

**OIL LEASE AUCTIONS:
RECONCILING ECONOMIC THEORY WITH PRACTICE**

by

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I. Introduction

Oil lease auctions have been the subject of a number of recent theoretical papers. Many of the conclusions relate to the optimal structure of these auctions from the seller's perspective. Since the actual auctions that are conducted in the United States, both privately and publicly, do not have these characteristics, the question arises: why do the owners of mineral rights not follow the rent-maximising strategy? This paper seeks to reconcile the empirical observations with economic theory, by showing that increasing the realism of the assumptions used to derive previous theoretical results makes the current practice in lease auctions better, from the landowner's point of view, than the auction structure suggested by the literature.

Petroleum production has a number of special characteristics that make it worthy of separate analysis. Two of these features are critical for this paper. First, petroleum and other extractive resources are exhaustible; there is a fixed (although possibly unknown) supply ultimately available at a given cost of exploration and extraction. Among the implications of exhaustibility are that the value of the resource is greater than the cost of extraction at the margin - along both the competitive equilibrium and socially optimal time paths of extraction - and that intertemporal choice is an essential element of the production decision. Second, there is uncertainty, prior to exploration, regarding the existence and size of an oil pool in a prospect. The first feature gives rise to the scarcity rents that mean mineral rights are valuable; the second is the source of most of the interest in the auction of those rights.

The basic question of this paper could be rephrased as: who captures the scarcity rent? Aside from its intrinsic interest, this question is important for a number of policy issues. Governments are the owners of a large fraction of the mineral rights; outside the US, they are typically the sole owners. An analysis of producer behaviour under alternative bidding mechanisms can suggest possible leasing strategies. In those jurisdictions where auctions are not used, the analysis provides a basis for comparison with current practice. Secondly, scarcity rents can be taxed, in the simple model, without distorting production and, therefore, without deadweight loss. When production complexities, such as uncertainty, are added, devising a tax which

accomplishes this for privately owned minerals may prove difficult. The model in this paper could be used to analyse the effect on exploration of some common taxes. In addition, the analysis of rent capture helps determine who bears the burden of resource taxation. Finally, to the extent that current practice in bidding for oil leases leads to inefficient or otherwise socially undesirable outcomes, government intervention may be appropriate.

The following section discusses some existing models which analyse the optimal type of auction (English, Dutch, sealed first - or second-price) or form of payment (bonus, royalty, profit-share) for oil leases. The recommended auction from the landowner's perspective is an English auction with profit-sharing. This contrasts with the typical practice in American oil leases: a sealed-bid, first-price auction with a fixed royalty and variable bonus payment. The third section presents three partial explanations for this divergence: cost of monitoring, comparability of offers, and risk aversion, particularly on the landowner's side. The two most interesting explanations are presented in section four: the possibility of collusion and potential asymmetry of information among bidders. Among other conclusions, these suggest that a reservation price is advantageous, even though this gives rise to private and social losses. The last section summarises the results and draws additional policy conclusions.

II. Summary of Received Results

An extensive, and thriving, literature on auction theory has developed in the wake of a paper by William Vickrey [1961]. Auction markets are characterised by a fundamental asymmetry: a single seller of an indivisible good faces a number of potential buyers. Most of the analysis has been focussed on the *type* of auction - the rules by which bids are presented and the level of payments are calculated from the bids.

Four types of auctions are commonly considered: English, Dutch, sealed-bid first-price (or high bid), and sealed-bid second price. In English auctions, used for works of art, the price rises incrementally until only one bidder remains, who wins the object for that price. In the pure form, everyone interested in purchasing the object would raise his hand, dropping them only when the auctioneer had increased the price beyond that which they

were willing to pay. The auction would end when only one hand was up. In Dutch auctions, the price starts at a very high level, then falls until someone bids. That person wins the prize. 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.

Two well-established results are that the Dutch and the sealed-bid first-price auctions are strategically equivalent and that, when bidder's preferences are independent of each other, English and second-price auctions have identical unique dominant-strategy equilibria. The need for the caveat on the latter result arises because much more information regarding the preferences of other bidders is revealed prior to a final decision during an English auction than in a sealed-bid second-price auction. In the open auction, the winning bidder sees the reservation prices of all lower bidders and, if preferences are not independent, will modify his bid accordingly.

More generally, Riley and Samuelson [1981] and Myerson [1981] prove a revenue-equivalence theorem which states that, under the assumptions of risk-neutrality, independence of preferences, and symmetry of beliefs, any two auction rules generate the same expected revenue to the seller if, in equilibrium, the incentives to participate in the auction remain the same. Thus, under these assumptions, all four of the common auctions yield the same expected revenue if they have the same announced reservation price.

There the analysis might cease were it not the case that for oil leases at least one of the assumptions is systematically violated. If all bidders have the same cost, the value of mineral rights in a prospect is the same to each. Bidders differ, rather, in their estimates of the value of the prospect. Other bidders' estimates regarding the prospect will not, in general, be irrelevant to a company contemplating a bid. The assumption that bidders' preferences, in this case value estimates, are independent is not realistic in auctions of mineral rights.

An important theorem regarding auctions when values are not independent has been proven by Milgrom and Weber [1980]. They show that when value estimates are *positively related* (roughly speaking, positively

correlated), English auctions generate higher expected revenue for the seller than second-price auctions, which in turn do better than sealed-bid first price or Dutch auctions. The intuition is that the English auction conveys more information (*all* lower value estimates) than does the second-price auction, which in turn conveys more information than a first price auction. In the English auction, it is as if the bidders with the two highest values see the estimates of everyone else, then conduct a second price auction between themselves. In the second-price auction, the winning bidder learns and pays the valuation of the second highest bidder (adjusted for "winner's curse" as discussed later) and therefore has more information than merely that his value estimate was highest. The latter is all a winning bidder knows in a first-price auction. The positive correlation of the information means that more information raises the expected selling price. As they note, the assumption of positive relatedness seems to be satisfied in mineral rights auctions. The prevalence of sealed-bid first-price auctions for mineral rights therefore seems incongruous.

Less attention has been paid in the theoretical literature to the form of payment made between the winner of the auction (and possibly other participants) and the seller. An interesting model of rent capture under alternative payment structures has been developed by Reece [1979]. In building on earlier work by Wilson [1977], himself [1978], and others, he considers a prospect with a common, unknown value and known fixed exploration cost. A known number of risk-neutral symmetric bidders get different, unbiased signals about the value. Only Nash equilibria are examined, but, as with the Milgrom and Weber paper, this still allows bidders to take account of the number of competitors and of the information that the winning bidder received the highest value estimate, which is therefore probably optimistic.

Three payment structures are analysed for a sealed-bid first-price auction. The first is profit (but not loss) sharing - bids are the fraction of the net value of the prospect the buyer is willing to give the landowner. The bidder's costs include a market rate of return on any capital inputs, but if costs are greater than revenues no payment is made by or to the landowner. Royalty bidding - fractions of the gross revenue the buyer is willing to share - and bonus bidding - the level of an unconditional payment -

are also examined. In all three cases, a bidder's profits depend on the value signal he receives and the expected profit to the winning bidder is positive. Landowners do not receive the full expected value of their mineral rights under any of these payment structures, but Reece demonstrates that they do better under profit sharing than with royalty bidding, with royalties dominating bonus bids. Intuitively, the ranking is in inverse order of the importance of the value estimate to the bidder.

Leland [1978] considers the three payment structures in a simpler model with risk averse buyers and seller. Profit sharing results in the landowner sharing dry-hole risks and cost uncertainty with the winning bidder, while under royalty bidding the landowner shares only dry-hole risk with the developer. If payment is made as a lease bonus, the landowner bears neither risk. If, as Leland expects, bidders are more risk-averse than landowners, he obtains the same ranking as Reece: profit, royalty, bonus. If the landowner is risk-neutral no bonus payment is desirable.

Given the rank ordering suggested by these two models, it seems that the current practice of bonus payments subject to bidding combined with a fixed royalty rate (which is usually either 12.5 per cent or 16.67 per cent of gross revenues) is decidedly suboptimal from the landowner's point of view. This apparent inferiority of payment structure becomes stronger when one considers full sharing of profits and losses, which under either of the above models leads to complete capture of the resource rent by the landowner. Costs again include a market rate of return on all capital inputs so any bidder would be willing to undertake the project if the landowner had a 100 per cent share. This would be the universal bid if there were competitive bidding, and so full sharing would amount to a hiring of developers by the landowner. The remainder of this paper is devoted to possible theoretical explanations for the observed choice of type of auction and of payment structure.

III. Monitoring Cost, Offer Comparability, Landowner Risk Aversion

The simplest, but not least important, explanation for the absence of full sharing and profit sharing payment structures is the cost of monitoring these arrangements. Both plans require that the landowner keep track of output, arms-length prices, capital costs (including an agreed rate

of return), operating costs and overhead. Under profit sharing, the developer has an incentive to shift as much cost as possible from dry holes to successful wells, since he does not get reimbursed for the losses suffered on dry holes. If all bidders knew that they could hide the same portion of their profits, they would raise their bid correspondingly, but, even in this case, these would be a wasteful duplication of accounting services. Under full sharing, the developer has no incentive to minimize costs since the landowner captures all profits and losses; the landowner must monitor effort as well. Costly bargaining or arbitration may become necessary if disputes arise. These objections are somewhat less critical if the government is the owner of the mineral rights, since it must already examine the firm's books for income tax purposes and may have criminal sanctions for cheaters. The difficulties with assessing project-specific shares, and the incentive problem with full sharing remain even in this case. For royalty payments, the landowner need only watch physical output and some agreed-upon price; bonus payments require no landowner effort.

The need for the landowner to be able to compare alternative offers should also influence the payment structure. If the landowner or bidder is unable to rank offers accurately, expected rent will be lost. This suggests that payment structures that vary in two or more dimensions would be avoided, since the landowner lacks the information to make the appropriate evaluation. It is another argument against profit or full sharing if producer's costs can differ. An offer of 80 per cent of the profits from a high cost bidder may yield less revenue than a 10 per cent offer from an efficient one. A related issue is devastating for full sharing. The landowner will not learn from the auction whether he will make money by undertaking the project; in fact, if the project is a loser, bidders would be willing to offer more than a 100 per cent share for the rights. If operating costs can differ, royalty bidding would be less desirable from this perspective than bonus bidding, since production paths might be affected and royalty collections vary.

Finally, the need for comparability of offers suggests an explanation for the existence of diligence clauses in oil leases. If the seller is due any contingent payment, he will need to assess its present

value, both to determine his own wealth and to choose among firms. A diligence clause will insure that potential bidders have similar development plans. Such a clause would specify that various activities must be completed by a certain date or the lease will be forfeit. Under profit sharing, the landowner, even if he could compare offers, might want a diligence clause if he had a higher discount rate than the firm. With royalty bidding, another possible reason is that the development schedule maximising profits may not be the same as the one maximising the present value of royalties. If the only payment made by the bidder is an unconditional bonus, the only incentive for a diligence clause would be one common to all: the land has a valuable alternative use.

If either bidders or seller are risk-averse, this will affect the choice of both the type of auction and the form of payment. There are two kinds of uncertainty associated with the mineral rights auction. The first is the obvious one that the value of the prospect is uncertain. The second is that a bidder may lose the auction when the winning bid is lower than what he is willing to pay.

For the independent values model, the first type of uncertainty does not exist unless the seller inserts it. Maskin and Riley [1982] show that, under reasonable assumptions regarding the utility functions of risk-averse bidders, the seller should not do so. They also prove under these same assumptions that, in the independent values model, sealed-bid first-price auctions generate a higher expected revenue for the seller than second-price or English auctions when either buyers or sellers are risk-averse. Recall that all three types of auctions generate equal expected revenue when values are independent and bidders are risk-neutral. Under the English or second-price auctions, the second type of uncertainty does not arise, since the best strategy will ensure that if a bidder loses, the winning bid was higher than he was willing to pay. This is not true under the first-price auction, and bidders, if they are risk-averse, will shade their bids less out of fear of losing the prize and therefore expected revenue to the seller will rise.

When value estimates are positively related, the implications of risk-aversion are less clear cut. As Milgrom and Weber [1980] prove, a

partial reduction in uncertainty will not always increase the willingness to pay of risk-averse bidders, unless they have constant absolute risk aversion. If the average willingness to pay does increase, they show that English auctions do better than second-price auctions, but that no general qualitative comparison between first and second-price auctions can be made. This is not surprising since the correlation of value estimates works in the direction of second-price and English auctions, while the risk-aversion works in favor of first-price auctions. The critical point for oil lease auctions is that the clear-cut preference for English auctions becomes ambiguous when risk-aversion exists.

Leland [1978] assumes that firms have identical information and are competitive, thus avoiding the second type of uncertainty. He is concerned with the optimal degree of risk-sharing between government and firm. The principal comment to be made on his results in the case of private oil lease auctions is that the landowner rather than bidders is likely to exhibit the greater degree of risk aversion. Bidders are able, through joint ventures if sheer size does not suffice, to effectively diversify their oil prospects to insure against dry hole risk. Even if the companies themselves cannot accomplish this diversification internally, shareholders may do it for them. As for the risk arising from uncertain oil prices, the stock market may prefer the company not attempt a partial internal diversification, especially since oil price movements may be negatively correlated with market movements. When the variation in oil price is due to demand shifts, one would expect a positive correlation with the general market, but when, as in the two price shocks of the last decade, there are supply shifts, there should be a negative relationship between oil industry profits and the rest of the market.

For landowners, including some governments, the prospect represents a large fraction of wealth. It cannot be diversified out of by selling a share in the land, since that amounts to accepting a bonus bid for the mineral rights. Therefore, this gives the landowners a reason to pass the dry hole and price and cost uncertainty risk onto the bidder by taking payment in the form of bonus payments, with royalty bidding, profit sharing, and full sharing being ranked below it in that order. A full development of the optimal auction under both types of uncertainty, with correlation of value estimates

under risk-aversion has been attempted neither here nor in the literature, so the results above remain suggestive, not conclusive.

IV. Collusion and Bidder Asymmetry

Up to now, bidders have been assumed to behave competitively; the analysis has focussed on Nash equilibria. The possibility of collusion, perhaps unsurprisingly, strongly affects the choice of auction structure. What is surprising is that the current type of auction and form of payment used in oil lease auctions bear a close resemblance to those theoretically suggested for a landowner concerned about collusion.

English and second-price auctions are much more susceptible to stable cartel formation than sealed-bid first-price auctions. In second-price auctions, the best strategy for the cartel to follow is to have the designated winner submit a bid equal to the cartel's reservation value. If none of the members of the cartel cheat, and if no competitive fringe exists, the cartel will win the prize at the reservation price of the seller. If the cartel is outbid, it will not regret its bid since it expects that the winner will not make money. There is no incentive for a cartel member to break ranks with a bid. If the firm outbids the cartel, it will not make money on average (unless the firm has private, optimistic information). If the firm underbids the cartel, it will cost the cartel money without gaining anything for itself. If the firm expects to receive a fraction of the cartel's profits or if making bids is costly, it will strictly prefer to play along with the cartel. Similarly, firms will not be caused to regret cartel participation by the existence of non-participants, for the same reason the cartel does not regret its bid; either the cartel will lose with no profits for anyone, or the cartel will win and earn maximum profits. For the English auction, the cartel should instruct the designated winner to keep bidding until all bidders drop out or the cartel's reservation value is reached. The discussion of the second-price auction carries through, with the additional point that the cartel can identify deviators and perhaps exact retribution.

For the sealed-bid first-price auction, there is great incentive to cheat. If the cartel did not have to consider the competitive fringe, it would maximise profits by having the designated winner bid the seller's

reservation price, assuming that is less than the cartel's reservation value. By secretly bidding a fraction higher than this, a cartel member could capture the entire difference between the cartel's reservation value and the seller's reservation price. At any price that the cartel chooses below its reservation value, a cheater would make positive expected profits - in fact, the entire available surplus. If, however, the cartel bid its reservation value it would have zero expected profits, by definition. Even if the cartel managed to overcome this difficulty (unlikely in a one-shot deal), it would still have to worry about the competitive fringe. The cartel, if it bids below the reservation value, has a positive probability that it will regret its bid because the winning call was between the cartel's bid and reservation value. If the cartel is risk-averse, this potential loss will cause it to bid more conservatively in the presence of the competitive fringe, thus increasing landowner revenue.

These results are summarised in the following theorems:

Theorem 1 In the common value (or mineral rights) model, if all cartel members have the same information:

- (i) any cartel solution giving a positive fraction of cartel profits to every cartel member is a dominant strategy equilibrium for the English and second-price auctions, but
- (ii) no cartel solution is an equilibrium in a non-repeated first-price auction if any cartel member earns positive expected profits.

Theorem 2 In the independent values model, if the values of the object to each cartel member are known to all members, at least after they join the cartel:

- (i) any cartel solution which, if the cartel wins the auction, awards the object to the individual valuing it most, requiring that individual to pay less than the difference between his value and the second highest value among all bidders, and gives positive fractions of the remaining profit to all remaining cartel members, is a dominant strategy equilibrium for the second-price and English auction. If the two individuals who most highly prize the object are members of the cartel, such equilibria exists.
- (ii) no cartel solution is an equilibrium in a non-repeated first-price auction if any cartel member but the most eager receives positive profits or if the most eager receives anything other than the difference between his value and the second highest among all bidders.

Remark The information condition in Theorem 1 is necessary to ensure that a member will not choose to hide or lie about his information, intending to cheat and make money. The complicated statement of Theorem 2 is made necessary by the fact that the buyer with the highest value on the object makes money in a competitive equilibrium. Theorem 3 relaxes the information assumption.

Theorem 3 In the mineral rights model, if potential bidders must reveal their information to the cartel only if they join it:

- (i) a cartel solution will be a dominant strategy equilibrium for a group of members for the second-price or English auctions if and only if it gives all members expected profits at least as large as they would earn in a Nash equilibrium.
- (ii) no cartel solution will be an equilibrium in the non-repeated first-price auction.

Theorem 4 If the cartel's valuation of the object is independent of the competitive fringe, and if the cartel is risk-averse, a sealed-bid first-price auction will raise greater revenue for the seller than the second-price or English auctions.

The proofs of the first three theorems are virtually identical. A bidder has three options: join and follow the cartel getting a share of the profits, join the cartel and cheat, or stay outside the cartel altogether. The statements of the theorems assure that followers make profits at least as large as they would get by staying out of the cartel. The information conditions assure that cartel members cannot cheat by lying about their value estimates. In the second-price or English auction cartel members would rather follow than cheat; the reverse is true for first-price auctions (at least when the auction is non-repeated and the cartel does strictly better than if it never existed).

Theorem 4 is really just a corollary to the previously discussed result that seller revenue rises for the first-price auction in the independent values model when bidders are risk-averse. Note, however, that the assumption that the *cartel's* valuation is independent is quite likely to be satisfied in a mineral rights auction - for instance, if the cartel encompasses the available information.

Suppose that even after switching to sealed-bid first-price auctions, the landowner has a positive subjective probability that the bidders will collude against him. How should he respond? Basically, he should

increase the reservation price. Riley and Samuelson [1981] show that, in the independent values model with symmetric, risk-neutral bidders, the seller should set a reservation price greater than his personal valuation. They prove that the private gain for a seller from raising the reservation price - making the top bidder pay more when the second highest bidder is between the personal valuation and the reservation price - outweighs the private and social loss from discouraging sale when the high bidder is only slightly fonder of the object than the seller, at reservation prices near the personal valuation.

The following theorem states that the possibility of collusion implies that the reservation price should be even higher:

Theorem 5 If the seller has a positive subjective probability that collusion will occur, he should set the reservation price higher than if he were certain that he was facing symmetric competitive bidders.

Proof If bidders do collude, the seller will receive only his reservation price, in the event that the cartel's reservation value is at least that high. The collusion will not, on average, lower the reservation price of the highest bidder under either of the two models we have been considering. Under the independent values model there will be no effect on the highest reservation price. Under the mineral rights model, thanks to positive relatedness, the expected reservation price rises. The loss from the competitive reservation price in the form of lost sales will therefore be no greater when collusion occurs, while the gain from increased revenue will be larger since every time the high value is above the reservation price and collusion occurs the seller will receive only the reservation price. Therefore, the competitive reservation price will certainly not be too high. Since identical arguments hold true as the probability of collusion comes into existence as the reservation price is marginally increased from the optimal level under competition, the theorem must be true. The result is only strengthened if the probability of collusion is an increasing function of the net-of-reservation price value of the item, since this provides an additional gain to increasing the reservation price.

A logical next step is to determine the appropriate form for the reservation price under the conditions prevailing in oil lease auctions:

Theorem 6 When the seller has less information regarding the value of the item auctioned than potential bidders, and when that value can be observed by the seller at some future time, it is preferable,

both from the points of view of a risk-neutral seller and society, for the reservation price to be an increasing function of that value rather than a constant.

Proof This theorem is true under much broader conditions than the independent values or mineral rights models. Society loses when reservation prices are set. That loss is equal to the probability that no sale will be made times the expected value of the difference between bidder's valuation and seller's personal reservation value when the sale falls through. The private gain to reservation prices is the probability of collusion times the probability that a sale will occur if there is collusion times the reservation price, plus the probability that the second-high bid is below the reservation price while the high bid is above time the expected gain. The private loss for the seller is one minus the probability of collusion times the social loss.

Holding the probability of collusion constant, a given expected value of reservation price will have a smaller probability of preventing sales if the price is an increasing function of the value. Alternatively, for given probabilities of the reservation price preventing a sale and of collusion, a higher expected reservation price preventing the sale and of collusion, a higher expected reservation price would result if it were made an increasing function of the value. Therefore, for any given gain in seller revenue from colluders and lonely high bidders, a smaller loss in seller and social surplus will occur if the reservation price is an increasing function of the value of the item. This conclusion is, once again, only strengthened if the probability of collusion is made an increasing function of the net-of-reservation-price value of the object, since this means that the marginal gain from increasing the reservation price by a fixed increment is higher for high value objects.

The intuition behind this result can be illustrated with full sharing between landowner and bidders. In this case, the landowner could insist on anything less than a 100 per cent share without causing any prospect with positive expected present value to be abandoned. This is an extreme example of the reservation price varying with the value of the item.

This theorem provides an explanation for the reservation price in oil leases being a fixed royalty rather than a fixed bonus payment. Such an explanation is important, given the discussion in section III which suggested that a bonus payment was best. The argument in favor of the landowner using bonus payments is strengthened by noting that the tax law favors bonus payments because of the expensing of dry holes and that royalty payments cause

a distortion in the starting time for exploitation of a field and can cause early abandonment of a field if costs rise faster than prices. These arguments, together with Theorem 6 and the results of section III regarding profit and full sharing schemes, suggest that the payment structure used in onshore lease auctions has quite a few reasons to recommend it.

The final modification made in this paper to existing results on oil lease auctions concerns the assumption that bidders are symmetric. Relaxing this assumption again changes the theoretically best auction in the direction of current practice. The symmetry assumption does not apply if one firm or cartel is known to have superior information. Engelbrecht-Wiggans, Milgrom and Weber [1981] and Milgrom and Weber [1981] establish that bidders who have access only to public information have zero expected profits in equilibrium in a sealed-bid first-price auction, while a bidder having private information makes positive expected profits.

All bidders are assumed in these papers to know the joint distribution of the value of the field and some random signal. Only one bidder has access to the realisation of that signal - that is, has private information - perhaps because of work on an adjacent tract or some private test. This informed bidder has, therefore, two advantages over his competitors - he has a better estimate of the value and he knows exactly what they know.

Uninformed bidders must bid conservatively, since otherwise they will lose money. The informed bidder expects this and bids more conservatively as well, in order to make profits. The paper derives the equilibrium strategies for both informed and uninformed bidders. The informed bidder follows a pure strategy, choosing a bid that depends on the expected value of the prospect given the signal and the ex-ante distribution, known to all bidders, of expected values of the prospect. Uninformed bidders follow a mixed strategy, with the probability of the high bid among them being a particular number a function of the distribution of expected values. The more accurate the information the informed bidder possesses, the more conservatively the uninformed will bid and, therefore, the higher will be the expected profits of the informed bidder.

If there is a possibility that such an asymmetry of information exists, then, once again, the landowner should raise the reservation price above that for the symmetric case:

Theorem 7 If the landowner in the mineral rights model has a positive subjective probability that one bidder has a finer information partition than the other bidders, he should set the reservation price higher than if he were certain bidders were symmetric.

Proof: The proof is similar to that for Theorem 5. The informed bidder is underbidding the expected value, by the results in two papers cited, more than in the symmetric case. The loss from the reservation price is the same as in the symmetric case: the landowner will be stuck if he sets the reservation price above the expected value. The gain from increasing the reservation price in the asymmetric case is larger since it will result in higher revenue more frequently.

Theorem 6 also applies in this situation, so this gives an additional reason for a reservation price which fluctuates with the value.

It is possible that bidders with only public information will choose to drop out of the auction. This will be their dominant strategy if it is costly to bid (even as little as a postage stamp), if their entry and exit can be observed by the bidder with superior information in time to modify his bid, and if acquiring information covertly is impossible and overtly is costly. Under these conditions the bidder with better information may be the only one to enter the auction.

The problem of an auction degenerating to a single bidder when bidding is costly and bidders having zero expected profits is quite general. The seller must bear the cost of bidding in such situations. If that is not possible, and the seller has some prospect of facing a single bidder, this obviously provides an even stronger justification for a reservation price and, again, Theorem 6 applies.

The optimal type of auction is also affected by asymmetric information. In a second-price auction, a bidder with only public information will have negative expected profits if he enters the auction. The bidder with superior information will bid the expected value of the auctioned item given

both public and private information. If the ignorant buyer gets the prize, he will lose money on average, especially when there is more than one ignorant bidder; if not, he breaks even. English auctions are somewhat better from the perspective of an ignorant bidder, if he know who the smart bidder is. An ignorant bidder will lose only a little money, in expected terms, if he stops bidding immediately after the smart bidder. Unless he makes a side deal with the landowner, though, an ignorant bidder still has no incentive to get involved. If he does, the informed bidder could, with little risk, outbid the true expected value to punish the uninformed.

Riley [1982] considers a different sort of asymmetry among bidders. He allows private valuations (or, equivalently, private information), but has it be common knowledge that one buyer is more likely to have a high value than the others. In the oil lease case, this might be a bidder known to have a locational or cost advantage for this prospect. He knows that, for at least some distributions of beliefs first-price auctions generate higher revenue for the seller than second-price auctions. Once again, the more general theory supports the practice in American oil lease auctions.

Different costs across bidders also imply a reservation price is optimal for the seller. If all information regarding the revenues of the project is known symmetrically and each bidder knows his own cost and is risk neutral, we are back to the independent values model. We can then appeal to the result of Riley and Samuelson [1981] that the seller should set the reservation price higher than his personal valuation. Theorem 6 still applies.

The reservation price that is being discussed has been assumed to be binding and public. If it were not binding - that is, if the seller could lower it, if no bids were forthcoming - then bidders could treat the reservation price as a call in a Dutch auction and decide whether to take it on that basis. There is clearly no purpose in not making the existence of a reservation price known, since the main advantage of a reservation price lies in altering bidder's behaviour. The conditions under which the seller should keep the price secret remain conjectural. The assumption that auctions are

anonymous, with payments independent of the identity of the bidder, has also been maintained.

V. Summary of Results and Policy Conclusions

Five major complications to existing theoretical models of oil lease auctions have been examined: the cost of monitoring different contracts, the need for comparability among bids, risk aversion on the part of the landowner, the possibility of collusion among bidders, and the possibility of asymmetry among bidders. These seem to be realistic difficulties faced by owners of mineral rights, especially private individuals holding oil prospects in auctioning off drilling leases. Together, these five considerations strongly suggest that the current practice in American oil lease auctions of a sealed-bid first-price auction with a fixed royalty rate and bonus bidding is superior, from the landowner's perspective, to the structure suggested in the received theory - an English auction with either full sharing or profit sharing.

Cost of monitoring, offer comparability, and landowner risk aversion all imply that bonus bidding is best for the landowner. All three arguments are more powerful against profit sharing and particularly full sharing than against royalty payments. Landowner risk aversion is also an argument in favour of sealed-bid first-price over English or second-price auctions.

The possibility of collusion should also influence the structure of the auction. Cartels are stable under second-price or English auctions, but not in sealed-bid first-price auctions. Since cartels among bidders are undesirable to the seller, as they reduce his payment, the latter type of auction is indicated. If the seller believes there is a chance of bidder collusion, he should set a reservation price. Since the bidders have better information regarding the value than the seller, the reservation price should be an increasing function of the ex-post value in order to reduce the risk that the property will remain unsold.

Asymmetry among bidders, with regard to information or cost, has implication for auctions similar to those of collusion. If one bidder has private information, the landowner will get a higher return by using a sealed-

bid first-price auction, since uninformed bidders may compete without losing money. A reservation price, which as above should be a function of the value, is also indicated in order to induce the informed bidder to raise his bid. Asymmetry among bidders regarding costs leads again to the conclusion that a reservation price should be set and, for at least some distributions of costs, that a first-price auction be employed.

The last two considerations help explain, therefore, the existence of reservation price and the use of sealed-bid first-price auctions. The landowner's lack of information suggests an explanation for the reservation price being a function of the ex-post value of the prospect. The first three considerations help justify the use of bonuses for the bid above the reservation price and the use of royalty payments rather than profit shares or full shares as the form of the reservation price.

These results have several policy implications. The most obvious relate to the appropriate choice of structure for oil lease auctions on publicly owned land or when the government owns the mineral rights. To the extent that the five considerations are relevant in this situation, the auction structure used in private US onshore auctions is recommended.

A number of factors are likely to differ when the government is the seller. Perhaps most important, in most countries, contracts between producers and the government are unenforceable if the government breaches, especially when signatory government loses power. Nellor and Robinson [1982] analyse this problem, using a model quite different from that in this paper. Under plausible assumptions, they find it in the current government's interest to require a periodic payment of the life of the well, and for the payment to fluctuate with the net revenues from the resource, in order to reduce expropriation risk and coax higher payments from producers. This result is, fortunately, not at all inconsistent with bonus bidding and a fixed royalty rate.

The possibility of collusion and asymmetry among bidders do not become unimportant when the government owns the mineral rights. Therefore, the implications that the seller should utilise sealed-bid first-price auctions and set a reservation price that increases with the value carry

through. In practice, the US government reserves the right to refuse to award a prospect to the high bidder, thus adding a second, secret reservation price on top of the fixed royalty rate.

The issues raised in section III are slightly less compelling when the government is the landowner. The government may have a lower cost of monitoring profit share agreements than private individuals particularly since it also collects corporate profits taxes. If the government own a large number of independent prospects, dry hole risks will be small, and if the government is large relative to a single prospect, there is good reason to expect landowner risk aversion to be relatively minor. Past experience with bidders may diminish the obstacles to comparing offers.

For these reasons, the case for the reservation price taking the form of a royalty, with its attendant distortions, rather than a fraction of profits or full ownership is weak when the government owns the rights. Certainly, all three options merit further analysis in a practical situation.

It is worth noting that, under any of the recommended policies, the government does not capture all the expected scarcity rent. The producers will earn positive profits when they have private information or when collusion occurs. The reservation price will discourage some development of profitable fields, so some rent will be lost to both government and producer. If bidders do not collude, some rent will be lost to both even when there is no reservation price if various bidder have private information. Since the information is not shared, some projects which are unprofitable, given all available information, are undertaken while some good prospects go undeveloped.

Taxes on a mineral project or company may be viewed as a reservation price set by the government. An ad valorem severance tax is equivalent to a royalty payment at the same rate. The American "windfall profits" tax is piecewise-linear royalty with different rates applying to different pools. The "resource rent" tax proposed by Garnaut and Clunies Ross [1975] is equivalent to profit sharing, since losses are not reimbursed. The Brown [1948] or cash flow tax is a form of full sharing.

The five considerations apply to these, and other, taxes when the government owns the mineral rights. If the government is equally likely to change the rates at some future time, a bidder will not care whether the government call the reservation price a severance tax or a royalty. The arguments of section III, therefore, weigh against the Brown and resource rent taxes when the government owns the mineral rights.

When the rights are privately owned, the analysis of the effects of taxes on landowners and producer becomes quite complex. Landowner revenue will fall as government tax revenue increases, since the landowner was previously maximising, but it is still possible for the landowner to be better off if there is sufficient reduction in the cost of monitoring. A more specific model is needed to do a useful analysis of the incidence of various taxes when there is private ownership, perhaps a modified version of that of Reece [1979].

Additional policy implications can be drawn concerning government provisions of information and reimbursement for bidding costs. When only one bidder has private information, but reports part of it to the seller, Milgrom and Weber [1981] prove the seller should make the report public. They also show the seller in this situation should make public any information positively related to the informed bidder's information. The government should clearly follow these policies when it owns the rights. The government should also structure auctions so that all information is public. This will not only avoid the possibility of one bidder getting an informational advantage, but also ensure that only projects with a positive expected value given *all* available information will be developed. The US government goes partway to this goal by publishing the outcome of a Geological Survey of the area prior to opening bidding. China seems to be adopting a policy towards their oil development which goes further; potential bidders are required to conduct joint surveys before entering bids. Whenever a government follows such a policy, it should be careful to reimburse bona fide bidders for the costs of bidding in some way, since otherwise it might kill the competition it is trying to foster.

Much of the analysis of this paper has more general application than just oil lease, or even mineral rights, auctions. Cartels are more stable under second-price and English auctions than with first-price auctions in a wide variety of models. The possibility of collusion implies a higher reservation price; when the seller is less informed, the reservation price should be an increasing function of the ex-post value. These results, together with others in this paper and the literature, suggest the possibility for fruitful examination of markets with different characteristics than oil leases.

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