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Auctions are used in many different markets, including the leasing of a substantial fraction of the natural resources in the United States. The procedures used in the auctions conducted by the federal government have been a continuing source of controversy. One of the concerns has been the possibility of collusion among bidders. This article shows that cartels are stable if the seller uses open ascending-bid (oral) auctions, but not if he uses sealed high-bid auctions. This may help to explain the frequent use of sealed high-bid auctions.

1. Introduction

■ Auctions are used in many different markets, including the leasing of a substantial fraction of the natural resources in the United States. The procedures used in the auctions conducted by the federal government have been a continuing source of controversy with one of the principal worries being the possibility of collusion among bidders (U.S. House of Representatives, 1977; Johnson, 1979).

Despite an extensive and thriving literature on auction theory (Engelbrecht-Wiggins, 1980; Milgrom and Weber, 1982a), the effect of different auction methods on the probability and stability of cartels among bidders has not been formally analyzed. Mead (1967) stated that oral auctions were more vulnerable to collusion than was sealed bidding, but he did not discuss clearly why this would be so or which of the features of oral auctions encourages collusion.

This article shows that as long as all cartel members share the same information, cartels are stable (i.e., incentive-compatible) in open ascending-bid (oral) auctions, but not in sealed high-bid auctions.[1] This is true in the common value as well as the independent values models. The implications for cartel formation when each bidder has private information are discussed.

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[1] All of the results in this article regarding oral auctions apply, with minor changes in terminology, to sealed-bid, second-price auctions. All of the results regarding sealed high-bid auctions apply to Dutch auctions. What is crucial for the results is *not* whether the auction is open or whether bidders can change their bids during the auction; it is whether the cartel members regret their strategies if cheating occurs.

2. Review of the literature

■ The auction considered in this article has a single seller of an indivisible object facing a number of potential buyers. The literature I shall discuss focuses on the *type* of auction—the rules by which bids are presented and the level of payments calculated from the bids. Four types of auctions are commonly considered: open ascending-bid (or oral), Dutch, sealed-bid, first-price (or high-bid), and sealed-bid, second-price.[2]

Riley and Samuelson (1981) and Myerson (1981) prove a revenue-equivalence theorem which states that, under the assumptions of risk neutrality, independence of valuations, and symmetry among bidders, all auction rules within a broad class generate the same expected revenue for the seller if, in equilibrium, the incentives to participate in the auction remain the same. Under these assumptions all four of the common auctions yield the same expected revenue for the seller if they have the same announced reservation price.

In many common situations, such as natural resource auctions, the assumption that the bidders' valuations of the object are independent of each other is unacceptable. An alternative set of assumptions is that the value of the object is the same to all bidders, but that each bidder has an unbiased estimate of the value drawn from an identical distribution. Milgrom and Weber (1982a) prove, in a more general version of this common-value model, that when bidders are symmetric and risk neutral but the value estimates are "affiliated" (roughly speaking, positively correlated), oral auctions yield the seller higher expected revenue than do sealed second-price auctions, which, in turn, do better than sealed high-bid auctions.

Given this last result, it might seem surprising that sealed high-bid auctions are used so frequently in situations where there might be a common value: offshore oil leases, construction contracts, etc. Recall, however, that Milgrom and Weber assumed symmetry, risk neutrality, and noncooperative behavior among bidders. It has been shown that risk aversion tends to favor sealed high-bid auctions, while relaxing the symmetry assumption has an ambiguous effect on the optimal choice among these auction types.[3] The implications of relaxing the assumption of noncooperative behavior, for both the independent-values and common-value models, are explored in the next section.

3. Auction type and cartel stability

■ Before discussing the interaction between the type of auction and cartel formation, it is important to examine the strategy of a cartel of bidders in an auction and the obstacles to stable cartel formation in different bidding environments. At the outset I shall assume that a cartel has been formed and that cartel members have credibly revealed their private information to each other. The incentive to participate in such a cartel will be discussed at the end of the section. The cartel is assumed to try to maximize joint expected profits. In an auction of a single indivisible item, joint profits will be maximized if the cartel

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[2] In oral auctions the price rises incrementally until only one bidder remains, who wins the object for that price. In Dutch auctions the price starts at a very high level, then falls until someone bids. That person wins the prize. It is usually assumed that bidders can observe each other in English and Dutch auctions. In sealed-bid, first-price auctions potential buyers submit closed offers, with the award going to the high bidder. The same is true in second-price auctions, except that the high bidder pays only what the second-highest bidder offered. Since, for the purposes of this article, Dutch and sealed-bid, second-price auctions are respectively equivalent to sealed high-bid and oral auctions, only the latter will be discussed.

[3] For a discussion of the consequences of relaxing the assumption of risk neutrality, see Maskin and Riley (1984) for the independent-values model and Milgrom and Weber (1982a) for the common-value model. Hansen (1984) and Milgrom and Weber (1982b) discuss auctions when there is asymmetry of information, while Maskin and Riley (1983) consider asymmetry of beliefs regarding other bidders' values.

pays the minimum price that will purchase the item whenever its value to the cartel exceeds the purchase price. The cartel is assumed to select from among its members a "designated winner" (who should be the member with the highest valuation if they differ) and to recommend that he follow a particular bidding strategy while requesting other cartel members to be inactive in the bidding.

The cartel, however, has an enforcement problem.[4] The cartel members, particularly the designated losers, may find it in their private interest to deviate from the recommended strategy, that is, to cheat. For the prospective cartel to be stable, the recommended cartel strategies should be *incentive-compatible,* at least in the weak sense that some other strategy for an individual bidder not be strictly preferred by that bidder, given what the others are doing.

Even in one-time auctions, cartel strategies are incentive-compatible for oral auctions in the independent-values and the common-value models. In a one-time, sealed high-bid auction, on the other hand, no cartel strategy which yields positive profits is incentive-compatible, even if all information is public.

These results are formalized in the following theorems. The cartel's expected value, conditional on the shared value estimates of the members and the "winner's curse"[5] (or the highest valuation in the cartel in the case of independent values), is V. This is assumed for simplicity to be greater than the seller's reservation price R, and the designated winner is assumed to be bidder H, who in the independent-values case has the highest valuation. All n potential bidders are assumed to be risk neutral and to maximize expected profits.

Theorem 1. In the common-value (or mineral-rights) model, if all cartel members know each other's value estimates, then: (i) in the oral auction, bidder H's having a dropout price V and all other cartel members' having dropout prices of R or not entering a bid is a stable cartel equilibrium[6] in the sense that bidder H is following a dominant strategy and all other bidders are following Nash strategies, but (ii) in the sealed high-bid auction, no Nash equilibrium exists in which any cartel members make positive profits.

Theorem 2. In the independent-values model, when bidder H is known to have the highest valuation among the cartel members, then: (i) for the oral auction, bidder H's having a dropout price V and all other cartel members' having dropout prices R or not bidding is a stable cartel equilibrium in the sense above, but (ii) in the sealed-bid, first-price auction, no Nash equilibrium exists where bidder H bids below the second highest valuation.

Proofs. In the oral auction, bidder H's dominant strategy is to bid until his own valuation is reached in either the independent-values or the common-value models. The conditions assumed are sufficient to ensure that no other bidder will make positive profits, given that bidder H has a dropout price of V. Since bidding R (which is assumed to be less

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[4] Stigler (1964) takes a similar view that the principal problem facing the cartel is policing the agreement. He also examines the conditions affecting the feasibility of a cartel. Since he is considering an oligopoly of sellers, each producing large quantities over a period of time, the main variable affecting cartel stability is the time until detection. In the one-time auction considered in this section detection would not be timely, so that the agreement must be self-enforcing in a more immediate sense. It is worth noting that Stigler states that "sealed bids, publicly opened with full identification of each bidder's price are the ideal instrument for the detection of price-cutting" (p. 48). Alchian (1977) makes a similar point. The results in this article suggest that an oral or second-price auction would be even more conducive to cartel formation.

[5] The "winner's curse" is that if a bidder wins an auction, his value estimate, since it was the highest, is probably optimistic. A cartel that does not include all bidders faces this problem in the common-value model, though because of the shared-value estimates, the difficulty is much less severe than for an individual bidder.

[6] This is a somewhat stronger equilibrium than a simple Cournot-Nash. Bidder H is following a dominant strategy; each other bidder is following a Nash strategy regardless of what any bidder save bidder H is doing.

than V) or not entering the auction will assure any bidder nonnegative profits, all of the other bidders might as well follow these strategies. Not entering the auction is certainly not the *unique* profit-maximizing strategy; many other bids would guarantee the designated losers zero profits, including bidding V. But once bidder H plays his dominant strategy, any other bidder might as well not enter the auction, no matter what the other bidders do.

In the sealed-bid, first-price auction, on the other hand, there is an incentive to cheat on the cartel. If bidder H and the others bid less than V, with bidder H the high bidder, then in the common-value model, each loser strictly prefers to bid between bidder H and V, since that is the only way to earn positive expected profits. No Nash equilibrium exists in the common-value model where every bidder bids below V, since any loser would want to change his bid, given what the others were doing. In the independent-values model, the bidder with the second highest valuation could make positive expected profits by outbidding bidder H if H bid below that value; but then bidder H would want to alter his bid. No cartel strategy is a Nash equilibrium in a sealed-bid, first-price auction for the independent-values model, either. *Q.E.D.*

Although these results show that a cartel strategy is incentive-compatible for an oral auction, they give no reason for a bidder strictly to prefer the cartel strategy. One way to assure compliance to the oral auction is for the cartel to pay bidders a fraction of the *ex post* profits of the cartel or for there to be a positive cost to entering a bid; even this would not lead to a stable cartel in the sealed high-bid auction.[7]

An important condition of the above theorems is that no private information remains inside the cartel. If bidders have private information, they will frequently have positive expected profits, even if they do not cooperate. For a stable cartel to be formed, every member must prefer both participation and compliance. For the independent-values model there is no advantage to private information in the oral auction. Division rules exist which give bidders an incentive to participate in the cartel, so long as valuations are credibly revealed to cartel members when it is joined.[8] In the common-value model if bidders are symmetric and if the value estimates will be credibly revealed to the other cartel members if the cartel is joined, a cartel solution guaranteeing every member an equal share of either the *ex ante* or the *ex post* cartel profit will be a Nash equilibrium in the oral auction. The sealed high-bid auction still does not have a Nash equilibrium in this case.[9]

4. Conclusions

■ The results of this article offer one justification[10] for the prevalence of sealed high-bid auctions. They also suggest that when oral auctions are used, the seller should be especially alert to the possibility of collusion among bidders.[11] The results do not imply that collusion will always occur in oral auctions nor that cartels will never form in sealed

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[7] See Robinson (1984a) for proofs of these results.

[8] One division rule would require that the item go to the bidder with highest valuation and that he receive at least the difference between his valuation and the second highest among all bidders, if the cartel wins. The condition on information revelation is necessary or potential bidders might overstate their valuation.

[9] These results are proved in Robinson (1984a). The condition that information be credibly revealed is necessary or some bidders with high value estimates might have an incentive to lie and then outbid the cartel.

[10] This is not, of course, the only justification, as mentioned in Section 2. In addition, the possibility of collusion may not be sufficient to outweigh the considerations of Milgrom and Weber (1982a).

[11] This may explain the existence of Scottish auctions, described in Cassidy (1967), which are oral auctions with a time limit (a flickering candle). Since a cheater has positive expected profits if he bids just before the candle goes out, the cartel strategy may no longer be a Nash equilibrium. I am indebted to John Riley for this point.

high-bid auctions. Collusion entails bargaining costs and may run the risk of prosecution. The cartel solution is only one of many Nash equilibria for the oral auction when *ex post* payments cannot be made. On the other hand, in a repeated-game context, cartels can (and do) form in the sealed high-bid case. Potential cheaters may be deterred by the loss of long-run profits.

The type of auction is only one of the important parameters of an auction; other variables include the use of a minimum price and the form of payment between buyer and seller. Robinson (1984b) explores, among other questions, how the possibility of collusion affects the seller's optimal choice along these other dimensions.

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