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OPTIMAL SELLING STRATEGIES FOR OIL AND GAS LEASES WITH AN INFORMED BUYER

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ABSTRACT

In this paper, we study different allocation mechanisms for selling oil and gas leases when there is a single informed neighbour firm and a fixed number of uninformed nonneighbour firms. We show that if the neighbour firm can be excluded from bidding, the government can capture essentially all the rents using a first-price, sealed bid auction. It should set the reserve price and royalty rate equal to zero, and give the neighbour firm an incentive to reveal its information to ensure that the winning firm uses the efficient drilling rule. If the neighbour firm cannot be excluded, the government may have to share some of the rents with the neighbour firm.

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From 1954 to 1990, the U.S. Department of Interior auctioned mineral rights to 12,288 tracts on federal offshore lands in a succession of lease sales. Each sale consisted of the simultaneous auction of many (usually one hundred or more) tracts. The auction format was first-price, sealed bid. (There was limited experimentation with alternative bidding rules, such as royalty rate and profit rate bidding, from 1978 to 1983.) The highest bidder on each tract was awarded the lease in exchange for the amount bid, known as the bonus, unless the government chose to reject the bid as insufficient. The firm had 5 years to explore the tract. If oil and/or gas was discovered in sufficient quantities to begin production, the lease was renewed for as long as production occurred. Otherwise, ownership reverted to the government. A fixed fraction of production revenues, usually one sixth, accrued to the government as royalty payments. To date, this offshore leasing program has earned the federal government about $40.3 billion in royalties and $55.8 billion in bonuses paid. (See Robert Porter (1992).)

Did the government earn a fair return on its offshore leasing program? We computed returns for three classes of leases sold off the coasts of Texas and Louisiana during the period 1954-73. Wildcat tracts are located in relatively unexplored areas. Firms are permitted to gather seismic information prior to sale, but no on-site drilling is allowed. Drainage and development leases are located next to a lease on which deposits of oil and/or gas have been discovered. Tract values were calculated by evaluating actual (monthly) production flows of oil, condensate, and gas at real wellhead prices of these commodities as of the date of the sale, and then discounting the revenues back to the sale date at five per cent. Net profit on each tract was calculated by deducting royalty payments, discounted drilling costs, and the purchase price from tract value. For leases sold prior to 1974, it may be a good proxy for expected returns, since real wellhead prices were virtually constant from 1954 to 1973, and firms may have expected this trend to continue. However, after 1973, prices increased dramatically, and bids would have reflected expectations of future price changes.

Our calculations indicate that the government recovered all the rents on wildcat tracts, but not on drainage and development tracts. Firm profits were approximately zero on wildcat tracts sold between 1954 and 1973, as revenues from bids and royalty payments were approximately equal to the value of the tracts. On drainage and development tracts, firms earned significantly positive economic profits, capturing approximately 30 per cent of the rents. (For the period 1954 to 1969, government recovery rates were lower, about 70 per cent for wildcat tracts and 60 per cent for drainage tracts.) These rents went to owners of adjacent leases (i.e., neighbour firms). Neighbours earned on average $5 million per tract, or 43 per cent of average value. Nonneighbour firms earned approximately zero profits. These estimates probably understate the actual recovery rates on drainage tracts, and overstate those on wildcat tracts. The prospect of earning rents in drainage auctions as a neighbour firm is likely to have increased bids on wildcat tracts.

We have argued elsewhere (Kenneth Hendricks and Porter (1988), Hendricks, Porter, and Charles Wilson (1990)) that the lower recovery rate for drainage leases is due to asymmetries in information. Neighbour firms have drilling data which provide them with relatively precise information about the geological strata of the drainage lease. Nonneighbour firms have access to, at best, seismic data and observable production on neighbouring leases. Thus, neighbour firms are significantly better informed. They have an advantage in bidding, provided they do not compete with each other, which appears to have been the case (see Hendricks and Porter (1988) for details). No such informational advantage is present in wildcat auctions. The private seismic surveys produce varied and imprecise estimates of lease value, but the quality or precision of the information is similar across buyers.

In this paper, we study whether the government can increase its revenues from the sale of drainage leases by using a different allocation mechanism. We characterize the optimal mechanism for selling a lease when there is a single informed buyer and a fixed number of uninformed buyers. We then discuss implementation, and the magnitude of potential revenue gains, if any.

I. Model and Notation

A drainage lease of unknown value V is to be sold. The participants consist of a seller, who chooses the transfer mechanism, an informed buyer, who observes a private signal X, and N uninformed buyers, who observe only a public signal that we hold constant throughout. We index the informed buyer by 0 and the uninformed buyers by $i = 1,..,N$. The seller does not have any private information concerning V. Its valuation of the lease is assumed to be zero. We shall also assume that the seller cannot force the informed buyer to reveal its information, but must provide financial incentives to elicit the truth.

We suppose that the realization of X lies in an n-dimensional Euclidian space and informs the buyer about the likelihood and size of an oil and/or gas deposit. The joint distribution of (V,X) is common knowledge. The informed buyer's information can be summarized by the conditional expected value of the lease, $E[V|X]$, which we denote by H. The (induced) distribution function of H is denoted by F, with support $R_+ = [0,\infty)$. For simplicity, we assume that H is continuously distributed.

To determine V, an exploratory well needs to be drilled. The cost of exploratory drilling is K. Define $\bar{H} = E(H)$ to be the expected value of the oil and/or gas on the lease. We shall assume that $\bar{H}$ exceeds K and $K > 0$. Efficiency implies that the exploratory well should be drilled if and only if h, the realization of H, is at least as large as K. Assuming the efficient drilling decision is always taken conditional on h, the ex ante value of the lease, or expected rent, is $\tilde{H} = \int_K^\infty (h-K)dF(h)$.

II. The Optimal Mechanism

Can the seller obtain all of the rents? It will be convenient to consider direct revelation mechanisms and then ask how the optimal direct mechanism can be implemented.

In a direct mechanism, the seller asks the informed buyer to report its estimate of the (gross) value of the lease. Let m denote the message sent by the informed buyer. Uninformed firms are not required to report anything other than their willingness to participate. A direct revelation mechanism is given by $[p_i(m),\ q_i(m)]$, $i=0, 1, \ldots, N$, where $p_i(m)$ represents the probability that buyer i obtains the lease and $q_i(m)$ represents i's expected payment to the seller conditional on the informed buyer sending message m. Let $p(m) = (p_0(m),\ldots,p_N(m))$ and $q(m) = (q_0(m),\ldots,q_N(m))$. The following feasibility conditions are imposed:

(1) $$p_i(m) \geq 0 \quad \text{for } i = 0, 1, \ldots, N, \text{ and}$$
$$p_0(m) + p_1(m) + \ldots + p_N(m) \leq 1 \quad \text{for all } m \in R_+.$$

Let $\pi_0(m,h)$ be the informed buyer's profit if he sends message m when his true value is h. That is,

$$\pi_0(m,h) = p_0(m)\max\{(h-K),0\} - q_0(m).$$

Define $\pi_0(h) = \pi_0(h,h)$. Incentive compatibility (IC) for buyer 0 requires:

(2) $$\pi_0(h) \geq \pi_0(m,h) \quad \text{for all } m \in R_+ \text{ and } h \in R_+.$$

Individual rationality (IR) for buyer 0 implies

(3) $$\pi_0(h) \geq 0 \quad \text{for all } h \in R_+.$$

Individual rationality implies that each uninformed buyer earns nonnegative profits in the truth-telling equilibrium. Hence, for each i = 1,..,N,

(4) $$\pi_i = \int_K^\infty [p_i(h)(h-K) - q_i(h)]dF(h) \geq 0.$$

Note that (4) assumes that the efficient drilling decision is taken by an uninformed buyer if awarded the lease.

The seller's expected revenue can then be written as:

$$W(p,q) = E_h[q_0(h) +, \ldots, + q_N(h)].$$

The optimization problem for the seller is to choose a direct revelation mechanism $[p(m), q(m)]$ to maximize $W(p,q)$ subject to the above constraints.

Proposition 1: The optimal mechanism [p(h), q(h)] satisfying constraints (1)-(4) is characterized as follows:

$$p_0(h) = q_0(h) = 0 \quad \text{for all } h \in R_+;$$

and for i = 1, ..., N,

$$p_i(h) = 1/N, \quad q_i(h) = \tilde{H}/N[1-F(K)] \quad \text{if } h \geq K$$
$$p_i(h) = q_i(h) = 0 \quad \text{if } h < K.$$

Proof: Consider piecewise differentiable direct revelation mechanisms $[p_i(m), q_i(m)]$ that satisfy conditions (1)-(4). By the envelope theorem, IC condition (2) implies

$$d\pi_0(h)/dh = p_0(h) \quad \text{for all } h \geq K.$$

Thus,

$$\pi_0(h) = \int_K^h p_0(t)dt + \pi_0(K) \quad \text{for all } h \geq K$$

and $\pi_0(h) = -q_0(h)$ for $h < K$. IR condition (3) is then equivalent to $\pi_0(K) \geq 0$ and $q_0(h) \leq 0$ for all $h < K$. Without loss of generality, we set $\pi_0(K) = 0$ and $p_0(h) = q_0(h) = 0$ for all $h < k$. Using the definition of $\pi_0(h)$ yields:

$$q_0(h) = p_0(h)(h-K) - \int_K^h p_0(t)dt \quad \text{for all } h \geq k. \tag{5}$$

Therefore, IC and IR conditions (2) and (3) for firm 0 are equivalent to (5) and $p_0(h)$ weakly increasing in h.

For firm i ($i \geq 1$), expected profit can be written as

$$\pi_i = \int_K^\infty [p_i(h)(h-K) - q_i(h)]dF(h).$$

Without loss of generality, condition (4) can be written as follows:

$$(6) \qquad \int_K^\infty [p_i(h)(h-K)]dF = \int_K^\infty q_i(h)dF(h).$$

It follows from (5) and (6) that the seller's expected revenue can be written as:

$$(7) \qquad EW = \int_K^\infty [p_0(h)(h-K) - \int_K^h p_0(t)dt + p_1(h)(h-K) + .. + p_N(h)(h-K)]dF(h)$$
$$= \int_K^\infty [p_0(h)J(h) + p_1(h)(h-K) +,\ldots, +p_N(h)(h-K)]dF(h),$$

where the last equality follows from integration by parts and $J(h) = h - K - [1-F(h)]/f(h)$. The seller then chooses $[p_0(h), p_1(h),\ldots, p_N(h)]$ to maximize (7) such that $p_0(h)$ is weakly increasing in h and (1) is satisfied. Since $J(h) < h - K$, it is optimal to set $p_0(h) = 0$ for all $h \in R_+$ and $p_i(h) = 1/N$ for all $h \geq K$ and $p_i(h) = 0$ for $h < K$, where $i = 1,\ldots,N$. Clearly, $p_0(h)$ is weakly increasing in h. Expected payments can be computed from (5) and (6). Q.E.D.

Proposition 1 states that, in the optimal direct mechanism, the informed buyer pays nothing and never obtains the lease. Each uninformed buyer pays an amount equal to (1/N)th of the expected value of the lease conditional on H exceeding K, and gets the lease with probability 1/N. The proposition implies that the seller can obtain all of the rents, at least in expectation. Receipts are less (on average) than the actual value when H is high, but more when the value of H is low. Averaging across the realizations of H yields expected revenues of $\tilde{H}$.

It should be noted that the mechanism possesses multiple equilibria. The informed buyer earns zero no matter what message is sent, and so is indifferent between truthful and false messages. However, it is important that the truth be reported, since the payment charged the uninformed buyers is predicated on the assumption that the uninformed buyer who is awarded the lease uses the efficient drilling rule. In practice, the informed buyer may need a small incentive to break indifference across messages.

III. Implementation

The optimal mechanism appears to be easy to implement. One approach would be to post a sale price of $\tilde{H}/[1-F(K)]$, invite nonneighbour firms to submit their names, and randomize across the set of interested buyers. Yet another approach would be to hold a first-price, sealed bid auction in which only nonneighbour firms are allowed to participate. The unique Nash equilibrium consists of each firm bidding $\tilde{H}/[1-F(K)]$. A random tie-breaking rule could determine which firm is awarded the lease. In both mechanisms, the government needs to induce the neighbour firm to tell the truth concerning the profitability of drilling. This could be achieved at a relatively small cost by giving the neighbour firm a small share in net returns.

However, neither of these mechanisms is likely to work. The problem is that it may be difficult to exclude the neighbour firm. In the auction mechanism, the neighbour firm can use a "dummy" firm to bid on its behalf. Similarly, in the posted price mechanism, the neighbour firm can use "dummy" firms to submit their names whenever its estimate exceeds the posted price. These secret partnerships would be virtually impossible to detect. Moreover, since production on a common pool is often unitized, private transfers between neighbouring firms are easily arranged.

In the posted sale mechanism, inability to exclude the neighbour firm can drive out the uninformed firms. A sketch of the argument is as follows. Let n denote the number of dummy firms. They participate if and only if $h-K \geq Q$, where Q is the posted price. Expected profit to an uninformed firm i if it participates in the sale is

$$\pi_i(Q,n) = (1/N)\int_0^{Q+K}(h-K-Q)dF(h) + (1/(N+n))\int_{Q+K}^{\infty}(h-K-Q)dF(h).$$ [1]

Let Q(n) denote the sale price at which $\pi_i(Q,n)$ is equal to zero. (It is easily shown that Q(n) exists and is unique.) As n increases, the uninformed firm is more likely to win the lease when its value is less than the posted price. Hence, Q(n) falls with n, and approaches 0 as n gets large. Thus, given any posted price Q, the optimal strategy of the neighbour firm is to send a sufficiently large number of "dummy" firms whenever h-K exceeds Q that participation by uninformed firms is unprofitable. Given this strategy, the best the government can do is post a price that maximizes the expected returns from selling the lease to the neighbour firm. That is, the optimal price Q^* maximizes $Q[1-F(Q+K)]$.

In the first price, sealed bid auction, the neighbour firm has no incentive to send more than one representative, since only the highest bid matters. As a result, uninformed firms may not be driven out of the market, and auction revenues may be higher than in the posted price mechanism. Let R denote the government's fixed reserve price and assume without loss of generality that N is equal to 1. If R is less than $\bar{H}-K$, the uninformed firm will not always stay out of the bidding. If it did, the neighbour firm (or its representative) would bid R whenever h exceeds R+K. But then the uninformed firm could bid slightly more than R, win the lease for certain, and earn positive expected profits equal to $\bar{H}$-K-R, contradicting the hypothesis that nonparticipation is optimal.

How does the uninformed firm participate, and what is the effect of its participation on the neighbour firm? Let $\tilde{h}$ denote the solution to the equation $E[H|H\leq h] = R+K$. Hendricks and Porter (1988) show that, in equilibrium, the informed firm bids R when its valuation is between R+K and $\tilde{h}$, and bids $E[H-K|H\leq h]$ at higher valuations. Thus, it bids R with probability $[F(\tilde{h})-F(R+K)]$, and more than R with probability $[1-F(\tilde{h})]$. The uninformed firm bids randomly between R and $\bar{H}$-K according to the distribution $F(\sigma^{-1}(b))$, where σ^{-1} is the inverse of the informed firm's equilibrium bid function on this interval. Thus, the probability that the uninformed firm bids at least R is $[1-F(\tilde{h})]$. Combining these two results yields a lower bound for auction revenues, $R[1-F(K+R)F(\tilde{h})]$. This exceeds the amount earned in the posted price mechanism if R is equal to Q^*. Hence, the first price, sealed bid auction can generate higher revenues whenever Q^* is less than $\bar{H}$-K.

The preceding argument assumes that the uninformed firm always drills when it wins the lease. This assumption makes sense if it learns nothing from the auction. However, if the uninformed firm observes the bids, or is told by the informed firm whether the lease is worth drilling <u>after</u> the auction, its valuation prior to bidding increases. The uninformed firm is then a stronger competitor. For example, under the efficient drilling rule, the upper bound of the bid distributions becomes $\tilde{H}$ instead of $\bar{H}$-K, and $\tilde{h}$ is defined by the equation $E[\max(0,H-K)|H\leq h] = R$. The result is higher auction revenues for the government. Consequently, if the costs of inducing the neighbour firm to tell the uninformed firm whether it should drill are low, then the government should provide the appropriate incentives.

IV. The Optimal First-Price, Sealed Bid Auction

Thus far we have considered only mechanisms in which payments are made prior to exploration and production decisions. Failure to capture all of the rents ex ante, however, suggests that the government may want to condition part of the buyer's payment on drilling outcomes. The royalty fee that firms currently pay on productive leases is an example of such a payment. Is this practice optimal?

A positive royalty rate induces inefficient exploration decisions. Let τ denote the royalty rate. Since the only tracts that the neighbour firm acquires are ones that it intends to drill, it bids for a lease if and only if $(1-\tau)h \geq K+R$. Nonneighbour firms may drill leases with lower expected values, depending upon what information is acquired from the auction. For example, if they learn the value of H after winning the lease, the tract is drilled if $h \geq K/(1-\tau)$. In either case, some leases are not developed even though the expected value of these leases exceeds drilling costs.

The reserve price affects the neighbour firm's participation decision in much the same way as the royalty rate. However, the royalty rate extracts more revenue per unit increase in the reservation value than the reserve price. This suggests that the government should use the royalty rate to extract rents and the reserve price to ensure efficient drilling decisions. To illustrate this point, suppose the only potential buyer is the neighbour firm. Then the expected revenue to the government is

$$W(R,\tau) = R[1 - F(\tilde{R})] + \tau\int_{\tilde{R}}^{\infty} h dF(h),$$

$$= \int_{\tilde{R}}^{\infty}(R+\tau h)dF(h)$$

where $\tilde{R} = (R+K)/(1-\tau)$. Let (R^*,τ^*) denote the reserve price and royalty rate which maximizes $W(R,\tau)$. The following proposition assumes that negative reserve prices are not politically or administratively feasible.

Proposition 2: Suppose $R \geq 0$. Then $R^* = 0$ and $0 < \tau^* < 1$.

Proof: Taking the derivatives of $W(R,\tau)$ with respect to R and τ, respectively, yield

$$\partial W/\partial R = 1 - F(\tilde{R}) - (R+\tau K)f(\tilde{R})/(1-\tau)^2,$$

$$\partial W/\partial \tau = \int_{\tilde{R}}^{\infty}hdF(h) - (R+K)(R+\tau K)f(\tilde{R})/(1-\tau)^3.$$

Suppose that the optimal solution (R^*,τ^*) satisfies $R^* > 0$. Then the first-order condition implies $\partial W/\partial R = 0$, which in turn implies

$$\begin{aligned}\partial W/\partial \tau &= \int_{\tilde{R}}^{\infty}hdF(h) - \tilde{R}[1-F(\tilde{R})] \\ &> 0.\end{aligned}$$

Consequently, τ^* should be equal to 1 and $W(R^*,\tau^*) = 0$. Clearly, this cannot be optimal. Therefore, $R^* = 0$. Since $\partial W(0,\tau)/\partial\tau > 0$ at $\tau = 0$ and $W(0,1) = 0$, we have $0 < \tau^* < 1$. Q.E.D.

If it is possible for the government to pay firms a share of the drilling costs, then it could implement the efficient allocation by setting $R^* = -\tau^*K$ and τ^* arbitrarily close to 1. This would induce efficient drilling decisions, and yield expected revenues equal to

$$W(-K,1) = \int_K^\infty (h-K)dF(h),$$

which is the expected value of the rents. Thus, government need not share the rents with the neighbour firm if it can contract on ex post outcomes.

The above model does not incorporate a moral hazard problem that may be important. A high royalty rate may induce inefficient development and production decisions. That is, a lease may be abandoned, even though the value of the oil and gas that has been discovered, or that remains to be extracted, exceeds production costs. If this is an important incentive issue, then the above results would have to be modified. Jean-Jacques Laffont and Jean Tirole (1986) have shown that the optimal mechanism for this kind of environment is a menu of linear contracts (i.e., combinations of (R,τ)) that is designed to solicit a truthful report from the neighbour firm on the value of the lease. Preston McAfee and John McMillan (1986, 1987) have extended this result to the case of many buyers who are symmetrically informed. Their findings on the effects of competition suggest that the optimal royalty rate in the drainage auction may be lower when nonneighbour firms are present. The intuition is that a lower royalty rate increases the value of the lease to nonneighbour firms, which in turn leads to more aggressive bidding by **all** participants. However, more work needs to be done to verify this conjecture for asymmetric auctions.

V. Conclusion

If the neighbour firm can be excluded from bidding, the government can capture all the rents using a first-price, sealed bid auction. It should set the reserve price and royalty rate equal to zero, and give the neighbour firm an incentive to reveal its information to ensure that the winning firm uses the efficient drilling rule. However, practical considerations suggest that it may not be possible to exclude the neighbour firm. In that case, the government has to share some of the rents with the neigbour firm. Although we have not characterized the optimal mechanism in this environment, the first-price, sealed bid auction with the reserve price and royalty rate set optimally, may generate revenues that are close to the maximum obtainable.

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FOOTNOTES

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[1] Here we assume that the uninformed firm always drills if it is awarded the lease. If informed about the value of H after it pays Q for the lease, then the lower bound of the first integral should be changed from 0 to K.