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Bidding behaviour in OCS drainage auctions

Theory and evidence*

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1. Introduction

Empirical economists frequently criticize game-theoretic models of markets on the grounds that they fail to generate empirically testable hypotheses. The complaint is that prices and quantities, or entry decisions, are explained using factors that are not observable to the econometrician, such as private valuations and beliefs of agents. The corollary to this argument is that the only way to proceed empirically is through experiments. However, this approach suffers from the problem that the experience of the subjects may be too limited and the compensation too small for them to perform the requisite optimizing calculations.

The objective of this paper is to discuss the above criticism of game-theoretic models in the context of our work on markets of offshore oil and gas leases. In this case study, one group of buyers is better informed about the unknown value of the lease being sold that another group, and the two groups can be identified. Game-theoretic models of markets with informational asymmetries generate restrictions on the relative behaviour and performance of the two groups of buyers, and some of these restrictions are empirically testable. We examine them using bid and profit data. More generally, the work serves to illustrate a basic point about testing models of

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markets where agents enjoy market power. When agents differ observationally, the sensitivity of outcomes to the manner in which agents interact and to what they know about each other can be exploited empirically.

2. The market institution and information structure

The markets studied consist of the sale of oil and gas leases off the coasts of Texas and Louisiana by the U.S. federal government during the period 1954 to 1979. A lease was usually a block of 5,000 or 5,760 acres, or one half of a block. The allocation mechanism was a first-place, sealed bid auction. Participants were invited to submit a separate bid on each lease in the sale. A bid is a dollar figure which the firm agrees to pay to the government at the time of the sale if it is awarded the lease. The firm must also pay a fixed fraction of any production revenues to the government. This fraction is known as the royalty rate, and for most of the leases in our sample, it was fixed at 1/6th prior to the sale.

Prior to 1980, leases were classified into three types: wildcat, development, and drainage. Wildcat leases are located in areas that have not been drilled and about which relatively little is known. Buyers are permitted to acquire seismic data on these leases prior to sale, but they are not allowed to drill on-site wells. Thus, buyers have very imprecise information, but the quality of that information does not vary much across buyers. Drainage and developmental leases are located next to a lease on which deposits of oil or gas have been discovered. Owners of the adjacent leases, which we will refer to as neighbour firms, have drilling data from their leases which provide them with information about the geological strata of the drainage lease. Nonneighbour firms have, at best, seismic data and observable production on adjacent leases. Thus, neighbour firms are better informed than nonneighbours.

The difference between drainage and developmental leases is that the latter are judged to be marginal leases. They were frequently reoffers of previously sold tracts with relinquished leases, or reoffers of tracts where previous bids were rejected as too low. After 1979, the government stopped distinguishing between development and drainage leases. The information asymmetries are probably less acute on developmental leases, given their history and marginal status.

An important institutional detail of auction markets which affects bidding incentives is the behaviour of the seller. In our sample, the preannounced minimum reservation price was usually (not always) $15 on wildcat tracts and $25 per acre on drainage and development tracts. Bids below that price were rejected. In addition, the government reserved the right to reject bids that were above the stated minimim if it believed they were too low. The

Table 1

Selected statistics on wildcat, development and drainage tracts[a]

	Wildcat	Drainage	Development
1954–1979			
Number of tracts	2,255	237	148
Number of tracts drilled	1,757	211	133
Number of productive tracts	881	147	67
Average winning bid	6.07	8.86	4.93
	(0.23)	(0.98)	(0.58)
Average tract value	5.24	11.45	1.60
	(0.47)	(1.80)	(1.13)
Average number of bidders	3.76	2.73	2.80
1954–1973			
Number of tracts	796	113	23
Average net profit	−0.73	3.43	2.34
	(0.51)	(1.75)	(4.66)

[a]Dollar figures are in millions of $1972. The numbers in parentheses are standard deviations of the sample means.

basis on which it made this judgment was the number of bidders and its own private estimate of the value of the lease. Thus, from the point of view of buyers, the reservation price was effectively a random variable. For drainage leases, the high bid was rejected approximately 20% of the time, and in 79% of these instances, the bid was submitted by the neighbour firm. The rejections usually occurred on marginal tracts which received only one bid [see Hendricks, Porter and Spady (1989) for details]. The rejection rule on wildcat tracts was similar.

Does this difference in information structure matter? Table 1 provides selected statistics on wildcat, drainage and development leases sold in the period 1954–1979. Tract values were computed by evaluating actual (monthly) production flows of oil, condensate, and gas into revenues 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 a rate of five percent. Net profit on each tract was calculated by deducting royalty payments, discounted drilling costs, and the winning bid from tract value. [See Hendricks, Porter and Boudreau (1987) for further details.] For leases sold prior to 1974, it may be a good proxy for expected returns, since real wellhead prices were virtually constant during this period and firms may have expected this trend to continue. But, after 1973, prices increased dramatically, and bids would have reflected expectations of this event. Consequently, we have reported the net profit statistics only for the 1954–1973 sample.

The table reveals that most of the developmental leases were sold in the last half of the 1970s. The outcomes confirm their status as marginal leases. However, behavior and outcomes on wildcat and drainage leases differed sharply. The average value of drainage leases was more than twice that of wildcat leases. Yet, fewer bids were submitted, and profit was roughly four times higher on drainage leases than on wildcat leases. These results imply that agents' information concerning the value of the lease, and what they know about their rivals' knowledge about the value of the lease, affects bidding behaviour and performance. Hence, a satisfactory model of auction markets must incorporate details about the underlying information structure as well as the institution.

3. Empirical methodology

The theoretical literature on first-price, single object auctions is well developed and provides well-specified statistical models. The fundamentals of the model are the number of buyers, the distribution of buyer valuations, and the distribution of the reservation price. Given this information, game theory imposes a specific relationship between the valuation of each buyer and its bid. This in turn can be used to determine the distribution of the market price.

But, can the relationship be estimated? The primary difficulty is that the bid function (assuming it exists) maps unobservables into observables. Neither the valuations of the buyers nor their number are typically known to the econometrician. Buyers who draw a valuation less than the reserve price do not bid, so the number of bids may differ from the number of buyers. Buyer valuations are private almost by definition. It is in this sense that auction theory is vulnerable to the criticism that it cannot be empirically tested.

How does one proceed? The approach followed by Paarsch (1991, 1992) and Laffont et al. (1991) makes strong assumptions about the bidding environment. These authors consider environments in which there is no unobserved heterogeneity across auctions and agents. Differences in bids are ascribed to differences in private valuations, which are viewed as independent draws from a common distribution. A formidable problem in estimating the bid function in this environment is its numerical complexity. The simulation estimation method developed by Laffont et al. (1991) provides a particularly attractive solution to this problem.

We have taken a different approach. We consider auctions in which agents differ in ways which are observable and strategically important. In particular, we focus on drainage auctions, where firms can be classified into neighbour firms, which are informed, and nonneighbour firms, which are not as well informed. The distinguishing feature of game-theoretic models in such enviornments is that each buyer's strategy depends upon its rivals' types as well as its own type. Equilibrium then imposes restrictions on the relative behaviour and performance. Several of these restrictions can be tested empirically by comparing outcomes conditional on buyer types in a cross-section of auctions.

We first verified that neighbour firms were better informed than nonneighbours by regressing ex post profits on the participation and bids of nonneighbour and neighbour firms. The neighbour variables accounted for 64% of the variation in profits, whereas the nonneighbour variables could account for only 15% of the variation. Their incremental contribution was negligible.

Next we established that the distinction between neighbour and nonneighbour was meaningful. If neighbour firms had bid competitively against each other, nonneighbour firms would have been driven out of the market. Fortunately, this did not happen [see Hendricks, Porter and Spady (1989) for details]. We found that, in most auctions of leases with more than one neighbour firm, at most one neighbour firm bid, and nonneighbour firms participated frequently. Both of these facts suggests coordination among neighbour firms. Such behaviour was not prohibited by the federal government. In fact, neighbour firms frequently formed a joint venture to manage production from the common pool. This agreement would have given them a mechanism for distributing the benefits from coordinating bids.

Further support for the coordination hypothesis comes from the pattern of returns. If neighbour firms had competed with each other, net profits on leases with multiple neighbour firms would have been significantly lower than on leases with a single neighbour firm. Table 2 reveals that this was not the case. [In Hendricks and Porter (1988), we reported this fact just for tracts sold prior to 1970.] In fact, net profits were somewhat higher on leases with more than one neighbour firm.

To conclude, competition in drainage auctions appears to be between one informed buyer, an arbitrary number of uninformed buyers, and a seller who may or may not be informed. Optimal bidding in first-price, sealed bid auctions with this kind of information structure and a fixed reservation price was initially characterized by Wilson (1967) and Weverbergh (1979), and subsequently generalized by Engelbrecht-Wiggans et al. (1983). In Hendricks, Porter and Wilson (1991), we extend the theory to incorporate a random reservation price. The theory yields a number of testable implications on the relative performance of the two types of firms and their bidding behaviour.

4. Drainage auctions: Main predictions and evidence

One set of predictions which is easily checked concerns the pattern of returns across the two classes of firms. Equilibrium implies that the expected profits are zero for nonneighbour firms, positive for neighbour firms. The

Table 2

The effect of number of neighbour tracts on neighbour profits.[a]

	Single neighbour tracts	Multiple neighbour tracts No. of neighbour bids 1	≧2	Total
1959–1979				
No of. tracts	30	130	53	186
No. of neighbour wins	15	86	37	123
Average winning bid of neighbour firm	5.95 (2.00)	7.41 (1.41)	17.43 (4.35)	10.48 (1.68)
Average gross profits of neighbour firm	14.96 (6.30)	7.79 (1.91)	14.10 (5.38)	9.69 (2.10)
1959–1973				
No. of tracts	24	68	24	92
Average net profits of neighbour firm	6.49 (4.89)	3.12 (2.23)	9.53 (8.63)	4.75 (2.73)

[a]Dollar figures are in millions of $1972. The numbers in parentheses are the standard deviations of the sample means.

Table 3

Selected statistics on neighbour and nonneighbour wins.[a]

	Wins by neighbour firms		Wins by nonneighbour firms		
	No N-N bid	Total	No N bid	N bid	Total
1959–1979:					
No of tracts	81	138	29	70	99
No. of tracts drilled	64	120	24	67	91
No. of productive tracts	48	96	10	41	51
Average winning bid	5.34	9.99	3.13	9.01	7.29
	(1.07)	(1.52)	(0.90)	(1.29)	(0.99)
Average gross profits	7.80	10.26	−0.50	8.54	5.89
	(2.46)	(1.99)	(0.62)	(2.78)	(2.01)
1959–1973:					
No. of tracts	44	75	12	37	49
Average net profits	4.22	5.03	−1.85	1.91	0.99
	(3.17)	(2.41)	(0.93)	(3.24)	(2.46)

[a]Dollar figures are in millions of $1972. The numbers in parentheses are the standard deviations of the sample means.

difference is a measure of the value of the neighbour firms's private information. A significant fraction of the tracts were dry, so the ability to identify which tracts possess oil and gas should have been worth several millions of dollars.

Table 3 reports statistics on tracts won by each type of firm. [It updates a previous table in Hendricks and Porter (1988) to include tracts sold in the 1970s.] The results are remarkably consistent with the implications of the theory. Here gross profit is measured as tract value less royalty payments and discounted drilling costs. By this measure, neighbour firms earned significantly more than nonneighbour firms. Moreover, earnings of nonneighbour firms were significantly lower on tracts where neighbour firms did not bid than on tracts where at least one neighbour firm bid, but the converse is not true. This reflects the adverse selection problem that nonneighbour firms experienced in bidding against the better informed neighbour firms. Finally, average net profits to nonneighbour firms were not significantly different from zero for the period in which our measure of expected returns may not contain much measurement error.

The above results can be criticized as a weak test of the strategic model of bidding. The only prediction that may be difficult to obtain from nonstrategic models is that nonneighbour firms should participate with positive probability and earn zero expected profits. Nonneighbour firms have to recognize that their participation is necessary to keep the neighbour firm from bidding too low on valuable tracts. At the same time, they cannot bid naively, but must participate so that the optimal response of the neighbour firm allows them to break even. Notice that this argument implies that average profits of nonneighbour firms on tracts where the neighbour firm bid must be positive, since nonneighbour firms can expect to incur losses on leases where the neighbour firm did not bid. This result is confirmed in table 3.

A further criticism is that expected profits may not be observable, or difficult to measure. In our initial study, we did not include any tracts sold after 1969 because production histories were truncated at 1979. We have subsequently obtained production data for the 1980s from the U.S. Mineral Management Service, and improved our measure of ex post returns on leases sold in the 1960s and 1970s. However, our treatment of expectations can be questioned, and is certainly not appropriate for leases sold after 1973. For these reasons, a more direct test based upon bids would be preferable.

Fortunately, such tests are available. In Hendricks, Porter and Wilson (1991) we have shown that equilibrium imposes strong restrictions on the distributions of the maximum nonneighbour and neighbour bids.[1] First, the percentage rate of increase in the distribution of high nonneighbour bid can never be greater than the percentage rate of increase in the distribution of the neighbour bid. Second, above the range of the reservation price, the two

[1] Neighbour firms are assumed to submit at most one serious bid: any others are 'shadow' bids. The number of nonneighbour firms is irrelevant. The role of the latter is to impose a zero expected profit constraint on the bid function of the informed buyer, and one uninformed buyer is sufficient for this purpose.

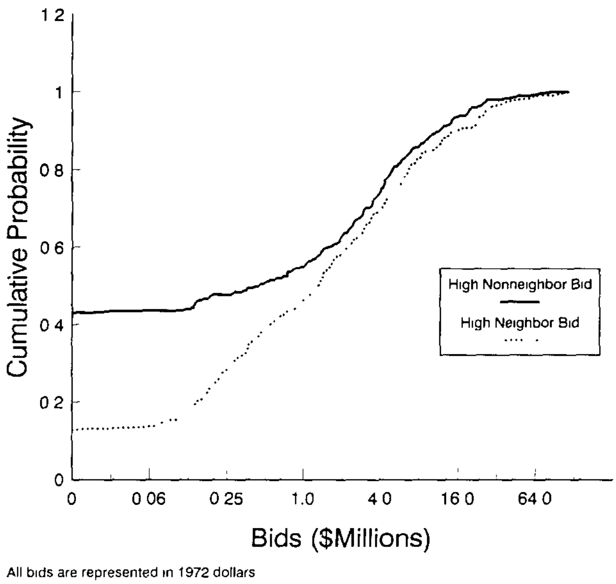

Fig. 1. Distribution of bids.

distributions must be identical. Third, near the lower bound of the range of the reservation price, only the neighbour firm bids with positive probability. Roughly speaking, these restrictions correspond to nonneighbour firms participating less often than neighbour firms but, if they bid, they bid high rather than low.

Fig. 1 depicts the empirical distributions of the (logarithm of the) highest neighbour and nonneighbour bid on each drainage lease in our 1959–1979 sample. The sample includes only those tracts which received at least one bid. Consequently, the height of a distribution at 0 represents the proportion of tracts on which the firms submitted no bid among those tracts which received at least one bid.

The restrictions mentioned above extend to the empirical distributions of fig. 1. All three sets of restrictions appear to be satisfied. The upper range of the reservation price in our sample was approximately 4 million dollars, as high bids above this amount were rejected on only 6 of 122 tracts (as opposed to 58 rejections on the full sample of 295 tracts). Above this range, the distributions are roughly equal. In the lower range of the reservation price, less than 0.5 million, there are many neighbours bids but few nonneighbour bids. Formal statistical tests of the restrictions are provided in Hendricks, Porter and Wilson (1991). They confirm the story told in fig. 1 and provide a direct, nonparametric test of the strategic model of bidding with a single informed buyer and a random reservation price.

5. Conclusion

Our study of drainage auctions indicates that a theory of price formation in markets where buyers have some market power cannot be indepedent of the manner in which buyers interact and what they know about each other. To economic theorists such as Fisher (1990), this dependence on institutional detail is less than desirable, but it appears to be the price that must be paid for relevance. Our study also suggests that game-theoretic models may be essential to understanding behaviour in such markets. It is difficult to construct alternative models that fit the data as well. For example, one might hypothesize that neighbour firms place a higher value on deposits of adjacent tracts than nonneighbour firms because they can internalize the production externalities associated with a common pool. However, this model fails to explain the equivalence of the distribution of the high neighbour and nonneighbour bids above the range of the reservation price, and the relatively weak correlation between lease value and nonneighbour participation and bids.

References

Engelbrecht-Wiggans, Richard, Paul R. Milgrom and Robert J. Weber, 1983, Competitive bidding and proprietary information, Journal of Mathematical Economics 11, 161–169.

Fisher, F., 1989, Games economists play: A noncooperative view, The Rand Journal of Economics, Spring.

Hendricks, Kenneth and Robert H Porter, 1988, An empirical study of an auction with asymmetric information, American Economic Review 78, 865–883.

Hendricks, Kenneth, Robert H Porter and Bryan Boudreau, 1987, Information and returns in OCS auctions. 1954–1969, Journal of Industrial Economics 35, 517–542.

Hendricks, Kenneth, Robert H Porter and R.H. Spady, 1989, Random reservation prices and bidding behavior in OCS drainage auctions, Journal of Law and Economics.

Hendricks, Kenneth, Robert H. Porter and C.A. Wilson, 1991, Auctions for oil and gas leases with an informed bidder and a random reservation price, Mimeo.

Laffont, J.-J., H. Ossard and Q Vuong, 1991, Econometrics of first-price auctions, Mimeo. Oct

Paarsch, H., 1991, Empirical models of auctions and an application to British Columbia timber sales, Discussion paper 91-19 (Department of Economics, University of British Columbia, Vancouver, BC).

Paarsch, H., 1992, Deciding between the common and private value paradigms in empirical models of auctions, Journal of Econometrics 51, Jan., 191–215.

Milgrom, Paul R. and Robert J. Weber, 1982, A theory of auctions and competitive bidding, Econometrica 50, 1089–1122

Weverbergh, M., 1979, Competitive bidding with asymmetric information reanalyzed, Management Science 25, 291–294

Wilson, Robert J., 1967, Competitive bidding with asymmetric information, Management Science 13, 816–820