out 5's profit from collusion.

cheating.[22] This is not a problem at an English auction.[23] Why is there such a difference between the two schemes? In order to secure a collusive gain at a first price auction the highest valuation bidder must decrease his bid relative to what he was bidding noncooperatively. As his bid falls the door swings open for deviant behavior by other bidders. To secure a collusive gain at an English auction the highest valuation bidder acts exactly as he would have noncooperatively. The gain comes from the suppression of bids by other bidders. The fact that the highest valuation bidder remains active up to his valuation implies that there is no opportunity for profitable deviant behavior by his co-conspirators.[24]

2.1.3 Entry

To study entry and collusion at English auctions consider a model in which there is a ring with $n-1$ members and one potential entrant. Suppose that all bidders have the identical valuation of V for the single item to be auctioned. Further suppose that the cost of entry is K, and that the auctioneer does not fix a minimal acceptable bid (known as a reserve price). We fix the parameter values so that $nK > V > K$. If there is no threat of entry, then ring members share equally in the collusive gain of V. A potential entrant sees the possibility of capturing V/n if admitted to the ring. Because this profit is less than the cost of entry, the outside firm would not enter the market to join the ring. But what about entering the market to bid noncooperatively? This cannot be profitable either. At an English auction, the ring will bid up to its

[22] Factors outside the scope of our discussion can promote collusion at a one-shot first- price auction. See, e.g., Marshall, Meurer, & Richard, (1994 – litigation settlement between colluding bidders); Porter & Zona, (1993 - labor union enforced collusion); Anton & Yao, (1989 – split award procurement).

[23] The greater susceptibility of English auctions to collusion has been discussed by Robinson, (1985); Fehl & Guth, (1987); Marshall and Marx (2007); and Lopomo, Marx, and Sun (2011).

[24] We have not yet commented on cheating by bidder 5. He has no interest in cheating in terms of his bid, but he has a strong incentive to cheat the ring by reneging on his promised sidepayments. This problem affects first price and English auctions equally. In practice, rings can overcome this problem when bidder 5 has some long-term stake in the transaction. We can think of four factors that induce bidders to make (unenforceable) sidepayments. First, many rings participate in a sequence of auctions, or bid sequentially on many items at a single auction. Sidepayments are made so that bidders are allowed continued participation in the ring. Second, colluding bidders often have other business relations with each other. Cheating in the ring may sour these relations. Third, a general concern about his reputation (honor among white-collar thieves) might induce bidder 5 to make the sidepayment. And fourth, the sidepayments might actually be enforceable through the coercive power of organized crime. Gambetta (1993) reports that an important function of the Sicilian Mafia is facilitating bid- rigging.

valuation, V, and keep the entrant from getting any profit at all.[25]

Now consider the same situation with a first price auction. Our previous analysis showed that collusion would not be profitable at a one-shot first price auction. Thus the impact of entry on collusive profits is a moot point. However, for the purpose of comparison, we assume that a ring of $n-1$ bidders is stable and can win the item for a price of zero. As was true of the English auction, the potential entrant cannot profitably enter to join the cartel because the entry costs are too high compared to an equal share of collusive profits. Unlike the English auction, the new firm can make a profit gross of entry cost from noncooperative behavior. If the ring always submits the fully collusive sealed bid of zero, then the entrant can bid slightly above zero and always take the item at a profit of $V-K$. To guard against this possibility, the ring will sometimes submit a positive bid ranging up to $V-K$. This strategy is optimal because it discourages (but does not completely deter) entry. The ring balances the increased purchase price against the increased probability of winning the item given the threat of entry. The shift of auction format from English to first price reduces the ring's expected profit from V to K.[26]

We note a feature of this story. With an English auction, potential

entrants see large positive profits being earned by incumbents but realize that they cannot profitably enter. This stands in sharp contrast to the usual notion in microeconomics that positive profits will attract entry until there are no more profits for the market participants.[27]

[25]There is an intriguing normative issue here. Posner (1975) has argued that the social loss from collusion is not just the usual deadweight loss but the entirety of monopoly profit as well. The latter is competed away in rent seeking activities by members of the ring. However, this effect is dampened for auction schemes where the ring's mechanism is inherently stable and, in addition, entry is difficult.

[26]There is no pure strategy Nash equilibrium for the first price auction. The ring will submit a single sealed bid x from the interval $x \in [0, V-K]$. The bid is chosen according to the cumulative distribution function $F(x) = K/[V-x]$. The mixed strategy Nash equilibrium has a mass point at $x=0$ such that the probability of $x=0$ is K/V, or $F(0) = K/V$. The entrant will choose not to enter, thereby avoiding the cost K, with the probability K/V. When the potential bidder does enter, then they submit a bid $y \in (0, V-K]$. The cumulative distribution function conditional on entry for the entrant's bid is $G(y) = \frac{K}{V-K}\frac{y}{V-y}$. There are no mass points in this distribution. The equilibrium profit to the potential entrant is zero, because this is what the firm gets in the case of no entry. Given that entry actually does occur, the entrant gets an expected profit of K from the auction, but also sinks the entry cost of K, implying again a net profit of zero for the entrant. The ring gets an expected profit of K from its bidding strategy.

[27]There are alternative means of protecting collusive profits from entrants. For example, a union allegedly played a role in enforcing highway construction bid-rigging in Long Island. See Porter and Zona (1993).

2.1.4 Changing from English to first price

A change in the auction format from English to first price can provide information regarding collusion by bidders because the former is less robust against collusion than the latter. If the auction prices greatly increase after the change, it would be reasonable to infer that a ring was present at the English auction. Of course, if the ring is able to remain coherent and stable after the change, then there will be little effect on price. The absence of a change is not evidence of the absence of collusion, but a substantial increase in the price would lead to the inference of collusion at the English auctions.

Other factors that have nothing to do with collusion can also cause price to change when the auction format changes. For example, risk averse bidders are likely to pay more at a first price auction relative to an English auction. However, one would expect those effects to be small relative to the price changes that would be observed if a large effective cartel reverted to noncollusive bidding as a result of a change to a first price format.

2.1.5 Inferences from observed bidding behavior

Because most English auctions allow bidders to stop actively bidding for a while and then start bidding again, one might think that only the top two bids are meaningful in terms of economic content. However, this is not true when collusion is a possibility.

If similar items are sold at a number of auctions and a certain subset of bidders never bids against one another at any meaningful level of the bidding, then it may be reasonable to infer that these bidders are in a ring. However, the ring can take actions that mitigate that inference. Specifically, if the ring occasionally has members bid against one another for one or two increments, then the inference is more difficult. But since taking steps to disrupt inferences from the bid sequence creates additional difficulty for a ring, the observation of the absence of competitive bidding within a subset of bidders remains a substantive indication of a ring.

As discussed previously, in a first price auction, ring members other than the highest valuing ring member may have an incentive to deviate. To deter secret deviations of this nature, the ring may want its highest-valuing member to submit a somewhat

higher bid, although still one that is less than his noncollusive bid.[28] For example, the highest-valuing ring member may have a value of \$100, and would have bid \$90 acting noncollusively, but given that other ring members are suppressing their bids, he may want to submit a bid of \$50. If the bid of \$50 creates substantial incentives for other ring members to deviate by submitting bids slightly above \$50, then the ring may instruct its highest-valuing member to bid more than \$50, say \$65. In order to give the highest-valuing ring bidder the incentive to follow this instruction, the ring may instruct another ring bidder to submit a bid just below \$65.[29] This second bid will always lose to the highest-valuing ring member's bid, but it ensures that the highest-valuing ring member will bid high enough to deter cheating by lower-valuing ring members. Thus, a ring may need to submit two bids that are close to one another. The frequent closeness of two bids allows the inference of collusion.

2.2 Multiple units for sale

We now consider the sale of multiple units. We study a simple model in which two units will be sold, simultaneously, by means of auction. We continue to assume that there are five bidders with valuations 5, 4, 3, 2, or 1 for a single unit. None of the bidders places any value on additional units. We compare the discriminatory and uniform price auctions.

2.2.1 Noncooperative behavior

We begin with noncooperative behavior. At a uniform price auction the two winners each pay the highest losing bid. All noncooperative bidders will submit bids equal to their valuations. Relative to truthful bidding, bidding in excess of one's valuation is unprofitable. The only difference it could produce is winning a unit at a price in excess of its value. Bidding below one's valuation would not change the price paid upon winning and may result in losing an item that would have yielded positive surplus. Consequently, each bidder reports their valuation truthfully. Just like the English auction we have a dominant strategy equilibrium. In our example, the winning bids are 5 and 4 and each of the winners pays 3.

Like the first price auction, bidders shade their bids below their valuations at a

[28] Details in this paragraph draw from Marshall and Marx (2012, Chapter 12).
[29] See Marshall and Marx (2007, Proposition 3).

discriminatory auction. The winning bids at the discriminatory auction are both 3. These bids are submitted by the bidders with valuations of 5 and 4.[30] They both pay what they bid. The revenue equivalence theorem still holds in this setting. The revenue from noncooperative bidding is 6 at either type of auction.

2.2.2 Collusion

Collusion is relatively easy to achieve at the uniform auction (like the English auction). In the five bidder uniform price example the ring {5, 4, 3, 2, 1} wins two items at a price of zero to gain a surplus of 9. Bidders 5 and 4 each bid their valuations. The other ring bidders all bid zero in exchange for sidepayments from bidders 5 and 4. The no cheat constraint is satisfied for any positive side-payments, because cheating cannot bring a positive profit to bidders 1, 2, or 3. Just as with the English auction, the high valuation ring members are protected from cheating by others because they do not shade their bids.

Rings that are not all-inclusive are less profitable, but limited membership is common in bidding rings. In practice, membership is not all-inclusive for a number of reasons (i.e. the ring wants to decrease the probability of detection, some bidders have no interest in committing a felony, and ring members do not want to share information with a large group). The following subsets of bidders constitute profitable and sustainable rings at the uniform price auction: {5, 4, 3}, {5, 4, 3, 2}, {5, 4, 2}, {5, 4, 2, 1}, {5, 3}, {5, 3, 2}, {5, 3, 2, 1}, {4, 3}, {4, 3, 2}, and {4, 3, 2, 1}. The subsets {5, 4, 3, 1}, {5, 3, 1}, and {4, 3, 1} are stable, but they are excluded from the list because bidder 1 could not contribute anything. Subsets that include bidder 3 achieve a collusive gain by depressing the amount paid below the noncooperative price of 3. Obtaining bidder 3's voluntary participation in the ring potentially comes at a small cost because bidder 3 would have earned zero surplus by bidding noncooperatively. Because bidders 4 and 5 will always bid their true valuations, bidder 3 will never be in a position to win an object by cheating on the collusive agreement. The same is true for bidders 2 and 1. Any sidepayment to suppress their bids would be acceptable and there would be no chance for profitable deviation.

Subsets that do not contain bidder 3 are sometimes not profitable.[31]

[30] Just like the first price auction, this is a trembling hand perfect equilibrium.

[31] It is worth noting that surplus maximizing bidding behavior may frequently entail inefficient outcomes. Suppose the five values were instead {5,4$-\epsilon$,3, 2,1}. Consider the ring of {5,4$-\epsilon$}. Recall

Exceptions are the subsets {5, 4, 2} and {5, 4, 2, 1}. These rings are profitable if bidder 4 bids zero. If bidders 5 and 4 both try to win an item, then they each pay 3. If bidders 4 and 2 (and possibly bidder 1) depress their bids, then bidder 5 can win an item for a price of one (zero). The reduction in purchase price more than compensates for the loss of the item by bidder 4. Bidder 4 can be induced to bid zero with an adequate sidepayment from bidder 5.

In contrast to the uniform price auction, at the discriminatory auction the all-inclusive ring cannot achieve winning bids of zero and still satisfy both the no-cheat and individual rationality constraints. Bidders 3, 2, and 1 could all cheat by submitting bids just above the zero bids submitted by 5 and 4. The total profit from cheating is 6; so the smallest aggregate sidepayment sufficient to stop cheating is 6. This payment is so large that bidders 5 and 4 would oppose a winning bid of zero by the ring. They would favor more limited collusion that required smaller side-payments and created less of a problem with cheating.

One profitable ring at the discriminatory auction is {5, 4, 3}. Bidders 5 and 4 submit bids of 2. Bidder 3 does not bid and receives an aggregate payment from 5 and 4 of at least 1. The no cheat constraint is satisfied for bidder 3 who could earn at most 1 by cheating with a bid just above the bid of 5 or 4. The individual rationality constraints are satisfied for bidders 5 and 4 because their total gain over the noncooperative outcome is 2 compared to a payment of 1.

If the ring is enlarged to {5, 4, 3, 2} no additional gain is possible. The winning bids cannot be pushed below 2 without violating one of the constraints. For example, if the ring attempted to achieve winning bids of 1.5 for bidders 5 and 4, then bidder 3 could get 1.5 from cheating and bidder 2 could get .5 from cheating. The total sidepayments made by bidders 5 and 4 would have to be increased from 1 to 2. This increased side-payment cost of 1 equals the total collusive gain of 1 from the reduced purchase price. If adding bidder 2 is costly to bidders 5 and 4 (e.g., from increased probability of detection), then they would oppose expansion of the ring. Whenever the ring attempts to depress the winning bid into the range from 1 to 2, the cost in deterring cheating matches the gain in reduced purchase price.[32]

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that {5,4} was not profitable but now {5,4$-\epsilon$} is profitable. Bidder 4 simply bids below 2. The ring earns a surplus of 3 whereas non-cooperative behavior would have yielded 3$-\epsilon$. Bidder 4 would get a side payment slightly in excess of 1$-\epsilon$ while bidder 5 would get a net surplus slightly below 1$+\epsilon$. The ring gains by intentionally not winning an object that would have yielded a positive surplus had the ring bid truthfully for the two highest values.

[32]The rings {5,4,3,2}, {5,4,3,1}, and {5,4,3,2,1} are feasible at the discriminatory auction. These

Two conclusions emerge from this analysis. First, a large number of bidding rings are profitable and sustainable at the uniform price auction whereas only a single limited bidding ring is profitable and sustainable at the discriminatory auction. Second and relatedly, the robustness of the one-shot, single item, first price auction to collusion does not fully extend to the discriminatory auction.

2.3 Private information

Until now we have assumed that bidders know each others' valuations. We now tackle the question of whether the existence of incomplete information creates an incentive for bidders to collude. We show that certain common value information environments stimulate collusion. There is not commentary on the linkage between private information and collusion in the antitrust literature on price-fixing. Athey and Bagwell (2001) analyze private information about production costs in the context of collusion in posted price markets. They warn that antitrust restrictions on communication or side-payments may have the perverse effect of reducing the productive efficiency of cartel members. For a similar conclusion see Clarke (1983). More recently, three papers have analyzed private information in the context of collusion at auctions with common values (Porter, 2005; Hendricks, Porter, and Tan, 2008; Pagnozzi, 2011). These papers address the interaction of the winner's curse with the conduct of bidding rings and they assess the impact of collusion on payoffs to non-ring members and on total surplus. We pursue similar concerns in this section.

2.3.1 Common value auctions and the winner's curse

We use the auction market for off-shore oil tract leases to explain the effect of private information about a common value on bidding and the incentive to collude.[33] There are two types of offshore oil tract leases let via auction by the federal government: wildcat tracts and drainage tracts. A wildcat tract is remote from other tracts so there is little evidence on oil deposits besides seismic analysis. A drainage tract neighbors a tract that is being successfully tapped. The rate of production on the neighboring tract provides information that is useful in estimating the magnitude of

rings could follow the same behavior as the {5,4,3} ring and ignore bidders 2 and 1. In a one-shot setting these larger rings will not be formed because they offer no advantage and may create disadvantages such as an increased risk of detection.

[33] See Hendricks and Porter (1988).

reserves under the drainage tract. We will discuss the influence of information on optimal bidding in each of these types of auctions to explain the "winner's curse" and incentives for collusion. We will start with wildcat tract auctions where bidders are likely to be symmetrically informed.

The term "winner's curse" was coined to explain the poor performance of oil companies in the early days of offshore oil tract auctions. A dominant factor in determining a bid submitted by an oil company is the estimate provided by the company's geologists about the expected amount of oil that can be removed from the tract. There is substantial variability associated with the geologic estimates. Naturally, the noncooperative equilibrium bids increase as the geologic estimate of oil reserves increases. In the early days, the oil companies' bids were too aggressive, and winners tended to regret their acquisition.[34] This was because the bidders did not account for the fact that the event of winning the auction was informative. The fact that bidder A won the auction was probably attributable to the fact that A's geologists provided the most favorable or most optimistic estimate of oil reserves. The most optimistic estimate from a large number of estimates is almost surely not the most accurate estimate. Thus the winner was cursed with a tract that was less valuable than they estimated.[35] Eventually, the bidders learned to shade their bids down to adjust for the winner's curse, and now they make a normal expected rate of return on wildcat tracts.

2.3.2 Collusion to preserve an informational advantage

We shift our attention to auctions involving drainage tracts. At wildcat auctions bidders are likely to hold similar information about the value of the oil reserves. At drainage tract auctions there is likely to be informational asymmetries. Firms that hold leases at neighboring tracts are likely to be better informed about the reserves available under a drainage tract.[36] For modeling purposes we assume that neighboring bidders are completely informed about the magnitude of the reserves. We consider a model with two bidders – one informed and one who is uncertain about the tract's

[34] See Capen, Clapp, and Campbell (1971). Of course, this was an "out of equilibrum" phenomenon. In equilibrium the winner's curse refers to the shading that occurs in bids to reflect the fact that winning is bad news in terms of the informational content of one's private signal.

[35] The winner's curse grows more severe as the number of bidders or uncertainty grows. See Bikhchandani and Huang 1991.

[36] See Reese (1978).

value.[37] Instead of analyzing a first price auction we will analyze a second price auction. We make this choice for analytic convenience. Assume that the object is worth one of three values $V_1 < V_2 < V_3$. Bidder 1 knows the true value, but bidder 2 only knows the probabilities of the different possible realizations. This is all common knowledge among the bidders.

In equilibrium bidder 1 simply bids the true value of the item, and bidder 2 bids V_1.[38] Bidder 1 wins for a price of V_1 when the true value is either V_2 or V_3, while if the value is V_1, then one of the bidders is arbitrarily chosen to win at a price of V_1. Bidder 2 makes zero profit, but the informational advantage of bidder 1 leads to positive expected profit. This result reflects a general phenomenon. A bidder with strictly worse information than some other bidder cannot make positive expected returns (all else equal), and a bidder with information unavailable to any other bidder can make positive expected returns.[39]

When bidders are asymmetrically informed as in the case of drainage tract auctions, some interesting effects arise from collusion. In our example bidder 1 has no interest in colluding with bidder 2 given a reserve set by the seller of V_1. Furthermore, the addition of a third bidder with the same information as bidder 2 would not affect bidding in the noncooperative setting, and would provide no incentive for any of the parties to collude.[40] In contrast, the addition of a third bidder with the same information as bidder 1 would lead to an equilibrium in which all three bidders always get zero profit. Bidders 1 and 3 would both bid the true value, and bidder 2 would bid V_1. Bidders 1 and 3 could recover their informational rents by colluding. Bidder 1 would bid the true value and bidder 3 would bid V_1 and receive a sidepayment from bidder 1. In response bidder 2 would still bid V_1. Thus, collusion restores the informational

[37] The argument was first developed by Hendricks and Porter, (1988).

[38] If bidder 2 were to bid any amount, she would always earn a zero profit in light of bidder 1's strategy. Why then would bidder 2 bid V_1? Suppose, regardless of the value realization, that bidder 1's value was slightly in excess of the realization V_i, say $V_i + \epsilon$. This might be case because knowing the value allows bidder 1 to make some minor value enhancing investment that bidder 2 cannot make. Then bidder 2 would never want to win with a bid in excess of V_1 because she would always earn a negative surplus. We rule out equilibria that would emerge with $\epsilon = 0$ that do not exist when is arbitrarily small.

[39] See Engelbrecht-Wiggans, Milgrom and Weber (1983). An empirical study of bidding for offshore oil tracts shows that non-neighbors earned zero expected profits from bidding on drainage tracts, but neighbors got positive expected profits. See Hendricks and Porter (1988).

[40] Hendricks and Porter (1988) observe this pattern in oil tract auctions. They note that collusion apparently was limited to neighbors of the tract up for auction.

rents for bidders 1 and 3 that noncooperative behavior totally dissipates.[41]

2.3.3 Collusion to overcome an informational disadvantage

Our next model shows that asymmetric information can also provide an incentive for collusion among the less informed bidders. Suppose the object for sale consists of two distinct components, but it is sold as one unit at a second price auction. Each component has a value of zero with probability π and a value V with probability $1-\pi$. These value realizations are independent, so the item is worth either 0 or V or $2V$. There are three bidders. Bidder 1 observes the value of both components and, thus, bidder 1 is completely informed. Bidder 2 observes only the value of component A while bidder 3 sees only the value of component B.

noncooperative bidding in this context results in bidder 1 bidding the value of the object. Bidder 2 bids the value he observes for component A while bidder 3 bids the value he observes for component B.[42] Bidder 1 always wins. When the item is worth nothing bidder 1 wins for a price of zero. When the object is worth V or $2V$ bidder 1 wins for a price of V. Bidder 1 gets positive expected profit while bidders 2 and 3 get zero profits.[43]

Now suppose bidders 2 and 3 collude. They share information and consequently know with certainty the underlying common value.[44] Both the ring and bidder 1 will bid the common value. All bidders get zero profit.[45] Collusion increases the

[41] With regard to off-shore oil drainage tracts, neighboring firms apparently were able to collude to retain the informational rents that derive from their superior information about the value of a drainage tract (Hendricks and Porter (1988)). There were 74 tracts with multiple neighbors, but only at 17 of these tracts did more than 1 neighbor bid. Furthermore, the profits to a winning neighbor were not affected by t h e presence of multiple neighbors. Finally, increasing the number of neighbors to a particular drainage tract, decreased the probability that a particular neighbor would bid. See also, United States Champion Int'l Corp.,557 F.2d 1270, 1272 (1977) (better informed bidders at timber auctions would exchange information prior to bidding).

[42] As in the previous subsection, we construct this equilibrium from the premise that a bidder who knows t h e value of an item with certainty can make it worth ϵ more than its "true" value through some form of ex ante investment. This small value premium is bid by all such bidders. We then let tend toward zero.

[43] Bidder 1's expected profit is $(1-\pi)^2 V$. The probability that both components have a high value times $2V$ minus V.

[44] This may be difficult to accomplish. Bidders have an incentive to distort the information they provide to other ring members. Here and throughout this article we have suppressed this issue. The problem does not exist if the information is easily verified when it is shared. The problem can be overcome in a repeated auction setting.

[45] If there is some cost to collusion, then bidders 2 and 3 would rather not collude. It is not difficult to introduce some heterogeneity into the model would give bidders 2 and 3 a positive incentive to

revenue to the auctioneer. If the supply is elastic, then output rises and collusion is socially beneficial. Collusion is socially beneficial here because the less informed bidders share information that eliminates the bid shading that would otherwise occur to prevent winner's curse. Even though there are effectively fewer bidders (two rather than three), the average bids are higher.[46]

2.3.4 Disclosure of information by the auctioneer

Besides the use of information by bidders, we also want to comment on the provision of information by the auctioneer or procurer. In the offshore oil lease auctions, the federal government provides seismic information to prospective bidders. In contrast, at timber auctions in the Pacific Northwest the federal government withholds information about the quality of timber on neighboring tracts.[47] The government should provide all relevant information to bidders in a CV setting because it eases the effect of the winner's curse and thereby allows bidders to bid more aggressively. The end result is a higher expected winning bid in auctions, and lower expected winning bid in procurements. Furthermore, the government release of information may be particularly helpful in cases in which there are asymmetrically informed bidders. Auction revenues may increase dramatically if the government puts the less informed bidders on the same footing as better informed bidders. Also, the government provision of good seismic information, for example, can help avoid some of the costs of duplicative seismic studies that individual bidders would conduct. In an IPV setting the issue does not arise because the auctioneer would not have any private information to disclose.

As just described, providing information about the object being sold can be valuable because it can reduce winner's curse issues, reduce informational asymmetries among bidders, and help to avoid duplicative expenditures. In contrast, providing

collude. For example, if collusion between bidders 2 and 3 allows for better risk sharing or some productive synergy, then they could get a positive profit out of collusion and the auctioneer would still benefit from more aggressive bidding.

[46] The CV setting yields stronger incentives to collude than the IPV setting. There is no counterpart to the winner's curse in the IPV setting – the fact of winning cannot convey disappointing information about the value of the object for sale. An IPV auction winner learns only that others do not share his passion for a particular item. He does not learn that he has bad taste. Furthermore, the existence of asymmetric information is not much of a problem at IPV auctions. If individual preferences account for the differences in valuations, then no one can be better informed than anyone else.

[47] See Baldwin, Marshall, and Richard (1997).

information about the bidders and their bids can increase the ability of bidders to collude.

Information disclosed by the auctioneer to bidders about the identities of the bidders and their bids can affect the ability of bidders to collude. In particular, this information can affect the ability of a bidding ring to monitor compliance with the collusive agreement. As shown in Marshall and Marx (2009), increased transparency in auction design can transform an auction from being robust to collusion to being susceptible to collusion.

To give a simple example, in a procurement setting the auctioneer might provide the incumbent supplier with information about the amount of the lowest bid and offer the incumbent the right of last refusal. However, informing the incumbent of the bids of others before the procurement ends allows the incumbent to monitor the bidding behavior of potential ring members and react in real time to potential cheating by those ring members. Thus, allowing a right of last refusal can deter deviations by ring members and so is pro-collusive.

If ring members at a sealed-bid auction have the ability to submit bids under disguised names, it can be more difficult for a ring to police the bids submitted by ring members. In particular, ring members who have been instructed by the ring to submit losing bids may have an incentive to try to win the item under a disguised name, thereby avoiding penalties for cheating. Thus, the auctioneer may have an incentive to use bidder numbers or other identifiers that disguise the true identities of the bidders or allow bidders to submit bids under multiple bidder numbers in an attempt to destabilize any bidding rings that may be present.

An auctioneer's registration process can affect whether certain collusive bidding agreements can be sustained. For example, an auctioneer might make collusion relatively more difficult by using a nontransparent registration process in which she does not reveal the bidder IDs that will be used at the auction nor any information linking bidder IDs with their underlying identities. Alternatively, an auctioneer might make collusion relatively easier by using a transparent registration process in which she announces the set of all assigned bidder IDs and their underlying identities.

Under transparent registration, a ring can police bids made by ring members and identify when a ring member has won the object, perhaps triggering payments to the other ring members. Under nontransparent registration, the ring only observes the bidder ID of the winner and cannot necessarily be sure whether that bidder ID

corresponds to a ring member or not.

As shown by Marshall and Marx (2009), nontransparent registration is disruptive to a ring at an English auction as long as the bidder identity of the current high bidder is not disclosed during the bidding process. However, Marshall and Marx (2009) also show that nontransparent registration need not disrupt a ring at an English auction where the bidder ID of the current high bidder is revealed throughout the auction. In that case, the ring can require that the highest-valuing ring member reveal its bidder ID to the other ring members and instruct the less than highest-valuing ring members to bid if and only if the price is less than their values and the highest-valuing ring member is not the high bidder and the auctioneer is about to close the auction. The highest-valuing ring member is instructed to bid promptly whenever it is not the current high bidder and the price is less than its value. Because ring members bid up to their values as long as they perceive competition from bidder IDs not claimed by the ring, deviations are deterred.

These results show that even among a particular type of auction, such as an English auction, the profitability of collusion can be reduced by altering other design parameters, such as the transparency of the bidder registration process.

3 Efficiency effects of bidder collusion

In all of antitrust law the per se rule is most entrenched in the area of horizontal price fixing. Application of the per se doctrine signals a consensus that horizontal price fixing almost always restricts output and causes social harm.[48]

One factor that contributes to cartel stability is the ease of detecting deviations from agreed prices. Detection is easier in markets with homogeneous goods. The manufacturing of sanitary pottery often yielded defective, but merchantable products, called seconds. The cartel required manufacturers to destroy all seconds. The motivation for this policy was that the sale of seconds would offer manufacturers the chance to offer price discounts that were larger than the reduction in value due to the defect. This is a means of chiseling on the price set by the cartel. Because the extent of the defect and implied reduction in value could vary considerably, the problem of detecting "excessive" discounts would be enormous. Thus, for the sake of cartel

[48]For example Whinston (2008) states that the prohibition on price-fixing is the "most settled and economically sound area of antitrust."

stability, the cartel destroyed merchantable output. Essentially the same argument applies to collusion by buyers to post prices below the competitive price. In both cases the social loss is attributable to the decline in the quantity transacted. The social harm caused by monopsony and collusion among buyers is output restriction, just as in the case of monopoly or collusion among sellers. In an auction context, the traditional view holds that bidder collusion depresses seller revenue. In turn, marginal sellers see the depressed revenue and choose not to bring their items to the market. This quantity restriction implies a deadweight loss that the antitrust laws are supposed to deter and correct.[49]

The traditional analysis may not be applicable to all auction markets. It generally applies to a fresh fish auction or the sealed bid procurement of sewer pipe. Collusion in these markets affects output by reducing the returns to fishing and ultimately the supply of fresh fish, or by increasing the cost of sewer pipe and possibly jeopardizing governmental demand for new water treatment programs. In these markets there are many auctioneers and procurers. The products are homogeneous and there are no subtle informational problems to thwart competitive forces. But in most auction and procurement markets, the market power of auctioneers or procurers and the scarcity of information may dampen the effects of competition. Competition by bidders does not always lead to an efficient outcome. Specifically, colluding bidders may bring countervailing power to bear on an auctioneer or procurer who also has market power. Further, collusion may be the only means of protecting the rents that flow from investments that raise the value of a transaction in an auction or procurement market. Thus we have come to question whether the per se rule is appropriate for all bid-rigging cases.[50]

[49]The second inefficiency created by collusion is peculiar to markets involving the gov- ernment as a buyer or seller. In these markets, collusion leads to increased government expenditures at procurements and decreased revenues at auctions. We disregarded such wealth transfers above, stating that they are a distributional issue. The difference in the case of the government is that raising government funds through distortionary taxes creates inefficiency. The increased revenue spent in procurements because of collusion is not simply a wealth transfer. If the revenue lost by the government as an auctioneer when facing colluding bidders is replaced by distorting taxes, then, once again, there is an efficiency loss.

[50]Outside of bid rigging, the Supreme Court has reexarnined various horizontal agreements that in the past would have been quickly condemned as price fixing and per se illegal. The Court applied a rule of reason standard to practices that impinged on price setting in Professional Engineers, National Society of Professional Engineers v. U.S., 435 U.S. 679 (1978), Broadcast Music.Broadcast Music, Inc. v. Columbia Broadcasting, Inc., 441 U.S. 1 (1979) and National Collegiate Atheletic Ass'n v. Board of Regents of the Univ. of Okla., 468 U.S. 85 (1984). The Court emphasized the

We provide standards to determine whether bid-rigging should be characterized as price-fixing and per se illegal or as a horizontal restraint that is subject to rule of reason analysis.

3.1 Collusion as countervailing power

The term countervailing power was first used by Galbraith (1952) to describe his vision of the typical market in a modern economy. He intended to highlight the departure from the competitive model that could be seen in many markets. Instead of a large number of price-taking buyers and sellers, there were a small number of powerful buyers and sellers. He claimed that efficiency losses associated with monopoly power would be diminished over time as buyers organized and gained countervailing monopsony power. Galbraith's notion of countervailing power seems quite apt in many auction and procurement markets.[51]

There are two key concepts in our countervailing power story – market power and bargaining power. If there is a single seller of a commodity, or a small number of sellers, or if most of the commodity is provided by a very few suppliers, then there is significant market power on the supply side. If there is a single buyer, or very few buyers, or if buyers have cartelized, then there is significant market power on the demand side. Bargaining power is a different concept. If sellers (buyers) can credibly commit to a pricing institution, for example by declaring a take-it or leave-it price, then sellers (buyers) have bargaining power. To illustrate, suppose a monopoly seller has a value of 0 for the single unit they have available for sale while the sole buyer in the market has a value of 1 for the unit. Suppose these values are common knowledge. If the seller has all the bargaining power, then the buyer will pay 1 for the unit. If the buyer has all the bargaining power, then the seller will receive 0 for the unit. If the bargaining power is shared equally, then the item will be sold for a price of 1/2.

Reaching the efficient output in a market depends on who has market and bargaining power and how they use it. If all power rests in the hands of a monopoly

possible pro-competitive effects of horizontal agreements in these markets, and in Broadcast Music, the Court permitted price fixing because it was ancillary to a legitimate pro-competitive purpose. This pattern has continued in recent years as the courts have continued to blur the once sharp lines between per se rules and the rule of reason standard. (Leary, 2004; Hovenkamp, 2005).

[51]The British Restrictive Practices Court is sympathetic to the countervailing power argument applied to price-fixing. See Scherer and Ross (1990). The Capper-Volstead Act (1922) exempts agricultural cooperatives from antitrust law in order to promote marketing efficiency and counterbalance the market power of suppliers and customers.

seller, that seller will normally use the power to restrict output and achieve monopoly profit.[52] Likewise, a monopsonist with all market and bargaining power will restrict output inefficiently. Although market power and bargaining power are separate concepts, it is intuitive to think that market power engenders bargaining power. For example, if a monopolist faces many small buyers, then it would seem unreasonable to think of these buyers calling out a take-it or leave-it offer to the monopolist. It is most natural to think of the monopolist as credibly committing to a price. However, microeconomists do not have a theoretical construct that describes how bargaining power endogenously evolves from market power. Of necessity therefore, our comments here are heuristic.

As a starting point, we compare unionization by workers in a monopsonistic labor market with an auction market in which colluding bidders face a monopolistic seller. Facing individual workers, a monopsonist will call out a profit maximizing wage below the competitive wage.

Compared to a competitive outcome, too few workers will be employed. When workers unionize it is reasonable to think that they can call out a minimally acceptable wage, or at least bargain to a wage above the monopsony wage where potentially more workers will be employed and deadweight loss will be reduced. But this presumes that bargaining power has shifted – if the monopsonist retained all bargaining power after unionization, then the monopsonist would simply call out the same wage that he called out to the non-unionized workers.

There is widespread acceptance of the notion that unionization raises employment and improves efficiency in monopsonistic labor markets. This attitude has never been transplanted to the field of bidder collusion. But the analogy is close. Most auctioneers have some degree of market power. Items sold at auction are often highly differentiated. In certain auction markets, fine art for example, there are few sellers. In certain procurement markets, automobiles for example, there are few buyers. It is rare to have a pure monopolist auctioneer, but it is also rare to have a company town with a pure monopsonist employer. After all, workers are mobile and can retrain themselves for alternative occupations.

We do see two significant distinctions between bidder collusion and worker union-

[52] One must be careful though, a monopolist that has complete knowledge about buyers preferences will not choose to inefficiently restrict output. Instead the monopolist will practice perfect price discrimination and offer the competitive output. We focus on the realistic case in which buyers and sellers have private information.

ization. First, unions are legal, bidding rings are not. Intuitively, a monopsonistic employer would forfeit much less bargaining power to an illegal cartel of workers than she would to a legal one (especially in a regime that banned permanent replacement workers). A bidding ring is constrained in its operations by fear of detection. Its bargaining position must be compromised to limit the disclosure of information that may provide enforcement authorities with verifiable information regarding the existence of the ring. The seller decides how many units to bring to the market. The seller decides upon a minimally acceptable price for units sold. An all-inclusive ring can test the commitment power of an auctioneer by withholding all bids and waiting to see if the auctioneer will offer the items again at a lower reserve price. But a ring cannot typically enter negotiations about the quantity or quality of items for sale at the auction.

Second, the mechanism of exchange differs between the labor market and auctions. Non-unionized, blue collar and clerical workers participate in a posted price labor market. The wage rate and benefit package is offered on a take-it or leave-it basis. Unionization changes the wage-setting mechanism into a bilateral negotiation. Noncooperative bidders participate in an auction. If bidder collusion were legalized, the auction would also be likely be transformed into a negotiation. The difference in the starting points reflects the informational differences between the two settings. A seller chooses an auction rather than posting a price because she is not well informed about the likely equilibrium price. The informational disadvantage of auctioneers would adversely affect their bargaining power in a bilateral negotiation.

The upshot from these observations is that bidding rings probably are less powerful than unions because they must lurk in the shadows to avoid antitrust prosecution. Rings, like unions, may have a desirable effect on efficiency. As bargaining and market power shift to the union or the ring, the quantity brought to market may increase. The following example illustrates this effect.

Consider a market in which the auctioneer can choose to bring either one or two items to the market. Suppose that there are three bidders who desire a single item and have valuations of 5, 3, and 1. The bidders know each others' valuations, and the auctioneer knows these three valuations are present, but not which bidder has which valuation. The method of auction is not important here, but to be concrete we suppose that a uniform price (highest rejected bid) sealed bid auction is used. If two items are sold, then the two highest bidders win an item and they each pay the third

highest price. If one item is sold, then the highest bidder wins and pays the second highest bid. To start we assume that the bidders behave noncooperatively. Then if one item is sold, the winner bids 5 and pays 3. If two items are sold, the winners bid 5 and 3, and they each pay 1 for the items. The auctioneer will of course choose to sell only one item (even if the second item has no value to her) because the revenue is higher. Now consider the case in which the two high value bidders collude, and this collusion is known to the auctioneer. If one item is sold, the highest valuation bidder bids 5, the second highest valuation bidder suppresses his bid to 1 or less, and the third bidder who is not in the ring bids 1. The ring takes the item at a price of 1. If two items are sold, then the two high valuation bidders take the items at a price of 1. Thus, the auctioneer will offer two items for sale if her valuation of a retained item is less than 1. Comparison of the two cases shows that collusion can increase output.[53] Although output rises,[54] revenue to the auctioneer falls, thus she has reason to complain about the collusion, but the gains to the colluding bidders outweigh the losses to the auctioneer.[55]

Besides adjusting quantity, there are a variety of other bargaining tactics that an auctioneer can use to combat bidder collusion.

1. Entry fees. These are relatively rare. Perhaps the purchase of a booklet which describes the items to be sold could be viewed as an entry fee.

2. Reserve Prices. These are very common at both government and private sales and procurements.

3. Quantity restrictions. The Mineral Management Service does not sell all feasible Gulf drilling tracts at one time. This would not be revenue maximizing.

[53] Less than all inclusive collusion is common in auction and procurement markets, but it is required for our result. The output effect disappears if all three bidders collude.

[54] The output expanding effect of collusion is lost if the valuations of the buyers are changed to 5, 3, and 2. When the two high value bidders collude and two items are offered, their strategy changes. If they do win two items at a price of 2, then their combined profit is 4. If instead the second highest bidder suppresses his bid to 0, then the ring wins one item and gets a profit of 5. The auctioneer's best response to collusion is to sell only one item. In contrast, with noncooperative bidding, the auctioneer's optimal choice is to sell two items. Thus countervailing power depresses equilibrium output.

[55] In the noncooperative setting, the auctioneer earns a profit of 3 and the winning bidder gets a profit of 2. In the collusive setting, the auctioneer gets a profit of 2 and the ring gets a profit of $5 + 3 - 2$ or 6. Under collusion, the total profit is 8 compared to 5 in the noncooperative case.

4. Ex ante denial of joint venture status. With very rare exception joint ventures are not approved for Forest Service Timber Sales but, on the other hand, are frequently approved for offshore oil lease bidding.

A secret reserve may remove the possibility of tacit collusion in which ring members bid the reserve.[56] If the auctioneer cannot prove bidder collusion in the courts, she may resort to self-help remedies that disrupt a suspected ring. For example, the auctioneer might retain an item or award it to a non-ring member even though the ring would be willing to pay more. Either of these tactics creates an ex post inefficiency assuming that some ring member had the highest valuation and resale is costly. In contrast to the quantity adjustment example, in the following examples collusion leads to less efficient outcomes.

In the private sector, auctioneers may attempt to combat bidding rings at English auctions by using a "quick knock." When a quick knock is used, the auctioneer ignores the attempts of the ring to raise the current high bid, and awards (or knocks) the item to a non-ring member. This strategy is only effective when the auctioneer knows who the ring members are (or at least who is not a ring member). Further, the auctioneer must expect that the bidders in the ring will attend future auctions. The quick knock is only worthwhile if it disrupts the ring, and the short run loss is outweighed by the long run gain from more competitive bidding in future auctions. Although the quick knock may be profitable to the auctioneer, it is inefficient because the highest value bidder might be in the ring. If resale is costly, then the award to a non-ring member is socially costly.

An alternative to the quick knock is provided by a protecting bidder. When using this tactic, the auctioneer instructs the protecting bidder to raise the prevailing ring bid (perhaps above what the protecting bidder would pay of his own accord) in an attempt to elicit a higher counterbid from the ring. Sometimes, the ring withdraws from the bidding leaving the protecting bidder with the item. The protecting bidder and auctioneer will typically have agreed upon some discounted price for items awarded to the protecting bidder in this way. As was true with the quick knock, the use of a protecting bidder leads to inefficiency when resale is costly, and the protecting bidder wins an item but some ring member has a higher valuation.

Frequently, the auctioneer acts as her own protecting bidder. She does this by announcing a reserve price, which means that the auctioneer retains the item if no

[56] See McAfee and McMillan (1992).

bid exceeds the reserve.[57] Reserve policies are often used in procurements as well, in which case the reserve price sets the maximum acceptable bid. If an auctioneer suspects, but cannot prove collusion, it may be optimal for her to raise the reserve price above what it would be if all bidders acted noncooperatively.[58] The reserve price compensates to some extent for the lack of competition between the bidders. The increase in the reserve is inefficient because a higher reserve implies a higher probability of retention by the auctioneer.[59]

The preceding discussion shows that bidder collusion may cause a pro-competitive increase in output. The gist of the argument is that market power held by the auctioneer is countered with market power in the hands of the colluding bidders. The countervailing power argument has intuitive appeal, but we have shown that when the auctioneer retains some bargaining power collusion may exacerbate inefficiencies. It seems sensible to consider relaxing the per se rule against bidder collusion. If the auctioneer (or procurer) has significant market power, then the rule of reason would allow colluding bidders the opportunity to demonstrate whether the effect of collusion is likely to be an increase in expected output and efficiency.

3.2 Pre-auction investments and bidder collusion

A second theory that justifies a more lenient attitude toward bid rigging is based on investment incentives. Cooperative behavior by bidders may be socially desirable because it is effective in stimulating socially productive investments that would not be profitable in the absence of collusion. Competitive bidding diminishes investment incentives for two types of ex ante investments by bidders – (i) investments that produce socially wasteful information about the common value of the item at auction and (ii) investments that directly raise the private and social value of the item at auction.

[57] United States v. Seville Indus. Mach. Corp., 696 F.Supp. 986, 991 (D.N.J. 1988) (even if the reserve is binding and no bid is accepted, there is still a Sherman Act violation).

[58] For example, if two bidders independently draw their valuations from the uniform distribution on the interval $[0, 1]$, then the optimal reserve is 0.5. If these bidders collude, then the optimal reserve is approximately 0.58.

[59] A phantom bidder may be used to implement a reserve policy. The auctioneer tries to force the ring's winning bid up by pretending to receive competing bids from some bidder in the back of the room or over the telephone. Like the reserve, phantom bidding leads to inefficient retention of the item by the auctioneer.

Ex ante investment in information is our main concern.[60] Noncooperative bidders have a weak incentive to acquire information before an auction. When the item for sale has a common value component, a single bidder with superior information can earn an informational rent. But that rent disappears if any other bidder acquires the same information. In markets like antiques and used machinery, dealers invest in learning the market value of items and the preferences of specific retail customers. With offshore oil exploration and timber, firms make investments specific to a particular tract that improves their information about that tract. Such investments are greatly affected by the prospect of using the information to profit at the auction. If firms anticipate that the best informed bidders will collude at the auction, then there is a strong incentive to make ex ante investments to become well informed.[61] If the firms anticipate noncooperative bidding, or collusion by less informed bidders, then this incentive is muted. The problem with the noncooperative outcome is that buyers do not have any property rights at the time of their investment. There is still some incentive as each firm hopes that it is the only one whose investment successfully yields relevant information or that it is the only firm that makes the investment necessary to gain certain information.

Whether the extra investment in information production induced by collusion is socially desirable is unclear. Just because a bidder is willing to make a costly investment in information gathering does not mean that the information is socially valuable. Bidders may be eager to obtain information that does nothing more than improve the precision of their estimate of the value of an item at auction. Such information has no social value. Eventually, the value of the item will be revealed to the winner regardless of whether they made an investment. But this information eases the winner's curse on a bidder and allows them to gain expected profits at the auction.[62] This scenario matches certain aspects of an oil tract lease auction. Oil companies each invest in geologic reports regarding the potential size of the oil pool and the cost of extraction.[63]

[60] We do not discuss ex post investment because usually collusion does not affect investment decisions that are made once an item has been auctioned or a contract let. Besides the acquisition of information, bidders make ex ante investments in physical assets. The incentive to make these investments may also be too low with non-cooperative bidding.

[61] Hendricks and Porter (1988) show that at oil lease auctions joint ventures sometimes formed after seismic surveys, but more stable ventures formed before surveys.

[62] Chari and Weber (1992) argue that the information gathered by bidders in Treasury auctions has no social value.

[63] It is unlikely that these investments would be wholly redundant (i.e. produce the same infor-

Many types of informational investments have positive private and social value. Bidders at natural resource auctions gather information that allows for more efficient extraction, harvesting, or processing. For example, by understanding the species and quality composition of timber in a given section of a forest a mill may be able to customize its production process to reduce the cost of converting logs into wood products. If more than one bidder makes such an investment, then noncooperative bidding dissipates the associated rents. Socially valuable investments would be dissuaded unless the bidders were to collude and preserve the rent.

Dealers gather socially valuable information that facilitates their intermediary role. For example, dealers of used merchandise, such as used industrial machinery dealers, typically make significant ex ante investments in the development of an expertise. Some machinery dealers specialize in presses while others primarily handle specific kinds of saws. This expertise allows them to more quickly reallocate machinery from low valued users to high valued users. An implication of the expertise is that they know who the high valued users are for a given type of machine tool. When buying machine tools at auction two bidders with expertise in presses will bid away all rents to their expertise if they act noncooperatively. Collusion averts this rent dissipation.

By now, the reader may have some enthusiasm for the efficiency promoting aspects of bidder collusion. That enthusiasm should be tempered by two considerations. First, the social value of the extra investment must outweigh the social cost of redundant investment by different bidders, as well as the effect of the price distortion and other social costs caused by collusion. Second, there may be other alternatives for encouraging the ex ante information investment. Auctioneers who benefit from the investment can encourage it by permitting joint ventures or joint bidding. Joint bidding occurs at certain Department of Defense procurements, offshore oil sales, and the current spectrum license sales by the Federal Communications Commission. The fact that an auctioneer does not permit joint bidding should not be dispositive, though. It is possible that a socially valuable investment is of no particular value to an auctioneer. This is easiest to see when the investment has lasting value over a sequence of auctions. In that case, an auctioneer who runs one sale would not want to promote an investment that would mostly benefit the bidders and other auctioneers.

mation). Nevertheless, there is the potential for substantial overlap in the information obtained by individual bidders.

4 Concluding remarks

The fundamental message of this article is that standard supply and demand analysis of cartel behavior is often deficient when applied to collusion by bidders at an auction or procurement. Supply and demand analysis is static, presumes perfect information is held by all participants, presumes there are many sellers and many buyers in the market, and presumes the commodity in question is homogeneous. In markets where auctions are used as allocation mechanisms, it is often the case that significant market power is held by the sellers, the item being sold is highly heterogeneous (even within a given sale), and significant resources must be expended to understand the item being offered in order to formulate a bid.

Using a game theoretic approach, we show that collusion is more stable at oral ascending bid and uniform price auctions than at other auction formats. Our finding makes us concerned about possible collusion at Forest Service timber auctions that use oral ascending bid procedures, at uniform price Treasury auctions, and at ascending bid auctions run by the Federal Communications Commission for spectrum licenses.[64]

Finally, we define circumstances in which bidder collusion might not be inefficient. If the auctioneer has market power and uses that market power to restrict output, then bidder collusion may produce countervailing market power that is socially beneficial. In addition, collusion may stimulate socially valuable ex ante investments in information gathering.

[64] In the case of spectrum licenses, ascending bid auctions have the benefit of allowing bidders to aggregate collections of licenses that take advantage of complementarities. This benefit of an ascending bid format must be weighed against concerns related to collusion. (Marx, 2006)

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