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SOME NEW EMPIRICAL MODELS OF FIRM AND INDUSTRY BEHAVIOR[†]

Optimal Selling Strategies for Oil and Gas Leases with an Informed Buyer

By KENNETH HENDRICKS, ROBERT H. PORTER, AND GUOFU TAN*

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 100 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 five years to explore the tract. If oil 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 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 1954–1973. 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 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 5 percent. 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 percent of the rents. (For the period 1954–1969, government recovery rates were lower, about 70 percent for wildcat tracts and 60 percent for drainage tracts.) These rents went to owners of adjacent leases (i.e., neighbor firms). Neighbors earned on average \$5 million per tract, or 43 percent of average value. Nonneighbor firms earned approximately zero profits. This finding implies that the above estimates probably understate the actual recovery

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rates on drainage tracts and overstate those on wildcat tracts. The prospect of earning rents in drainage auctions as a neighbor firm is likely to have increased bids on wildcat tracts.

We have argued elsewhere (Hendricks and Porter, 1988; Hendricks et al., 1990) that the lower recovery rate for drainage leases is due to asymmetries in information. Neighbor firms have drilling data that provide them with relatively precise information about the geological strata of the drainage lease. Nonneighbor firms have access to, at best, seismic data and observable production on neighboring leases. Thus, neighbor 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 $i = 1, \dots, N$. 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 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 $[0, \infty)$. 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 . 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 that the efficient drilling decision is always taken conditional on h , the *ex ante* value of the lease, or expected rent, is $\bar{H} = \int_K^\infty (h - K) dF(h)$.

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 $[p_i(m), q_i(m)]$, $i = 0, 1, \dots, N$, 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 $\mathbf{p}(m) = [p_0(m), \dots, p_N(m)]$ and $\mathbf{q}(m) = [q_0(m), \dots, q_N(m)]$. The following feasibility conditions are imposed:

$$(1) \quad p_i(m) \geq 0 \quad \text{for } i = 0, 1, \dots, N$$

$$p_0(m) + p_1(m) + \dots + p_N(m) \leq 1$$

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

$$(2) \quad \pi_0(h) \geq \pi_0(m, h)$$

for all $m \in R_+$ and $h \in R_+$.

Individual rationality (IR) for buyer 0 implies

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

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

$$(4) \quad \pi_i = \int_K^\infty [p_i(h)(h - K) - q_i(h)]$$

$$dF(h) \geq 0.$$

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

$$W(\mathbf{p}, \mathbf{q}) = E_h[q_0(h) + \dots + q_N(h)].$$

The optimization problem for the seller is to choose a direct revelation mechanism $\{p(m), q(m)\}$ to maximize $W(\mathbf{p}, \mathbf{q})$ 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 $i = 1, \dots, N$,

$$\left. \begin{aligned} p_i(h) &= 1/N \\ q_i(h) &= \bar{H}/N[1 - F(K)] \end{aligned} \right\} \quad \text{if } h \geq K$$

$$p_i(h) = q_i(h) = 0 \quad \text{if } h < K.$$

(See Hendricks et al. [1993] for the proof.)

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 \bar{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 $\bar{H}/[1 - F(K)]$, invite nonneighbor 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 nonneighbor firms are allowed to participate. The unique Nash equilibrium consists of each firm bidding $\bar{H}/[1 - F(K)]$. A random tie-breaking rule could determine which firm is awarded the lease. In both mechanisms, the government needs to induce the neighbor firm to tell the truth concerning the profitability of drilling. This could be achieved at a relatively small cost by giving the neighbor 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 neighbor firm. In the auction mechanism, the neighbor firm can use a "dummy" firm to bid on its behalf. Similarly, in the posted-price mechanism, the neighbor 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 neighboring firms are easily arranged.

In the posted sale mechanism, inability to exclude the neighbor 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:¹

$$\begin{aligned} \pi_i(Q, n) = & (1/N) \int_0^{Q+K} (h - K - Q) dF(h) \\ & + (1/(N + n)) \\ & \times \int_{Q+K}^{\infty} (h - K - Q) dF(h). \end{aligned}$$

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 neighbor firm is to send a sufficiently large number of "dummy" firms whenever $h - K$ exceeds Q so 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 neighbor firm. That is, the optimal price Q^* maximizes $Q[1 - F(Q + K)]$.

In the first-price, sealed-bid auction, the neighbor 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 neighbor firm (or its representative) would bid R whenever h exceeds $R + K$. However, 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 neighbor 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

¹Here 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 .

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 *after* 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 neighbor 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. The only tracts that the neighbor firm acquires are ones that it intends to drill. Hence, it bids for a lease if and only if $(1 - \tau)h \geq K + R$. Nonneighbor 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, a positive royalty rate implies that

some leases are not developed even though the expected value of these leases exceeds drilling costs.

The reserve price affects the neighbor 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 (see Hendricks et al. [1993] for details). This implies that the government should set R as low as possible. In fact, if the government pays the firm to drill by setting $R = -\tau K$, and sets τ close to 1, it will induce the efficient drilling decision and obtain essentially all the rents.

The problem with this recommendation is that a very high royalty rate is almost sure to induce inefficient development and production decisions. 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. Jean-Jacques Laffont and Jean Tirole (1986) have shown that the optimal mechanism in 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 neighbor firm on the value of the lease. R. Preston McAfee and John McMillan (1986, 1987) have extended their 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 is lower when nonneighbor firms are present. The intuition is that a lower royalty rate increases the value of the lease to nonneighbor 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 neighbor 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 neighbor firm an incentive to reveal its information to ensure that the winning firm uses the efficient drilling rule. However, practical con-

siderations suggest that it may not be possible to exclude the neighbor firm. In that case, the government has to share some of the rents with the neighbor 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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