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THE ROLE OF INFORMATION IN U.S. OFFSHORE OIL AND GAS LEASE AUCTIONS[1]

BY ROBERT H. PORTER

This paper describes the U.S. offshore oil and gas lease sales conducted by the Department of the Interior since 1954. Several decisions are discussed, including bidding for leases, the government's decision whether to accept the highest bid, the incidence and timing of exploratory drilling, and the formation of bidding consortia. Equilibrium models of these decisions that emphasize informational and strategic issues and that account for institutional features of the leasing program are analyzed, and their predictions compared to outcomes in the data.

KEYWORDS: Auctions, bidding, information, oil and gas leases.

1. INTRODUCTION

AN IMPORTANT ASPECT of any market is the information available to participants. The social and private costs of information imperfections are compounded in strategic settings, where participants may exploit informational asymmetries.

Information can play a crucial role in an auction. A seller (or a buyer in a procurement auction) often resorts to an auction market because of uncertainty about the market price for the item in question. That is, the seller is uncertain about others' willingness to pay. At the same time, buyers may be uncertain about their rivals' valuations of the item, and they may be uncertain about the value of the item for themselves, such as when there is an unknown common valuation component. If one buyer has access to information superior to that of its rivals, such as a more precise signal of the item's worth on a future resale market, informational rents may be obtained. Even if buyers have symmetric information, in the sense of equally precise signals, they must account for the winner's curse in uncertain environments because the item will be won by the buyer with the most optimistic assessment of the item's worth. Buyers have incentives to pool information or to gain an advantage by learning of a rival's intentions. If ex post signals of the item's worth are available, the seller can increase profits by making payment contingent on the ex post signal, say via a royalty payment that supplements any fixed payment. However, if the buyer can affect the value by ex post actions, a moral hazard problem arises, and excessive reliance on a royalty rate may distort incentives. The game is not zero-sum, so inefficiencies may result.

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The auction literature has been motivated primarily by substantive policy issues; namely, how should the government optimally lease mineral or timber rights, sell treasury bonds, or procure services. Theories of strategic behavior in auction markets, and of optimal auction design, are strongly influenced by these concerns. (McAfee and McMillan (1987), Milgrom (1985, 1987), and Wilson (1992) ably summarize the literature.) Accordingly, auction theory often directly addresses issues of concern to empirical researchers.

In addition, excellent data are available for several auction markets. For example, timber rights have been allocated by open and sealed bidding, even within a single sale. Therefore, it is possible to test Vickrey's (1961) revenue equivalence theorem, which states that these auction institutions should yield identical average revenues if bidders are risk neutral and behave noncooperatively. (See Hansen (1986), for example. Revenue equivalence results also assume that bidder valuations are independent.) Similarly, procurement data often provide information on all potential bidders, as well as characteristics of the job or object, so that hypotheses about bidding behavior can be tested.

The most notable auction, in terms of attention in the literature, has been the U.S. offshore oil and gas lease sales conducted by the Department of the Interior. The federal government auctions mineral rights to its offshore lands, or Outer Continental Shelf (OCS hereafter). The purpose of this paper is to discuss the role of information in the OCS leasing program and survey my recent research with Ken Hendricks. We investigate whether equilibrium models that emphasize informational and strategic issues, and account for institutional features of the OCS leasing program, have predictive accuracy.

There are (at least) two reasons for concentrating on this relatively narrow topic. First, the OCS data set is quite detailed and permits the study of strategic behavior under imperfect or incomplete information in several settings. Second, game theory emphasizes the importance of the rules of the game and the characteristics of the economic environment in the positive description of equilibrium behavior. Some aspects of the strategic environment of the OCS lease sales are relatively simple to describe, so specific equilibrium predictions can be derived. There is no presumption, however, that the predictions will apply to other strategic situations, or even to other auction markets. On the contrary, a detailed study of institutions, and of the economic environment, is necessary before game theoretic models can be applied. What follows, then, is a case study of a specific market. Equilibrium models incorporating rational strategic behavior under imperfect information appear to provide accurate predictions of outcomes in the OCS leasing environment. Therefore, game theoretic models may be useful for policy analysis of the OCS leasing program.

2. THE AUCTION MECHANISM AND THE DATA SET

The U.S. federal government holds the mineral rights to the offshore lands more than three miles from the coast, out to the 200 mile limit. The adjacent state owns the rights out to the three mile mark. The federal government began auctioning mineral rights in 1954. This paper focuses on the oil, condensate, and natural gas auctions off Texas and Louisiana. Approximately 80 percent of the offshore area that has been sold is in this region of the Gulf of Mexico, and it accounts for an even higher fraction of offshore production. Production from offshore federal lands currently accounts for about 12 percent of U.S. oil production and 25 percent of gas production. A similar fraction of estimated U.S. reserves are located on federal offshore lands. Through 1990, the federal government received $40.3 billion in royalties and $55.8 billion in bids. In 1981 alone, $9.96 billion was collected (Barbagallo et al. (1991); the dollar figures are nominal).

Production rights are transferred to the private sector by a succession of lease sales. A lease sale is initiated when the government announces that an area is available for exploration, and nominations are invited as to which tracts should be offered for sale. A tract is typically a block of 5,000 or 5,760 acres, or half of a block, and much larger than the area covered by leases onshore.

Table I summarizes all OCS oil and gas sales, including sales outside the Gulf of Mexico, divided into five periods between 1954 and 1990. In the earliest period, sales were held sporadically, with gaps of as much as four years. Recent sales were more frequent, essentially quarterly. By 1968, the OCS was established as a major producer of oil and gas, and 1968–1974 saw an increase in the number of bidders and in bid levels. Leases sold after 1974 tended to be less productive and attracted fewer bidders, although bid levels remained high because of increases in the real prices of oil and gas. After 1982, the number of tracts offered for sale increased dramatically and included relatively marginal areas. There was a corresponding decrease in the number of tracts receiving bids and in the number of bids and bid levels.

TABLE I

SUMMARY OF OFFSHORE OIL AND GAS LEASE SALES, 1954–1990[a]

		Tracts Receiving Bids		Tracts Sold				Tracts with Rejected Bids	
Period	# of Tracts Offered	#	Bids per Tract	#	Mean Acreage	Total Winning Bids	Mean Winning Bid	#	Mean High Bid
1954–1960	950	454	2.94	419	4,153	621	1.481	35	0.137
1961–1967	1,460	841	2.95	801	4,672	1,317	1.645	40	0.151
1968–1974	2,041	1,269	4.04	1,103	4,779	12,855	11.655	166	1.254
1975–1982	6,811	2,753	2.59	2,383	5,207	26,591	11.159	370	1.963
1983–1990	136,952	8,011	1.38	7,582	5,313	14,394	1.898	429	1.535
1954–1990	148,214	13,328	2.03	12,288	5,163	55,778	4.539	1,040	1.542

[a] Bids are in millions of nominal dollars.

There are three kinds of oil and gas lease sales. A wildcat sale covers tracts whose geology is not well-known and on which exploration involves searching for a new deposit. Firms are permitted to gather seismic information prior to the sale, but no on-site drilling is allowed. In contrast, drainage and development sales consist of tracts in areas where a deposit has been discovered. On-site drilling is not permitted, but firms owning adjacent tracts can conduct off-site drilling, which may be informative. Drainage leases differ from developmental leases. Developmental leases are often reofferings of previously sold tracts with leases which were relinquished because no exploratory drilling was done, or reofferings of tracts where previous bids were rejected as inadequate. Developmental leases are less valuable than drainage leases on average, and information asymmetries are less acute.

Based on pre-sale exploration, firms nominate tracts, and the government constructs a final list. Many more tracts are nominated than receive bids, and the nomination process probably conveys little or no information. Nominated tracts are then sold simultaneously in a first-price, sealed bid auction. From 1954 until 1990, 125 leases were sold on average in 98 sales. A participating bidder submits a separate bid on each tract that it has an interest in acquiring. A bid is a dollar figure, known as a bonus, that the firm pays on the sale date if it is awarded the tract. (There was limited experimentation with alternative bidding rules, such as royalty rate bidding, from 1978 to 1983.) The highest bidder is awarded the tract, unless the government chooses to reject the bid as insufficient. There may be an announced minimum bid, but higher bids can be rejected. Announced reserve prices were $15 or $25 per acre on wildcat sales, and $25 per acre on drainage sales. Reserve prices vary from sale to sale, but not across tracts within a sale.

The government's rejection decision takes into account its private estimate of the value of the tract. This estimate is based in part upon the geological and seismic information that firms are required to submit, and on the bids themselves when more than three bids are submitted. High bids were rejected on 8 percent of the tracts receiving bids between 1954 and 1990. Tracts with rejected high bids can be reoffered at some future sale.

The results of the bidding, including the identities of all the bidders and the amounts of their bids, are announced at a public meeting. It is not possible to alter bids during a sale.

When a tract is won, a firm usually has 5 years to explore it. If no work is done during the lease term, the lease reverts to the government, and the tract may subsequently be reoffered. A nominal rental fee, typically $3 per acre on wildcat tracts or $10 on drainage or developmental tracts, is paid each year until either the lease is relinquished or production begins. If oil or gas is discovered in sufficient quantities, the lease is automatically renewed as long as production occurs. A fixed fraction of the revenues from extraction accrues to the government as royalty payments. The royalty rate is one sixth of revenues on almost all tracts.

There is very little incidence of tracts being resold after the auction, except as part of a larger corporate acquisition. Of course, there is an adverse selection problem associated with the sale of tracts before deposits are verified. Also, symmetric bidding models predict that equilibria are efficient, so there should be no resale.

The U.S. Department of the Interior publishes a rich data set concerning the OCS auctions. The following information is available for each tract receiving at least one bid: the date of sale (or dates, in the case of reoffered tracts); location and acreage; the identity of all the bidders and the amount they bid; the identity of participants in joint bids and their shares in the bid; whether the government accepted the high bid; the number and date of any wells that were drilled; and monthly production through 1991 of oil, condensate, natural gas, and other hydrocarbons.

The data are typical of many auction data sets, although more detailed than usual, but distinct from many other data sets that are employed to study game theoretic models. Reliable information is available about both the actions taken by the players and their subsequent payoffs. An unobservable factor is the information available to the participants when they make their decisions, such as their perception of the value of the deposits, and the degree of uncertainty. (Experimental data sets can fill this void, because the economic and informational environment is part of the experimental design. They suffer from less experienced players and much smaller payoffs, and therefore perhaps less motivated players, or players with nonmonetary objectives.) Several decision problems can be studied with these data, including: bidding on wildcat tracts, where information is relatively symmetric; bidding on drainage tracts, where informational asymmetries are present; the government's decision whether to accept the highest bid; the decision whether to join a bidding consortium; and the incidence and timing of exploratory drilling after a tract is acquired. Each of these decisions is discussed below.

3. BIDDING ON WILDCAT LEASES

This section describes bidding for wildcat tracts, which are located in regions where no exploratory drilling has occurred previously. I characterize the government decision whether to accept the winning bid and the fate of tracts with rejected bids. The role of joint bids is also described. The discussion is relatively informal, in part because of the difficulty in posing testable hypotheses or estimating structural models.

I restrict attention to the set of tracts in the Gulf of Mexico off Texas and Louisiana, with all dollar figures henceforward denominated in 1972 dollars. Except where noted, I consider the period from 1954 to 1979, where the data are more reliable.

There is considerable dispersion in submitted bids. The distribution of bids is approximately lognormal (Smiley (1979)). Consider the set of wildcat tracts that received bids in sales from 1954 through 1979. Let B_{it} denote the ith highest bid in 1972 dollars on tract t, for i from 1 to n_t, the number of bids on tract t. In a regression of log B_{it} on a vector of tract specific dummies, where there are 8,833 bids on 2,510 wildcat tracts, the R^2 statistic is 0.583. That is, only 58 percent of the variation in log bids can be explained by across tract variation, as accounted for by the 2,510 tract dummies, and the remaining 42 percent is due to within tract variation in bids. (This statistic understates the amount of within tract dispersion, since 902 tracts received only one bid.) The estimated standard error of the regression equation is 1.33, which also indicates substantial within tract variation. (The estimated standard error is the same for the sample of tracts receiving two or more bids, as the sum of squared errors and the degrees of freedom are the same.) The distribution of log bids is heteroskedastic, and the standard error increases roughly linearly in the number of bidders for tracts with two or more bids.

An alternative measure of dispersion is the amount overpaid by the winning bidder. Table II reports "money left on the table," as a function of the number of bidders, for wildcat tracts receiving two or more bids. Money left on the table is reported as a fraction of the winning bid, or $(B_{1t} - B_{2t})/B_{1t}$, where B_{1t} denotes the highest bid on tract t and B_{2t} the second highest bid. Money left on the table is a significantly decreasing function of the number of bidders. Moreover, its magnitude is economically significant. The average amount left on the table is 44 percent of the winning bid, where the winning bid averages $7.9 million (in 1972 dollars) on the 1,608 tracts with two or more bids. (This measure overstates the amount overpaid, because the government is more likely

TABLE II

CHARACTERISTICS OF WILDCAT TRACTS 1954–1979, BY NUMBER OF BIDDERS[a]

	Number of Bidders							
	1	2	3	4	5–6	7–9	10–18	Total
No. of Tracts	902	463	255	212	264	234	180	2510
B_1	1.283	2.667	4.070	5.523	7.871	14.103	21.778	5.538
	(0.087)	(0.198)	(0.375)	(0.491)	(0.605)	(1.166)	(1.355)	(0.211)
$(B_1 - B_2)/B_1$	—	0.549	0.490	0.460	0.386	0.336	0.298	0.442
	—	(0.013)	(0.017)	(0.017)	(0.016)	(0.014)	(0.015)	(0.007)
No. Sold	707	424	241	207	263	233	180	2255
(fraction)	(0.784)	(0.916)	(0.945)	(0.976)	(0.996)	(0.996)	(1.000)	(0.898)
B_1	1.495	2.756	4.170	5.624	7.898	14.160	21.778	6.071
	(0.109)	(0.214)	(0.394)	(0.510)	(0.607)	(1.170)	(1.355)	(0.232)
No. Drilled	431	315	208	176	239	210	178	1757
(fraction)	(0.610)	(0.743)	(0.863)	(0.850)	(0.909)	(0.901)	(0.989)	(0.779)
No. Productive	175	148	97	90	117	132	122	881
(fraction)	(0.406)	(0.470)	(0.466)	(0.511)	(0.490)	(0.629)	(0.685)	(0.501)
Discounted	13.497	15.509	19.451	25.063	26.244	28.845	33.382	22.507
Revenues	(2.040)	(2.108)	(2.478)	(4.105)	(3.885)	(3.331)	(5.087)	(1.263)

[a] B_1 denotes the highest bid on a tract, and B_2 the second highest bid. Dollar figures are in millions of 1972 dollars, and refer to means of preceding sample. (So the mean of discounted revenues is for the sample of productive tracts.) Standard errors of the sample means are displayed in parentheses, except where noted.

to reject lower bids, as noted below.) Even on the 180 tracts receiving 10 or more bids, on average 30 percent of the winning bid is left on the table, and the mean winning bid is $21.8 million. (For this subsample, no bids were rejected.)

These measures of dispersion suggest that OCS wildcat auctions are essentially common value auctions. There are active markets for oil and gas, so that heterogeneities in valuations arise primarily from differences in exploration and drilling costs. The examples described by Wilson (1992) indicate that the distribution of ex ante signals of valuation will be more disperse than the distribution of bids in a noncooperative equilibrium. Since the within tract dispersion in bids swamps likely cost differences, wildcat auctions may be regarded as common value, where firms are uncertain about deposit sizes, common extraction costs, or future prices.

Table II shows that there is also substantial dispersion in the number of submitted bids. The number of bids ranges from 1 to 18, with mean 3.5. For several categories of numbers of bids, Table II indicates how many tracts were sold (i.e., the high bid was accepted) and what became of purchased tracts. Bids are much more likely to be accepted on tracts with several bids and, given the number of bidders, accepted bids were larger than rejected bids. In this sample, exploratory drilling occurred on 78 percent of the 2,255 purchased tracts, and the likelihood of exploration increases with the number of bidders. Half of the 1,757 explored tracts are productive, with sufficient deposits that hydrocarbons are extracted. Conditional on being explored, tracts receiving more bids are more likely to be productive and to have larger deposits if productive. Here deposits are measured by discounted revenues using a five percent real discount rate, where outputs are evaluated at real wellhead prices as of the date of the lease auction. (Hendricks, Porter, and Boudreau (1987), or HPB, provide further detail.) It is difficult to infer ex post profits for this sample, because real oil and gas prices increased dramatically after 1973, and bids would reflect expectations of future prices. Nevertheless, Table II indicates that realized returns are lowest on tracts receiving the most bids. For example, compared to tracts with 7 to 9 bids, accepted bids in the 10 to 18 bids category are 54 percent higher, yet tracts are 10 percent more likely to be drilled, 9 percent more likely to be productive if drilled, and 16 percent more valuable if productive. That is, average tract values are only 35 percent higher ex post in the category with more bidders, ignoring drilling costs. This finding might be consistent with a winner's curse.

Capen, Clapp, and Campbell (1971) first asserted that OCS bidders suffered from the winner's curse. (Thaler (1988) summarizes recent evidence.) Consider a symmetric common value auction where bidders' information is imperfect. Bidders should realize that they will win the auction only if they are relatively optimistic about the value, and should lower their expectations and therefore their bids accordingly. Of course, they should make their rivals aware of the winner's curse phenomenon, so that the rivals also lower their bids. The majority of empirical studies of OCS auctions have tried to determine whether bidding was rational.

Many theoretical papers characterize rational noncooperative bidding under varying assumptions about preferences and information. In an attempt to corroborate Capen et al., some empirical papers have exploited comparative statics results about the relationship between the number of bidders and optimal bids. Conditional on their signal, bidders compute the expected value of the lease. Equilibrium bids will be a fraction of the expected value, where the fraction depends on the precision of the expectation and on the level of competition. As the number of bidders increases, winner's curse considerations are magnified, and bidding should be less aggressive. (When there are only a few bidders, more bidders may imply more aggressive bidding, if competitive effects predominate.) For the offshore bidding data, there is a fundamental difficulty with this empirical approach. These comparative statics results refer to the potential, as opposed to actual, number of bidders. Yet only the actual number is observed. Unfortunately, the actual number of bidders in OCS auctions is endogenous, and all firms submit bids on less than half of the tracts offered for sale. The positive reserve price, and the possibility of negative ex post returns, imply that the firms that actively consider bidding (by obtaining a seismic survey) will not bid on all the leases. Low participation rates may also result from exposure constraints, as firms allocate limited bidding capital to a subset of available tracts (Palfrey (1980)). The likelihood of participation is a function of the expected value of the lease and, if prior signals are informative, higher on more valuable tracts. Table II indicates that the decision to submit a bid is correlated with ex post returns, as tracts that receive more bids have higher average discounted revenues. Some studies find that average bids are an increasing function of the number of bidders, even conditioning on proxies of tract value, perhaps contrary to optimal bidding. This finding is not conclusive if prior beliefs are not observed and difficult to proxy. It is important, then, to treat the number of bidders as endogenous. The difficulty is that it is virtually impossible to obtain adequate instruments. Any variable that is correlated with ex ante signals, and so is a candidate instrument, should affect bidding and participation decisions. Therefore, it is difficult to derive testable reduced form equilibrium predictions.

The same concerns also imply that the structural estimation methods of Paarsch (1991, 1992) and Laffont, Ossard, and Vuong (1994) cannot be directly applied to the OCS data. They infer the joint distribution of valuations from the joint empirical distribution of the winning bid and the number of bids submitted, or the distribution of all bids. In the OCS data, the number of bids is endogenous, and it is difficult to infer how many potential bidders there are. The number of potential bidders varies by sale, and perhaps by region within a sale. In addition, there is unobservable heterogeneity across tracts that would be difficult to proxy. Estimation of structural models of OCS wildcat bidding would also be complicated by two other features: the government rejects many bids above the announced reserve price, and firms often submit joint bids or form bidding consortia.

The relatively low returns on tracts receiving 10 to 18 bids are consistent with the winner's curse, but they are also consistent with equilibrium bidding when there is uncertainty concerning the number of potential rivals. Pre-sale expenditures on seismic analysis are not observable, so firms may not know how many rivals are potential bidders on any given tract. In that case, the prior estimate of the value of a tract conditional on submitting the winning bid is too low on average if the realized number of competitors is below average, and too high if the number is above average.

HPB investigate bidding strategies in further detail, by conducting the following exercise. For a sample of tracts sold from 1954 to 1969, when returns data are more reliable, HPB consider the set of tracts on which a given firm submits bids. Assume that the bids of rival firms and ex post returns gross of the winning bid are fixed. (Cost estimates are derived using the annual survey of drilling costs by the American Petroleum Institute.) Then proportionately vary the vector of bids submitted by the firm in question. For example, if all of the firm's bids are increased, it will win more tracts but earn less per tract. HPB calculate the bid proportion that maximizes ex post returns. They find that a few firms did not behave optimally and overbid, and in at least one case tracts were consistently overvalued. However, most firms appear to follow approximately optimal bidding strategies, conditional on the set of tracts selected and rivals' bids. Of course, this exercise is merely suggestive, and structural estimation would be preferable.

HPB also calculate divisions of rent for the 1954–1969 sample. On wildcat tracts, they estimate that firms capture 23 percent of ex post tract value (discounted revenues less costs), with the remainder accruing to the government as bonus bids and royalty payments. This figure accords with industry lore, and with the noncooperative equilibrium of a common value auction where values are distributed lognormal with an appropriate level of uncertainty (Wilson (1992)).

I now describe the rejection policy of the government in more detail. Table II documents the fraction of tracts where high bids were rejected as inadequate by the government for different numbers of bidders. The government was much more likely to reject the high bid when there were few bidders. Also, the mean high bid on tracts that were sold ($6.07 million) is more than seven times that on tracts with rejected high bids ($0.82 million).

The data identify whether tracts are reoffered, and the history of bidding on reoffered tracts. Of the 2,510 wildcat tracts, 160 were reofferings. 51 tracts were reoffered after the lease was sold and relinquished, either because no exploratory drilling was conducted or because deposits were insufficient to justify production. Hence 2,401 tracts were sold de novo or following relinquishment. A total of 233 high bids, or 10 percent, were rejected on these tracts. On the tracts with rejected bids, 47 percent were subsequently reoffered. Reofferings following rejection occurred 2.7 years after the initial sale on average. On the 108 tracts that were reoffered "as is," the average number of bidders increased from 1.56 to 2.07, and mean bids increased from $1.31 million to $3.27 million. (Some of the increase is due to higher oil prices.) Nevertheless, 20 percent of the high bids were rejected in the reoffering.

In summary, the apparent intention of government's rejection policy was to discourage low bids on tracts with little competition, as measured by the number of bids. These are marginal tracts, and probably not those where another round of bidding is likely to result in much higher bids. Also, the long period between rejection and resale and the low fraction of reofferings may be inconsistent with revenue maximization. McAfee and Vincent (1992) argue that the announced reserve price should have been increased from $15 per acre to more than $200 per acre, or $1 million in total. A high reserve price would preclude the sale of marginal tracts, but McAfee and Vincent note that the reserve price is far below most bids, and therefore few tracts are marginal. Alternatively, there should not have been a common reserve price for all tracts in a sale, but instead a higher reserve on more valuable (ex ante) tracts. However, if there is concern about potential collusion, a secret reserve price may be preferable.

In an auction market with as much uncertainty as the OCS, firms have an obvious incentive to communicate, to avoid leaving too much money on the table. Joint bids provide a legal mechanism for coordination. In addition, joint bids serve to overcome exposure constraints by pooling capital, and they may help to pool information or spread risk. Given the potential benefits of joint bidding, one wonders why firms ever submit solo bids. A cost of joint bidding is the positive externality a joint venture generates for firms not participating in the agreement. For example, an agreement to reduce bids benefits potential entrants, as well as existing rivals not party to the venture. An agreement must include all potential bidders to realize the full benefits of cooperation.

Another obstacle to successful collusion is uncertainty whether rivals are serious potential competitors, for there is an incentive to free ride on others' informational investments. Prior to a lease sale, firms acquire information by investing in seismic surveys and a staff of geologists. The quality of these investments is not publicly observable. Firms would like to communicate and coordinate with all serious rivals, but they may be unable to distinguish serious rivals from free riders beforehand. A joint bid with a nonserious rival dilutes the ex post returns from investments in information. Therefore, solo bidding is likely to occur in equilibrium, especially on less valuable tracts. (See Hendricks and Porter (1994b) for a simple model.)

Table III lists the bidding activities of the twelve largest firms and bidding consortia for the sample of 2,510 wildcat tracts receiving bids from 1954 through 1979. Three bidding consortia pooled their exploration budgets, thereby overcoming free rider problems via ex ante agreements, and can be thought of as single firms. The twelve firms and consortia listed in Table III are designated as large firms, and all other firms are referred to as fringe firms. Table III indicates how many solo bids each large firm submitted, as well as their joint bids. Table III distinguishes between joint bids with other large firms alone (L Only), and those including fringe firms (L&F). In 1975, Congress banned joint bids

TABLE III

WILDCAT BIDDING BY LARGE FIRMS, 1954–1979[a]

Firm	Solo Bids	Joint Bids L Only	Joint Bids L&F	# of Bids	# of Wins
A/C/G/C	1036	71	439	1546	426
SOCAL (*)	493	112	262	867	281
Amoco (SOIND) (*)	197	248	374	819	213
Shell Oil (*)	551	6	184	741	251
Kerr/Marathon/Felmont	63	341	387	791	170
LaLand/Hess/Cabot	18	268	348	634	132
Sun Oil	412	158	36	606	156
Exxon (*)	522	47	32	601	197
Union Oil of Ca.	122	185	284	591	173
Gulf Oil (*)	222	122	242	586	218
Mobil (*)	83	236	146	465	199
Texaco (*)	148	174	122	444	158

[a] A/C/G/C refers to ARCO/Cities/Getty/Continental. L Only bids are joint bids involving only the firms listed in this Table. L&F bids are joint bids involving one or more of the firms in this table and at least one other firm. The three bidding consortia listed in the table are each counted as single bidding units. Firms indicated by (*) were prohibited from joint bids with each other in 1975.

involving two or more of eight designated companies, in order to limit collusion. Large firms affected by this ruling are indicated by an asterisk (*). Table III indicates that there is a substantial number of joint bids, although firms differ in the number and type of joint bids. Less than 20 percent of high bids on wildcat tracts involved only fringe firms.

Hendricks and Porter (1992) note that most of the joint "L&F" bids involve one large firm and one or more fringe firms. 67 percent of the "L Only" joint bids entail equal shares for the participants, yet only 37 percent of L&F bids have equal shares. Instead, the large firm in an L&F bid typically holds a larger share. Large firms appear to bid jointly with relatively inexperienced partners in L&F bids, so that expertise and information is being traded for capital. Consistent with this view of L&F bids, L&F bids tend to occur on hotly contested tracts with many bids and a high winning bid, where a large firm might seek outside capital. Further, among high bid tracts, large firms earn higher returns on their solo bids, so outside partners are sought on tracts with lower expected profits. Because large firms retain an ownership share, adverse selection problems are mitigated in L&F joint bids, which should earn nonnegative profits. Most of the L&F bids occurred after 1970, when average bids increased substantially. In summary, L&F joint bids probably enhance competition by allowing large firms to bid on more tracts.

In the process of forming a joint venture, participating firms may reveal their bidding intentions on all of the tracts under discussion. The concern is that L Only joint bids allow firms to win leases on more favorable terms, either by bidding jointly or by modifying their solo bids. The joint bidding ban led to fewer L Only joint bids, but not to their elimination. Profits for L Only joint bids are similar to those for solo bids by large firms, and higher than those for L&F

joint bids. Consistent with the view that cooperation is more likely on more valuable (ex ante) tracts, L Only bids are more frequent on tracts that attract many bids.

4. EXPLORATION OF WILDCAT LEASES

This section analyzes exploratory drilling on wildcat tracts after their sale. Purchase of a tract does not obligate the buyer to conduct exploration. Firms have five years to begin exploration and, if they do not, the lease is relinquished and reverts to the government. Table II indicates that 22 percent of wildcat leases in the 1954–1979 sample were allowed to expire without any wells being drilled. Bids on tracts with expired leases average $2.5 million in 1972 dollars. In addition, there is a clear deadline effect, as the fraction of unexplored tracts where exploration begins (the hazard rate for initial drilling) falls over time but then increases rapidly as the five year deadline approaches.

Two alternative explanations of abandonment rates suggest themselves. First, firms may have unintentionally acquired more tracts in the auction than they were capable of drilling, because of limited drilling rig availability. This seems unlikely because there is an active rental market in drilling rigs. Alternatively, firms may acquire information after the auction that causes them to revise their forecasts about tract profitability. This must entail a dramatic shift in beliefs, since bids are sunk investments after the auction, and a tract should be drilled if expected gross profits (rather than profits net of the bid) are positive.

There are several potential sources of ex post information. One is the revelation of the other bids. If rivals bid much less than anticipated, or not at all, then a reevaluation may be in order. Second, changes in oil and gas prices alter the expected payoffs from exploration. Prior to 1973, real wellhead prices were virtually constant, yet abandonment rates were similar to those after 1973. Finally, firms observe when drilling in the same area occurs, and production information on previously explored tracts is publicly available. This information will be influential if local drilling results are more reliable predictors of tract profitability than seismic data.

If information externalities are important, a game of timing similar to that modelled by Hendricks and Kovenock (1989) will ensue. In particular, in considering whether and when to drill, firms compare the costs and benefits of waiting. The costs of delay arise from discounting, as profits are deferred. These costs are proportional to expected gross profits. The benefits arise when other firms drill neighboring tracts during the wait, thereby permitting more precise inferences concerning own drilling outcomes. Such information is valuable if the probability of drilling a dry hole falls. If tract holdings are dispersed across several firms, there is an information externality and noncooperative drilling may result in too little exploration at the beginning of the lease term. The benefits of delay depend on characteristics of the tract in question. Firms will follow sequential drilling programs, where tracts that are viewed as more valuable ex ante are explored first.

For concreteness, consider the following example from Hendricks and Porter (1994a). Suppose that two firms own adjacent wildcat leases. The value of the leases, net of development costs and royalties, are perfectly correlated and equal to one with probability p and zero with probability $1-p$. Exploratory drilling costs c, where $p > c$. Assume that in each quarter t, where $t = 1, 2, \ldots, 20$, the firms decide whether to drill if they have not done so already. Leases not explored by the end of quarter 20 are relinquished. The quarterly discount rate is r, and the discount factor $\delta = 1/(1+r)$. Assume that firms observe the outcome of rival drilling programs. A war of attrition arises if firms prefer that their neighbor drill first, or $\delta p(1-c) > p-c$. Expected profits from drilling in the first period are $p-c$. If a firm waits and its rival drills, the lease is productive with probability p, and discounted profits $\delta(1-c)$ are earned.

In the symmetric subgame perfect equilibrium of this game, firms follow a mixed strategy when there has been no prior drilling. If the rival has drilled a productive well, a firm drills immediately. If the rival has drilled a dry hole, the lease is abandoned. In the last period of the lease, both firms will drill if there has been no prior drilling, with expected payoff $p-c$. In all previous periods, if there has been no prior drilling, each drills with probability $q = (1-\delta)(p-c)/\delta c(1-p)$. By assumption, q is between zero and one. Hendricks and Porter (1994a) derive the implied hazard rate for a sample of tracts corresponding to this example, where the hazard aggregates tracts with differing prior drilling conditions according to the probability of observing different drilling histories. The equilibrium involves a relatively high incidence of drilling concentrated at the deadline, as long as the discount factor is not too low, and a U-shaped hazard function.

In contrast, the optimal coordinated plan entails sequential search, in which one tract is drilled in the first period and, if the first well is productive, the second is drilled in the next period. Relative to the optimal plan, the noncooperative equilibrium is inefficient, as drilling is delayed, and there may be duplicative drilling in the final period of the lease. In this model, abandonment occurs only on unproductive tracts, in response to unsuccessful drilling on adjacent tracts. If firms had private information, delay would be an informative event, and Hendricks and Kovenock (1989) show that productive tracts may be abandoned in equilibrium.

If $\delta p(1-c) < p-c$, both tracts are drilled at once under the optimal plan and the noncooperative equilibrium. Presumably, some subset of the OCS sample is thought to be sufficiently profitable ex ante that the costs of delay outweigh the expected benefits, and these tracts are drilled immediately. Similarly, if lease holdings are asymmetric, Hendricks and Porter (1994a) show that there is less delay than in the symmetric noncooperative equilibrium.

The data are consistent with the noncooperative equilibrium described above. Tracts average about 5,000 acres, a size unlikely to cover a typical oil or gas field. It takes about a quarter to initiate exploratory drilling. 22 percent of the wildcat leases with five year leases sold between 1954 and 1979 were relinquished without exploratory drilling. In order to examine the incidence and

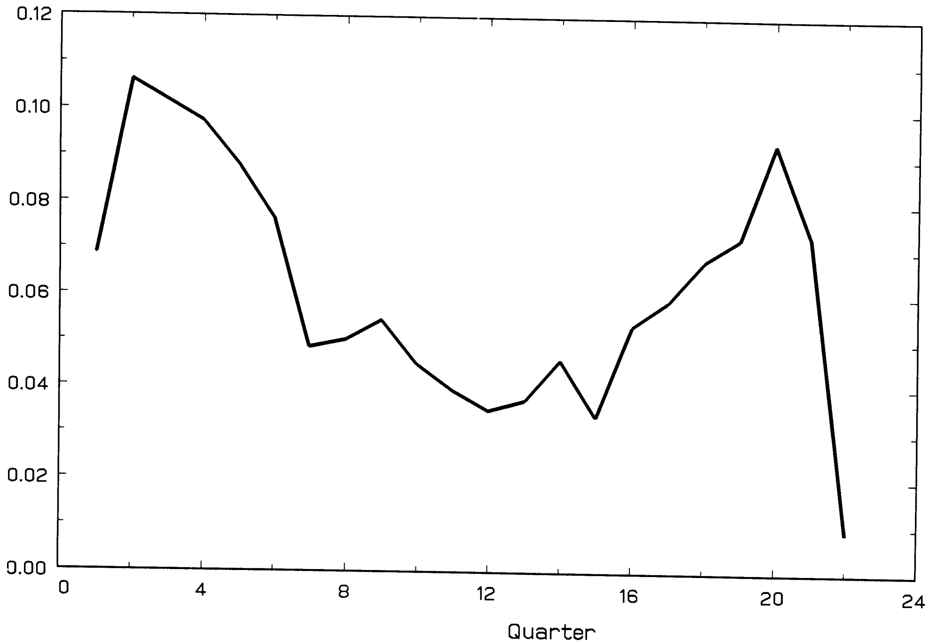

FIGURE 1.—Hazard rate for exploratory drilling on wildcat tracts, 1954–1979.

timing issue, Figure 1 plots quarterly hazard rates for the 2,255 wildcat leases with five-year leases and royalty rates of 1/6, sold between 1954 and 1979. The horizontal axis measures the length of time, in quarters, since the tract was sold. The vertical axis measures the (Kaplan-Meier) hazard rate; that is, the fraction of tracts that had not been drilled previously where exploratory drilling began in that quarter. The hazard rate is initially high (0.106 in the second quarter), levels off at a lower rate for most of the remainder of the term (as low as 0.034 in quarter 15), and increases at the end of the lease (to 0.093 in quarter 20). The standard error of the hazard rate ranges from 0.005 in the first quarter to 0.011 in the twentieth, so the differences are statistically significant. The initial increase in the hazard indicates that a quarter may be too short a decision period for exploratory drilling.

There are many reasons to pool exploratory activities, and unitization agreements offer a mechanism to implement side payments, yet the U-shaped pattern evident in the hazard rate is difficult to reconcile with a model of coordinated drilling. However, it is consistent with the noncooperative outcome of a war of attrition.

Table IV provides tangential evidence that firms do respond to post-sale information. First, tracts drilled early in the lease term had higher bids on average, consistent with nontrivial discounting. Presumably, bids are an increasing function of ex ante valuations, as suggested by equilibrium bidding models. Consider the variable BIDDIF, the mean of the log bid for tracts that are drilled in a particular year after a sale, less the mean log bid on tracts that have

TABLE IV

WILDCAT TRACT CHARACTERISTICS, 1954–1979, BY YEAR OF INITIAL DRILLING[a]

	Year After Acquisition				
	1	2	3	4	5
Risk Set					
Number	2255	1522	1159	971	816
BID	14.46	13.91	13.64	13.52	13.46
	(1.62)	(1.48)	(1.43)	(1.44)	(1.46)
Tracts Drilled					
Number	733	363	188	155	214
(fraction)	(0.325)	(0.239)	(0.162)	(0.160)	(0.262)
BID	15.62	14.77	14.26	13.82	13.50
	(1.26)	(1.31)	(1.18)	(1.31)	(1.18)
BIDDIF	0.769	0.679	0.579	0.525	0.213
	(0.041)	(0.058)	(0.078)	(0.098)	(0.075)
HIT	403	163	87	70	82
(fraction)	(0.550)	(0.449)	(0.463)	(0.452)	(0.383)
REV	16.29	15.52	15.55	15.52	15.22
	(1.54)	(1.64)	(1.71)	(1.96)	(1.55)

[a] Except when noted, standard deviations are displayed in parentheses. BIDDIF is the difference between the BID (the logarithm of the winning bid in 1972 dollars) and the average value of BID on tracts in the risk set that were sold in the same year. For BIDDIF, standard errors of the sample means are displayed in parentheses. REV is the logarithm of discounted revenues on productive tracts, where outputs are evaluated at wellhead prices at the sale date, and a 5 percent discount rate is employed.

not yet been drilled and are sold in the same year. Clearly, an important early factor in the drilling decision is pre-sale information, for which the bid serves as a proxy. However, as the drilling history unfolds, pre-sale information, as exemplified by the bid, is less important. That is, BIDDIF indicates that tracts drilled early in the lease term had much higher bids than the typical tract that was sold in the same year and also not yet drilled. Hendricks and Porter (1994a) report some regression results on whether a tract is drilled in a given year of the lease if it has not yet been drilled. The pattern of the predictive importance of the bid is replicated, and statistics capturing post-sale drilling outcomes on tracts in the same area are important after the first year.

Table IV contains some other informative statistics. Both hit rates (the fraction of tracts that are productive) and discounted revenues are higher on tracts drilled in the first year. Thereafter, hit rates are roughly constant at 50 percent, and then fall in the final year of the lease. The constancy of hit rates and discounted revenues in years two through four suggests that drilling information externalities may be substantial. For these years, tracts drilled later in the lease term are as likely to be productive, and productive tracts have similar average discounted revenues, yet average bids are lower, so that ex post profits are higher.

Furthermore, HPB show that the probability of drilling a given tract in a particular year is independent of the number of tracts held in that area by a leaseholder, suggesting that firms are playing a game of timing, rather than spreading exploration activity over time. The only advantage to delay for firms with a few tracts is information acquisition. However, drilling timing patterns are similar to those for firms with many tracts, suggesting that all leaseholders face similar tradeoffs from delay. Therefore, informational concerns may be more important than those of production smoothing.

The econometric work of Hendricks and Porter (1994a) suggests that ex post drilling information is significant, insofar as drilling programs are responsive to this information (and outcomes are correlated with it). There is little learning from (or, more accurately, little impact on drilling decisions of) information about rivals' bids. There appears to be less delay in areas where lease holdings are relatively asymmetric, and therefore information externalities less severe, consistent with the noncooperative outcome of a game of timing.

The possibilities of useful post-sale information revelation should not be underestimated. Hit rates are approximately 50 percent, and conditional on a hit, the standard deviation of log discounted revenues exceeds 1.5. These are risky prospects and drilling costs are nonnegligible (about $1.5 million in 1972 dollars on average for unproductive tracts), so any useful information is potentially decisive.

During the exploration period, bids in the preceding wildcat auction may reveal private information. In addition, concerns about the outcome of the drilling game are likely to influence wildcat bidding. For example, firms may attempt to acquire asymmetric lease holdings. The implications of post-sale drilling outcomes for bidding strategies are a research topic of potential interest.

5. BIDDING ON DRAINAGE LEASES

In contrast to the symmetric equilibrium models of bidding on wildcat leases, it is possible to test equilibrium bidding models with asymmetric information by examining drainage leases. In these auctions, some firms have explored adjacent wildcat tracts and are likely to have better information than other firms. Further, the data indicate who the "neighbor" firms are. In auctions with asymmetric information, the key strategic variable is the number of well-informed firms. The number of other potential bidders is irrelevant if they have no private information. Indeed, a number of theoretical predictions lend themselves to direct tests with available data. These results are relatively robust and do not rely on functional form assumptions. It is also possible to determine whether bidding by neighbor firms is relatively competitive or collusive.

Consider an auction for a drainage lease of common value V, net of any exploration and production costs, and net of any royalty payments. Suppose there are two risk-neutral bidders. The first owns and has explored the neighboring wildcat lease and knows the realization of V, denoted v. The second firm has access only to publicly available information. Based on public information, this uninformed firm knows that random variable V is continuously distributed with expectation $E[V]$. There is an announced reserve price of R. Suppose that $E[V] > R$.

The Bayesian Nash equilibrium strategies of a first-price, sealed bid auction are as follows. For notational convenience, I suppress the dependence of strategies on the realization of public information. The uninformed firm will follow a mixed strategy. Why should it participate, given its informational disadvantage? If it did not bid, the best response of the informed firm would be to bid R if $v \geqslant R$, and not bid otherwise. But then the uninformed firm should bid slightly higher than the reserve price, say $R + \varepsilon$, win the object for sure, and earn $E[V] - R - \varepsilon$, which is greater than zero for small ε. However, the uninformed bidder should not follow a pure strategy. A pure strategy dictates a bid B for a given realization of the public information. But the best response of the informed firm, when it knows B, is to bid $B + \varepsilon$ if $v > B$, and not bid otherwise. Then the uninformed firm will win the lease only if $v \leqslant B$. This is an extreme example of the winner's curse because the uninformed firm wins only if its bid exceeds the value. Therefore, the uninformed firm will participate, but it must follow a mixed, or unpredictable, strategy, denoted by the distribution function $G_\alpha(b) = \Pr\{B < b\}$.

The expected payoff of the informed firm, if it bids b, is $(v - b)G_\alpha(b)$, for $b \geqslant R$. In equilibrium, the informed firm (pure strategy) bid function will satisfy:

$$\begin{aligned} \beta(v) &= E[V|V \leqslant v] && \text{for } v \geqslant v', \\ &= R && \text{for } R \leqslant v \leqslant v', \quad \text{and} \\ &= 0 && \text{for } v < R. \end{aligned}$$

Here v' is the solution to $E[V|V \leqslant v'] = R$. (If the distribution of V contains mass points, then the informed firm might pursue a mixed strategy.) This is a markdown strategy, for the bid is less than the valuation v, and the markdown is increasing in v. In the limit, as $v \to \infty$, $\beta(v) \to E[V]$. There will be a mass point in the distribution of the informed firm's bids at R, and β is monotone increasing above R. The uninformed firm pursues a mixed strategy, and the bidding of the informed firm is constructed so that the uninformed firm earns zero expected profits for all bids it submits with positive probability. (If the uninformed firm earned negative expected profits, it would prefer not to bid, and this cannot be an equilibrium. Similarly, it cannot earn positive expected profits in equilibrium, for then the informed firm is not maximizing profits. Hendricks, Porter, and Wilson (1994), or HPW, provide more detail.) Consider Figure 2a, where V is assumed to be distributed according to an exponential distribution with mean 6, and the reserve price R equals 1. If the uninformed firm bids above the range of the informed firm's bid, so $B > 6$, it surely wins the lease, with expected value $E[V]$ less than its bid. If it bids between zero and R, or doesn't submit a bid, it earns zero. If its bid B is between R and $E[V]$, then it wins the object only if $\beta(v) < B$, or if v is less than $\beta^{-1}(B)$. But then the expected value of the lease, conditioning on the event of winning the auction with bid B, is given by $E[V|V \leqslant \beta^{-1}(B)] = B$. Thus bids between R and $E[V]$ break even on average, by construction. Bids at R earn negative expected profits, as indicated in Figure 2a, because $\beta(v)$ lies to the right of $E[V|V \leqslant v]$ for v in the interval $(1, v')$.

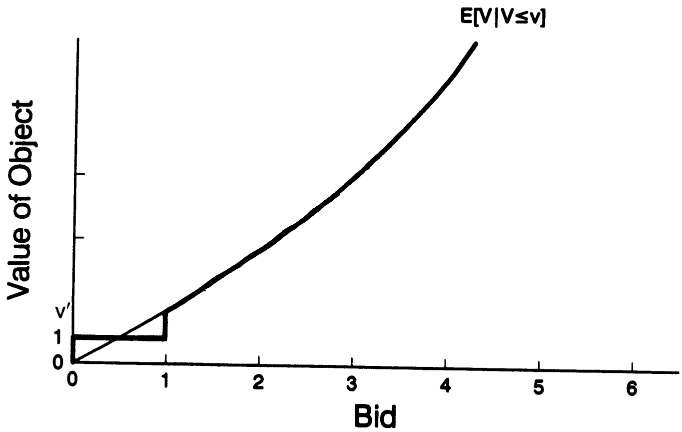

FIGURE 2a.—Bid function for example with fixed reserve price.

The mixed strategy $G_\alpha(b)$ chosen by the uninformed firm induces the informed firm to optimize by choosing the strategy $\beta(v)$. The equilibrium outcomes can be characterized by the following properties.

1. The informed firm is more likely to submit a bid, and more likely to win the lease.

2. The distribution functions of the bids of the two firms will coincide above the reserve price. The distribution functions differ because the informed bid distribution has a mass point at the reserve price, and because its bid is a function of the true value; whereas the uninformed bid is random, conditional on publicly available information.

3. The uninformed firm earns zero expected profits. It loses money on tracts where the informed firm does not bid, and makes money on tracts where it outbids the informed firm. It expects to earn profits in the latter instance because the informed firm pursues a markdown strategy.

4. The informed firm earns positive profits, and the magnitude of the information rent is related to the dispersion in the distribution of V.

Figure 2b illustrates the first two implications of the theory for the bid distributions in the example underlying Figure 2a. The informed firm bid distribution function, denoted G_β, differs from the uninformed distribution function, G_α, between zero and the reserve price R (which equals 1 in the example), indicating a greater propensity to submit a bid, as accounted for by the mass point at the reserve price. The informed firm is more likely to win the lease because G_β stochastically dominates (lies below) G_α and the bids are independently distributed.

The example sketched above makes a number of assumptions. The assumption that there is only one uninformed bidder is not important, provided that all uninformed bidders observe only public information. Then the equilibrium distribution function $G_\alpha(b)$ characterizes the highest bid submitted by the uninformed bidders. If uninformed bidders have access to informative private

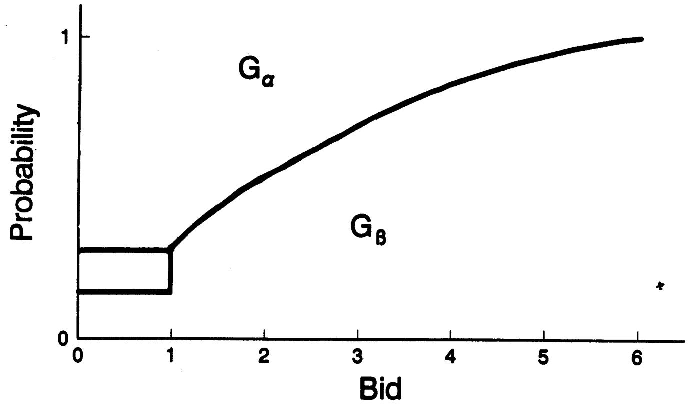

FIGURE 2b.—Bid distribution functions for example with fixed reserve price.

signals of V, then winning is an informative event for the informed firm (if it has less than perfect information concerning V), and the strategy of the informed bidder depends on the potential number of (relatively) uninformed bidders. The mixed strategy equilibrium described above is the limit of the equilibrium in which the uninformed bidder observes a private signal concerning V, where the limit is taken as the precision of the signal goes to zero. Nevertheless, the modelling assumption, that the firms without access to drilling records from neighboring tracts have little private information of value, appears to be reasonable for predictive purposes. One indication is that ex post tract profitability, on tracts sold between 1959 and 1969 (when one can reasonably proxy price expectations as static) is highly correlated with the bidding behavior of firms owning neighboring leases, but not with the bidding behavior of uninformed firms, conditional on publicly available information (Hendricks and Porter (1988)). (Note that drainage sales began in 1959.)

A second assumption is that there is only one informed bidder. In fact, there are on average 3.8 neighboring leases, as indicated in Table V. However, there are both institutional and empirical reasons to believe that the informed bidders coordinate their actions, and effectively bid as one. There are two institutional reasons. First, joint bids are legal, as described in Section 3. Second, tracts sharing a common pool are typically unitized, to avoid inefficiencies associated with excessive drilling (Libecap and Wiggins (1985)). A unitization agreement

TABLE V

FREQUENCY DISTRIBUTIONS ON DRAINAGE TRACTS, 1959–1979

	Number							
	0	1	2	3	4	5–6	7–12	Mean
Neighbor Tracts	*	33	70	59	38	57	38	3.78
Neighbor Bids	42	198	47	6	2	0	0	1.08
Non-Neighbor Bids	122	77	47	22	8	11	8	1.37

allocates revenues from a common pool according to a pre-specified scheme, typically on the basis of acreage above the pool, and is an institution that facilitates side payments. (In addition, there is the threat to dissolve unitization partnerships and over-drill, should anyone break an agreement.)

The empirical reasons are several as well (Hendricks and Porter (1988)). First, multiple informed bids on a tract were relatively uncommon, as indicated in Table V. Table V gives the frequency distribution of the number of neighboring leases, where there is at least one adjacent lease, as well as the number of bids submitted by firms owning neighboring leases (informed bids), and by nonneighbors (uninformed bids). The mean number of neighbor bids is about one. Second, multiple neighbor bids tend to occur on high value tracts, and ex post returns are higher than on single bid tracts, contrary to what might be predicted by competitive bidding. Finally, the potential winner's curse problems faced by uninformed bidders are augmented by the presence of several competing informed bidders. If uninformed bidders have access only to public signals, they should not participate in this case. Yet the bidding of uninformed bidders appears to be independent of the number of firms owning neighboring leases. All three of these facts are consistent with coordinated bidding by informed firms, where multiple bids are occasionally submitted to create the appearance of competition. (Porter and Zona (1993) describe a collusive scheme for highway paving jobs that relied on nonserious bids.) The facts are also consistent with one of the informed bidders having superior information, and the others being essentially uninformed, with the same empirical predictions.

The third and fourth predictions, concerning profits, are confirmed by the data, as indicated in Table VI, which differentiates between tracts won by neighbors and nonneighbors, and within those categories depending on whether the other type of firm submitted a bid. Profits are reported only for the 1959–1973 subsample, where profit figures are more reliable. (Recall that profits

TABLE VI

BIDDING ON DRAINAGE TRACTS, BY TYPE OF BIDDER[a]

	Wins by Neighbor Firms		Wins by Non-Neighbor Firms		
	No N-N Bid	Total	No N Bid	N Bid	Total
1959–1979:					
No. of Tracts	77	135	32	70	102
No. Drilled	60	117	27	67	94
No. Productive	46	95	12	40	52
(fraction of total)	(0.60)	(0.70)	(0.38)	(0.57)	(0.51)
Mean Winning Bid	5.19	10.16	3.31	8.90	7.14
	(1.09)	(1.55)	(0.85)	(1.30)	(0.96)
Mean Discounted	11.67	19.83	4.24	18.29	13.88
Revenues	(2.60)	(3.14)	(1.57)	(4.16)	(2.96)
1959–1973:					
No. of Tracts	43	75	12	37	49
Mean Net Profits	1.56	4.93	−2.00	1.83	0.89
	(1.82)	(2.41)	(0.92)	(3.23)	(2.45)

[a] Dollar figures are in millions of 1972 dollars. Except where noted, standard errors of sample means are displayed in parentheses.

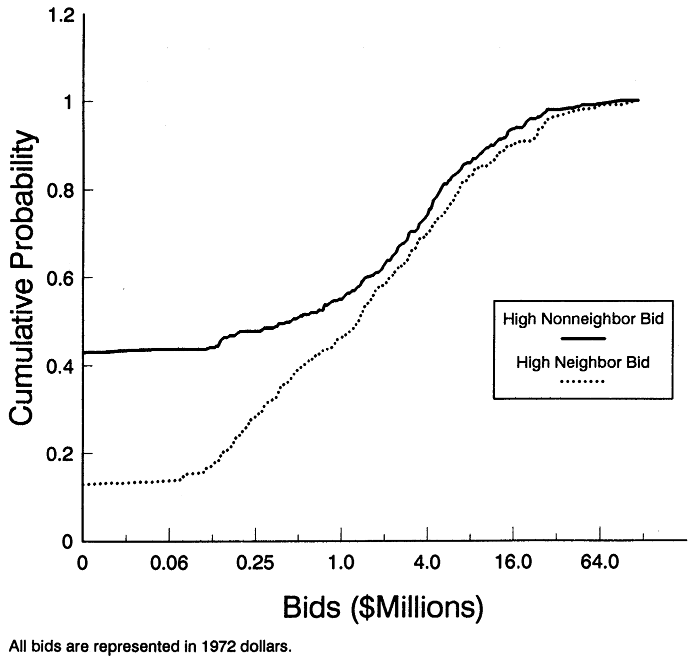

FIGURE 3.—Distribution of bids on drainage tracts, 1959–1979.

are discounted revenues net of royalties, bids and estimated discounted drilling costs.) Consistent with the third prediction above, uninformed firms break even approximately, and lose money on tracts where no informed firm bids.

On drainage tracts, HPB calculate that firms capture about a third of social rents, compared with a quarter on wildcat tracts. Nevertheless, fewer bids are submitted on average (2.5 on drainage leases versus 3.5 on wildcat leases in 1954–1979). There appear to be informational barriers to entry of nonneighboring firms.

As for the first two predictions, as illustrated in Figure 2b, only the first is borne out. Figure 3 depicts the empirical distribution function of the highest informed and uninformed bids submitted on the 295 drainage tracts that received bids in the period 1959–1979. Informed firms bid more often, as indicated by the height of the distribution functions at zero, and submit the highest bid more often (on 61 percent of the leases). However, there is no evidence of a mass point at the announced reserve price, which is about $62,500 (at $25 per acre for 2,500 acres, the average drainage tract size). Nor do the distribution functions coincide above the reserve price, although they are similar above $4 million. The striking aspect of Figure 3 is not that uninformed firms submit bids less often, but rather that when they bid they tend to submit high bids.

Another assumption of the preceding theory is that the government accepts all bids above the announced reserve price. On the contrary, 58 of the 295 high bids submitted on drainage tracts, or 20 percent, were rejected. Table VII

TABLE VII

COMPARISON OF ACCEPTED AND REJECTED DRAINAGE BIDS, 1959–1979[a]

	Accepted	Rejected
High Bid	8.861	1.453
	(0.978)	(0.312)
No. of Bids	2.73	1.26
	(0.14)	(0.30)
No. of Neighbor Tracts	3.73	4.00
	(0.14)	(0.30)
Fraction with High Bid by Neighbor	0.57	0.79
No. of Tracts	237	58

[a] Bids are in millions of 1972 dollars. The numbers in parentheses are standard errors of the sample means.

compares bidding on accepted and rejected drainage tracts. Two aspects are of note. First, a higher fraction of rejected bids are by informed firms. Second, the government is much more likely to reject a bid if it is low, analogous to the rejection policy on wildcat tracts described in Section 3.

As HPW demonstrate, it is possible to reconcile the disparities between the predictions depicted in Figure 2b and the empirical distribution of Figure 3 if one accounts for the propensity of the government to reject low bids. Consider the previous example, but now assume that there is an unannounced tract specific reserve price, unknown to the bidders, that is distributed uniformly on the interval [1, 3], where 1 is the announced minimum bid. (The independent and uniform distribution is chosen for convenience. HPW examine a general model.) Then a bid b between 1 and 3 will be accepted with probability $(b-1)/2$. Hence lower bids are more likely to be rejected. Assume also that the reserve price is determined prior to the bidding, and unaffected by submitted bids. Then denote by $\beta_0(v)$ the optimal bidding strategy of the informed firm when there is no uninformed bidder. Here $\beta_0(v)=(1+v)/2$ for v in [1, 5], and $\beta_0(v)=3$ for $v>5$, as depicted in Figure 4a. When there is an uninformed bidder present, the equilibrium bidding strategy of the informed bidder is $\beta_1(v)=\max\{\beta_0(v), \beta(v)\}$, as depicted by the solid line in Figure 4a. That is, for low value tracts, the informed firm is concerned with the possibility of having its bid rejected, and so increases its bid. The effect of this increase is to knock out low uninformed bids. Low uninformed bids earn negative expected profits, because the more aggressive bidding strategy of the informed firm means that the uninformed firm can win only when its bid exceeds the expected value of the tract conditional on winning. In Figure 4a, β_0 lies to the right of β for bids less than 3. The implications for the bid distribution functions are shown in Figure 4b. There is no longer a mass point in the informed firm bid distribution function at the reserve price, and the uninformed firm no longer submits low bids. The distribution functions coincide above 3, the upper bound on the support of the reserve price. The other predictions from the simple model remain valid. In the drainage auctions, only 6 of the 122 bids above \$4 million

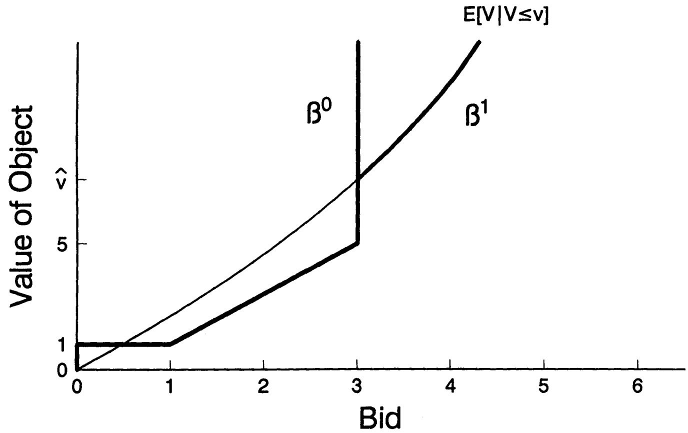

FIGURE 4a.—Bid functions for example with unknown reserve price.

were rejected, and the empirical distributions essentially coincide above that level. Thus a simple adaptation of the theory can account for bidding behavior on drainage leases. The fact that informed firms submit a higher percentage of rejected bids is consistent with the prediction that they are more likely to bid low, and low bids are more likely to be rejected.

The theory is too simple in that it assumes that the government has no private information of its own, and because the bidders do not account for the possibility of a reoffering in the event that the low bid is rejected. On the latter point, it is notable that less than a third of the tracts with rejected bids were reoffered, and reofferings occurred a year and a half later on average (Hendricks, Porter, and Spady (1989)). Therefore, it is not unreasonable to assume that firms ignore the possible repercussions of their bidding for future reofferings. On the former point, the government also has access only to seismic information before the auction, and submitted bids do not seem to influence reserve prices,

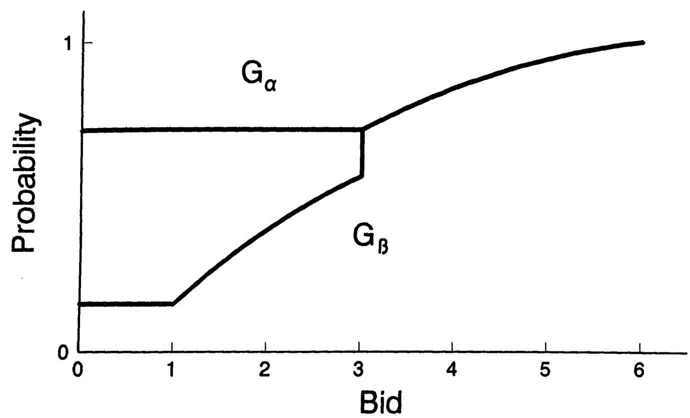

FIGURE 4b.—Bid distribution functions for example with unknown reserve price.

except when more than three bids are submitted. (Informed firms may submit multiple bids on valuable tracts to manipulate bid adequacy decisions in these cases.) As HPW demonstrate, if one accounts for private information observed by the government, the theoretical predictions of the example are still valid. They show that the distribution of the informed bid will stochastically dominate that of the maximum uninformed bid, and the distributions should coincide above the support of the reserve price. These predictions are satisfied by the empirical distribution in Figure 3. HPW show that similar predictions obtain for more general distributions, and if there is unobservable heterogeneity across tracts (in public information, say).

Therefore, a theoretical model that accounts for important institutional features is consistent with many aspects of the data. The model emphasizes informational asymmetries, rather than cost asymmetries. While cost asymmetries may be present, their influence is swamped by informational asymmetries. A model of cost asymmetries alone cannot account for the lack of correlation between the uninformed bids and ex post tract values. Also, cost asymmetries should be mitigated by unitization agreements, which encourage efficient production plans. In contrast, the predictions of a model with asymmetric information are confirmed by the bidding data, after the government rejection decision is accounted for.

6. SUMMARY

In some important respects, the OCS leasing program is well designed. Bidding for wildcat leases appears to be relatively competitive, and the government probably captures a reasonable share of the rents, given the risks involved.

Owners of adjacent leases extract information rents in drainage lease sales. Anticipated profits in subsequent drainage sales are likely to be reflected in bidding for wildcat leases. If expected drainage profits are not fully capitalized in wildcat bidding, perhaps because drainage sales follow wildcat sales less than 20 percent of the time, then the government could increase royalty rates on drainage leases. The Bayesian Nash equilibrium of the asymmetric bidding game predicts that nonneighbor firms earn zero expected profits if they have access only to public information. Then a higher royalty rate taxes the firms owning neighboring leases and with access to superior information. The problem is that for tracts with relatively small deposits, it no longer pays to submit a bid. In addition, a higher royalty rate exacerbates the moral hazard problem of less ex post exploration and recovery than is socially optimal. These arguments assume that the current royalty on revenues is employed, and that costs are difficult to measure. Alternatively, royalties might apply only to revenues above a prespecified estimate of likely drilling costs, based on industry experience. Nevertheless, some caution is in order, since changing the rules of drainage auctions would probably alter bidding and exploration decisions on wildcat leases, which are qualitatively much more important.

Hendricks, Porter, and Tan (1993) discuss optimal selling mechanisms for drainage tracts. In common value auctions with asymmetric information, the seller can extract most of the available rents without knowing the joint distribution of signals and the value of the lease. Instead, it may be sufficient to know who has private information (here, who owns adjacent leases).

In contrast, the optimal selling mechanism for wildcat leases, where information is relatively symmetric, depends on the joint distribution of signals and the tract value. The structural estimation methods of Paarsch (1991, 1992) and Laffont, Ossard, and Vuong (1994) are designed to recover the parameters of this joint distribution. As noted above, their methods are designed for simpler auction environments than the OCS (e.g., a fixed reserve price, independent private rather than common values, and no joint bids). They exploit simulated moments estimators, so that their methods can be generalized to more complex environments. This constitutes frontier research in empirical applications of game theory. Another direction for future research would be to abandon the functional form assumptions embodied in these structural estimation methods. For example, Elyakime, Laffont, Loisel, and Vuong (1993) implement a nonparametric estimation method for an independent private values auction with a secret reserve price.

The apparent delay of exploration decisions until the end of the lease term is troubling. The fixed lease term induces a deadline effect, which may entail duplicative drilling at the end of the term. However, a fixed term also reduces purely speculative motives for acquiring, and probably not exploring, a tract.

There are potential gains from the coordination of drilling programs. There may be a concern that coordination in exploration might extend into bidding. Of course, current joint bidding arrangements are potentially collusive, as are unitization agreements, and yet they appear not to have had a detrimental impact on competition. The heterogeneity in tract values, and in perceptions of values of individual tracts, as exemplified by the variation in bidding across and within tracts, is probably an obstacle to cooperation. However, the ban on joint bids involving two or more of the largest firms may exclude bidding consortia that limit competition. Further, if consortia are beneficial because they raise capital, then joint bids with industry outsiders (L&F bids) serve the same purpose and probably enhance competition. (This argument is analogous to the notion that entry by building a new plant is socially preferable to entry via acquisition of an existing plant, as competition is enhanced.)

Another issue is whether more information could be made available prior to wildcat sales. Under current practice, firms acquire a risky prospect, and royalty schemes do not provide much insurance. In particular, they do not provide any insurance for drilling costs, since royalties apply only to revenues. As on drainage sales, royalties on wildcat leases could apply only to revenues above a predetermined level.

A final issue concerns what the Department of Interior should maximize. The optimal auction design literature, and some of the above discussion, assumes that government revenue maximization is the goal. However, another goal is the expeditious exploration and development of offshore oil and gas supplies. To that end, the possibility of profits in the bidding process encourages firms to incur pre-sale exploration expenses, and thereby identify productive tracts for bidding and exploratory drilling.

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