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INFORMATION, RETURNS, AND BIDDING BEHAVIOR IN OCS AUCTIONS: 1954–1969*

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This paper examines federal auctions for leases on the Outer Continental Shelf (OCS) in the light of the predictions of the first-price, sealed bid, common values model of auctions. We find that the data strongly support the model for auctions in which one bidder is better informed than the other bidders. The evidence for auctions in which bidders have noisy but qualitatively similar information is less conclusive, but is consistent with a model in which each bidder does not know either the actual or potential number of bidders on a lease.

I. INTRODUCTION

THIS PAPER provides a preliminary statistical analysis of bidding and returns data for the US government auctions of oil and gas leases for the Outer Continental Shelf (OCS) from 1954 through 1969. We have two objectives. One is to document the relationships between information, competition and profits, and the other is to examine whether the assumptions and predictions of the theoretical bidding models are consistent with these data.

As Weaver *et al.* [1973] document, by 1970 16.7 per cent of US domestic oil and lease condensate production, and 15 per cent of marketed gas production, came from offshore wells. These shares have since increased. Through the end of 1970, 7.1 million offshore acres had been auctioned off by the federal government, for a total of $5607.8 million (in constant 1972 dollars) in bonus bids, royalty payments and rental fees. Of course, leases auctioned off in this period continued to contribute royalty payments after 1970. By the end of 1980, 22 million acres had been auctioned. In short, these auctions have involved an increasing fraction of US domestic hydrocarbon production, and are an important source of revenue to the federal government.

The oil lease auctions are also an excellent source of data on the strategic behavior of firms in situations of imperfect and asymmetric information. In recent years, there has been a great deal of theoretical and experimental work on this issue, particularly in the context of auctions, but almost no work using field data has been done. This is unfortunate, since the predictions of the theoretical models often rely upon the assumption that each agent is able to correctly predict the behavioral rules adopted by the other agents in his

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decision environment. It is important to verify whether this assumption is valid empirically. This paper takes a small step toward answering this question by evaluating whether the common values model of auctions (see Wilson [1975]), or some modification of it, provides an appropriate description of bidding behavior in oil lease auctions.

We begin in section II with a description of the auction mechanism. Section III describes the data set. In addition to detailed bidding information, we have post-auction production and drilling data. From these latter series, we construct estimates of the *ex post* profitability and social value of each lease. Some summary statistics are then provided, together with a cross-tabulation which succinctly describes the joint distribution of bids and *ex post* (or the realization of) profits.

In section IV we document individual firm participation rates and returns. There is substantial interfirm variation in the return figures, part of which may be attributable to luck. To identify other causes, we conduct two experiments. The first compares the profits which each firm earned to the profits it would have earned, had it won every tract on which it bid at the price it submitted. This reveals whether there were any biases in the firms' evaluations of tracts. The second experiment consists of proportionately varying all bids by a particular firm, holding constant the bids of all other firms, and computing the change in returns associated with these bid variations. This determines whether, given the set of leases which the firm chose to bid on, and given the bids of all other firms, the firm's bidding strategy maximized its *ex post* net returns. The results of these experiments indicate that a few firms did not behave optimally, and that, in at least one case, a firm consistently overestimated the value of tracts. Most firms seemed aware that their valuations of tracts they win are biased upward, although a subset of the firms may have underestimated the extent of this bias. Furthermore, there is little evidence of collusion in bidding.

In section V we examine several hypotheses about the joint distribution of firm valuations and *ex post* profits. The evidence suggests that there is significant variation in this distribution across geographical areas and across sale dates, but not across firms. The variation in firms' profitability appears to be primarily due to differences in their criteria for determining which tracts to explore and bid on. Furthermore, the factors accounting for these differences are not area- or sale-specific, but are common to all of the firms' bidding decisions.

In section VI we examine the drilling decisions of firms and the impact of (local) information externalities on these decisions. We find that firms adopt sequential drilling programs in which they first drill leases that are viewed *ex ante* as being more valuable. Twenty-seven percent of all leases were allowed to expire without any wells being drilled. We also find that there is a sharp distinction between leases in new geographical areas and those which are adjacent to previously sold leases. In the former case, the probability of a tract being productive does not depend on when the tract is drilled. Thus, the acquisition of information from drilling outcomes appears to be sufficient to offset the decline in the average quality of the tracts. In the latter case, those leases drilled earliest are more likely to be productive, and the winning firm captures a higher percentage of social rents, as much as 37 per cent, versus 26 per cent for all leases. This probably represents a return for superior information.

The penultimate section categorizes leases according to the number of bidders and examines the effect of competition on bidding and returns. Our most important finding is that bidding and return patterns are qualitatively different on leases adjacent to previously explored areas than on leases in *de novo* areas. In the former case, some firms are likely to be better informed, since they had won neighboring leases in previous sales. For these leases, we find that the *ex post* profits on tracts which receive no informed bids is substantially lower than on tracts which receive an informed bid; that the average net return on tracts won by uninformed firms is zero; that informed firms won about half of the tracts; and that the informed firms earn very high returns, which are independent of the number of uninformed bids. These facts match the predictions of theoretical work on auctions with asymmetrically informed bidders (e.g. Engelbrecht–Wiggans *et al.* [1983] and Milgrom and Weber [1982a]). We also note that very few leases received more than one informed bid, an outcome which is not due to informed firms forming joint ventures. Indeed, if there is any collusion in these auctions, it probably only arises via bid rotation schemes. Such schemes are unlikely to be effective in these auctions, because of the infrequency of lease sales.

Our analysis of the effect of competition in *de novo* areas is less definitive. Consistent with theoretical predictions, both winning bid and the difference between the two highest bids, or "money left on the table", increase with the number of bidders, and the ratio of money left on the table to the winning bid falls. In addition, higher value tracts attract more bidders. However, *ex post* profits net of bids are a decreasing function of the number of bidders, and are even negative when this number is seven or greater. The difficulty with establishing whether or not this pattern is consistent with the common values model is that the number of bidders is not the correct measure of competition on tracts. It is clearly an endogenous variable, since active firms with sufficiently low valuations of a tract do not submit bids.

An explanation of the return pattern which is *not* consistent with the common values model is that firms do not adequately account for the "winner's curse". That is, they may fail to recognize that, when the number of bidders increases, the firm with the highest *ex ante* evaluation of lease profitability is increasingly more optimistic relative to the true lease value, and so should reduce its bid accordingly. (See, for example, Capen, Clapp, and Campbell [1971].) An equally plausible explanation, which is consistent with the common values model, is based on the assumption that firms did not know the number of competitors on a lease. In that case, its prior estimate of the value of the tract conditional on winning is on average too low if the realized number of competitors is below average, and it is too high if the number is above average. To discriminate between these explanations, one needs to develop and estimate an explicitly parametric econometric model of bidding strategies. This is what we intend to do in our future research.

We conclude with a brief discussion of some implications of our findings.

II. DESCRIPTION OF THE AUCTION MECHANISM

The federal government transfers the production rights to oil and gas deposits on offshore public lands to the private sector by means of a sequence of lease sales. The organization of a lease sale begins when the government makes a particular area available for exploration and invites nominations from the oil industry as to which tracts should be offered for sale. A tract typically consists of 5000 or 5760 acres. The firms are permitted to gather information about the tracts using seismic surveys and off-site drilling, but they are not allowed to drill any on-site wells. After the firms make their nominations, the government constructs a final list of tracts, which it then offers to the public through the first price, sealed bid auction procedure described below.

There are two kinds of lease sales. A wildcat sale consists of tracts whose geology is not well-known, and only seismic exploration precedes these sales. The wells which are drilled on such tracts are called *wildcat* wells, since they involve searching for a new deposit. In contrast, a *drainage* sale consists of tracts which are adjacent to tracts on which a deposit has been discovered. Wells drilled on these tracts are, for the most part, developmental, rather than exploratory, wells.

A sale consists of the simultaneous auction of the nominated tracts. In our sample, the average number of tracts sold in wildcat and drainage sales were 132 and 27, respectively. A firm which participates in a sale submits a separate bid on each tract that it is interested in acquiring. A bid is a dollar figure which the firm promises to pay to the government at the time of the sale if it is awarded the tract. This payment is called the *bonus.* The firm submitting the highest bonus is awarded the tract. The results of the bidding on all tracts, as well as the identities of the bidders and the values of their bids, are announced at a public meeting.

When a firm wins a tract, it has 5 years to explore it. If no work is done during this period, ownership of the lease reverts to the government, which may subsequently auction off the tract in some future sale. In our sample, a nominal rental fee of \$3 per acre on wildcat tracts, and \$10 per acre on drainage tracts, is paid by the firm each year until either the lease expires or production begins. If oil and/or gas is discovered in sufficient quantities so that the firm begins production, the lease is automatically renewed for as long as it takes the firm to extract the hydrocarbons. A fixed fraction of the revenues from any oil and/or gas extracted, 1/6th throughout our sample, accrues to the government. This sum is paid on an annual basis and is called the *royalty* payment. There is virtually no incidence in our sample of tracts being resold from one firm to another after the auction is held. There was little or no motive for speculative purchases of leases, since real wellhead prices were constant for practical purposes in the US until 1973.

The government may enter the auction as a bidder in two ways. In our sample, it announced a reservation price of $15 or $25 per acre on wildcat leases and $25 on most drainage leases. (The reservation prices varied from sale to sale.) In addition, it retains the right to reject the high bid on a tract if it believes the bid is too low. The usual basis on which it makes this judgment is its private estimate of the value of the tract. These estimates may be based in part upon the geological and seismic reports which the firms are required to submit. For sales in our sample, the high bid was rejected on 7 per cent of the wildcat tracts, and on 15 per cent of the drainage tracts..

III. DATA DESCRIPTION

Our study focuses on the federal lands off the coasts of Louisiana and Texas which were leased between 1954 and 1969. During this period, the government held 8 wildcat sales and 8 drainage sales, in which it auctioned off 1056 wildcat tracts and 144 drainage tracts. (These numbers do not include the 81 wildcat and 25 drainage tracts on which the high bid was rejected.) There were also several wildcat sales off the Florida and the Pacific Coasts in this period. We have dropped these sales from our sample because of their relatively low level of post-auction drilling activity, and because they are in geologically distinct areas.

Our data set, which we obtained from the Department of the Interior, contains the following information for each tract: the date it was sold; its location, water depth, and acreage; which firms bid and the value of their bids; the number and date of any wells that were drilled; and its annual production through 1980 if any oil or gas was extracted. The drilling and production data were used, together with the annual survey of drilling costs conducted by the American Petroleum Institute, to calculate *ex post* value for each tract.

Our projected production profile for each tract was constructed as follows. Each productive well potentially yields four separate commodities: oil, condensate, natural gas, and other hydrocarbons. For each of these commodities, if the tract had stopped being productive by 1980, we assumed that production had terminated on that tract. (It is not inexpensive to cap and reopen an offshore well.) If production was still continuing in 1980, we determined the year of peak production for that commodity on that tract, and then filled in the missing values of the production path for 15 years after the peak production year by using a 25 per cent per annum decline in the rate of production, where the base is the production in the peak year. Production more than 15 years after the peak year was assumed to be zero. This production model describes the terminated production profiles in our sample quite closely.

In order to convert these four output sequences into revenues, we noted that real wellhead prices in the US were virtually constant from 1950 until 1973, and assumed that the expectations of the bidders in our sample would be for this pattern to continue. Accordingly, we took the real wellhead price of each of the four commodities received in the year the tract was auctioned off, in 1972 dollars (adjusted by the GNP deflator), and multiplied that price times production of that commodity for each productive year. This real revenue sequence was discounted at a 5 per cent per annum rate to the year of the tract sale to obtain the present discounted value of revenues. Formally, the real revenue, R, from a tract sold in year t is calculated as:

$$R = \sum_{s=0}^{\infty} \beta^s \left(\sum_{i=1}^{4} p_{i,t} \cdot q_{i,t+s} \right) \tag{1}$$

where $\beta = \exp(-0.05)$ is the discount factor, $p_{i,t}$ is the real price of commodity i in year t, and $\{q_{i,t+s}\}_{s=0}^{\infty}$ is the actual and projected sequence of production of commodity i. Again, note that, for each i, $p_{i,t}$ is almost constant.

Our construction of discounted costs is similar to that of Mead *et al.* [1980]. We consider only the cost of drilling and equipping wells. Each well drilled on a tract is classified according to four criteria: (1) its location, whether it is offshore Texas or offshore Louisiana, (2) its spud year, (3) its depth, on the basis of which it is assigned to one of eleven categories, and (4) its production status. A well is called an oil well if the majority of its revenue was from oil and condensate; all other productive wells are called gas wells. Unproductive wells are called dry, and are less costly, since some drilling and equipping costs are avoided.[1] Given this four-way classification, we rely upon the annual Joint Association Survey of the American Petroleum Institute to impute a cost per foot for each well drilled on each tract.[2] Well costs are then discounted back to the auction year according to the 5 per cent rate, and then

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[1] For productive tracts, we designated wells as productive or dry according to the following formula. Of the first 11 wells drilled on a tract, 65 per cent were assumed to be productive; of the next five wells drilled, 77.5 per cent were assumed to be productive; and of any additional wells drilled, 90 per cent were assumed to be productive. This scheme, also used by Mead *et al.*, is roughly consistent with offshore experience, and accounts for the fact that later wells are more likely to be productive.

[2] Cost estimates for 1957 and 1958 were unavailable, and their values were estimated by interpolation of estimated costs in adjacent years. Additional interpolation and extrapolation was also necessary for some categories of wells in early years or when there were small sample sizes.

TABLE I

LIST OF VARIABLES

N : number of bidders

A : tract acreage

R : *ex post* value of revenues

C : *ex post* value of drilling costs

V : discounted social value, or rent

B : bid

$B1$: winning bid

π : *ex post* gross profits

$\pi - B1$: *ex post* net profits

$B1-B2$: "money left on table"

$B2$: second highest bid, or if there is one bidder, the government reservation price.

summed to yield the estimated discounted value of costs for that tract, also in 1972 dollars, which we denote by C.

Table I lists some of the variables. All monetary variables are denominated in millions of 1972$. We denote bids by B, winning bid by $B1$, and the second highest bid by $B2$. If there is only one bidder, $B2$ equals the announced government reservation price. Our estimate of the *ex post* discounted social value of a tract is $R-C$, which we shall refer to as *rent* and denote by V. Our estimate of the *ex post* discounted gross profit, which is net of royalty payments, but not the bonus bid, is $\pi = (5/6)R - C$. Finally, our measure of *ex post* net profits is $\pi - B1 = (5/6)R - C - B1$.

These measures of *ex post* returns ignore costs associated with presale exploration, bid preparation and other overhead costs, as well as some post-auction costs. As a result, our *ex post* profit and rent figures are best thought of as a residual comprised of omitted costs, together with *ex post* profit or rent. We have tried to control for most variable costs, so that omitted costs should be relatively constant across tracts, particularly within a given sale. We should point out, however, that most of the omitted costs are pre-sale geophysical expenditures, which are sunk when the bidding decisions are made. Hence, they should not affect the bidding behavior of the firms. It is also important to note that our measures of profit and social rent will understate realized profits and rent on productive tracts, since our projections of real prices are significantly lower than realized prices, especially from 1973 through 1985. Recall that our measures of returns are constructed so that their distribution best approximates the actual distribution of *ex post* value, conditional on plausible forecasts of future prices at the auction date (i.e., an approximately constant sequence of real wellhead prices).

Note that these numbers represent before-tax returns. We have not taken into account any of the special tax treatments afforded offshore drilling activity. Finally, these numbers will be biased if we have selected an incorrect discount factor, or if this factor has varied over the sample period. However, the comparison of return figures across tracts and firms is not altered significantly when alternate discount factors are employed.

Table II provides several statistics on some of the more important variables. Note that, except for B/A, the relevant sample is defined as the set of tracts, rather than the set of bids. The latter is a much larger set. For this

TABLE II
SUMMARY STATISTICS OF MAJOR VARIABLES*

Variable	*Mean*	*St. Dev.*	*Minimum*	*Maximum*
(i) Wildcat				
N	3.46	2.81	1	14
π/A	793.7	6323.1	−153 231	59 638
B/A	443.9	874.6	18.98	22 913.6
$B1/A$	607.2	1235.1	21.4	22 913.6
$(B1-B2)/A$	287.9	712.4	0.24	16 348.4
(ii) Drainage				
N	2.73	2.09	1	14
π/A	4863.8	11 740.2	−5036.3	79 854
B/A	1846.1	3310.1	23.96	33 196.1
$B1/A$	2377.2	3853.0	40.94	33 196.1
$(B1-B2)/A$	1254.9	1908.3	0.66	11 976.1

Correlation Coefficients

	N	π/A	$B1/A$
(i) Wildcat			
π/A	0.03		
$B1/A$	0.56	−0.32	
$(B1-B2)/A$	0.31	−0.41	0.87
(ii) Drainage			
π/A	0.20		
$B1/A$	0.31	0.52	
$(B1-B2)/A$	0.06	0.52	0.78

* All dollar figures are in $1972 per acre.

table, we normalize by dividing by the number of acres, to obtain a dollar per unit area figure. This exercise does not alter the coefficient of variation of the bid variable (i.e., the ratio of the standard deviation to the mean in the sample) very much.

The table reveals important differences between wildcat and drainage tracts. Both gross profits and bids were much higher on drainage tracts, and net profits ($(\pi - B1)/A$) higher still. However, the average number of bidders on a tract was lower on drainage tracts. For both wildcat and drainage tracts, money left on the table ($(B1-B2)/A$) is about half the winning bid on average. Note that all of these variables have relatively large standard deviations.

The correlation coefficients show that winning bid, money left on the table and the number of bidders are positively correlated for both wildcat and drainage tracts. While this is also true of gross profits on drainage tracts, it is not true for wildcat tracts. This latter finding is a consequence of the relatively large number of wildcat tracts which are never drilled, as the next table demonstrates.

TABLE III

JOINT DISTRIBUTION OF BID PER ACRE AND GROSS PROFITS PER ACRE*

	π/A					
B/A	*< 0*	*0*	*0–1500*	*1500–5000*	*> 5000*	*Total*
(i) Wildcat						
0–50	351 9.6	232 6.3	88 2.4	64 1.8	48 1.3	783 21.4
50–100	390 10.7	173 4.7	71 1.9	46 1.3	55 1.5	735 20.1
100–200	397 10.9	128 3.5	65 1.8	53 1.5	50 1.4	693 19.0
200–500	328 9.0	87 2.4	71 1.9	50 1.8	66 1.8	602 16.5
> 500	499 13.7	47 1.3	91 2.5	88 2.4	119 3.3	844 23.1
Total	1965 53.8	667 18.2	386 10.6	301 9.2	338 9.2	3657 100.0
(ii) Drainage						
0–200	35 8.9	10 2.5	11 2.8	8 2.0	7 1.8	71 18.1
200–500	30 7.6	7 1.8	9 2.3	14 3.6	21 5.3	81 20.6
500–1000	35 8.9	5 1.3	11 2.8	7 1.8	17 4.3	75 19.1
1000–2000	25 6.4	5 1.3	12 3.1	9 2.3	17 4.3	68 17.3
> 2000	22 5.6	1 0.3	13 3.3	4 1.0	58 14.8	98 24.9
Total	147 37.4	28 7.1	56 14.3	42 10.7	120 30.5	393 100.0

* The number in the upper left corner of each cell is the number of tracts in that category, and the other number expresses this figure as a percentage of all wildcat or drainage tracts. π/A and B/A are expressed as \$1972 per acre.

Table III provides a cross-tabulation of the joint distribution of bid per acre and *ex post* gross profits per acre, for the entire set of bids. We compute two such tables, one for wildcat tracts and one for drainage tracts. The bid per acre categories approximately correspond to quintiles for each type of tract. Again, note that bids are much higher on drainage tracts. Tracts with zero *ex post* gross profits were never drilled. Note that tracts with higher bids

TABLE IV
INDIVIDUAL FIRM RETURNS

Firm	# *Bids*	# *Wins*	# *Tries*	# *Hits*	$\pi - B1$	$\pi - B1/$ # *Wins*	$\pi - B/$ # *Bids*	θ^*	$R(\theta^*)$
1. *Shell*	426	164	105	58	533.3	3.25	5.09	0.85	557.4
2. *SOCAL*	398	125	93	56	195.9	1.57	5.76	0.30	358.4
3. *SONJ*	293	94	66	31	341.1	3.63	2.78	0.90	382.4
4. *Gulf*	142	64	51	31	289.5	4.52	4.64	0.75	373.1
5. *Forest*	142	57	46	29	−9.9	−0.17	3.81	1.10	42.9
6. *Sunoco*	182	54	17	4	−25.2	−0.47	1.61	1.20	76.8
7. *Texaco*	128	44	38	13	−373.9	−8.50	−1.18	0.15	1.6
8. *SOInd*	140	20	13	6	−6.5	−0.32	2.18	1.65	59.8
9. *Tenneco*	117	38	33	23	186.2	4.90	5.97	1.00	186.2
10. *Union*	117	30	20	11	186.3	6.21	6.32	0.60	231.6
11. *Murphy*	99	13	12	4	23.2	1.79	1.99	0.95	23.6
12. *Phillips*	128	33	25	11	−91.0	−2.76	2.56	0.00	0.0
13. *SOCONY-Mobil*	207	74	57	31	94.7	1.28	3.77	1.15	188.5
14. *C/C/A/G**	488	132	91	49	287.3	2.18	3.62	0.45	387.3
15. *La. Land/Hess*	87	22	21	9	9.1	0.41	2.18	0.35	22.6
16. *Texaco/SOInd*	137	43	40	26	72.6	1.69	9.53	1.05	77.3
17. *Misc. Joint*	154	40	31	17	68.0	1.70	0.96	0.25	122.6
18. *Fringe*	665	153	113	63	168.2	1.10	3.24	0.60	275.0
Total	4050	1200	872	472	1951.2	1.63	3.76	na	na

* Continental/Cities/Arco/Getty.

are more likely to be drilled, since the tracts with zero gross profits receive lower bids on average than tracts with negative or positive profits. This result implies that the correlation coefficients for gross profits per acre and the other variables in Table II are somewhat misleading. Also, high value tracts receive higher bids. This indicates that while firms' information is imperfect, it is nevertheless correlated with tract gross profitability.

IV. INDIVIDUAL FIRM RETURNS

In this section we examine the bidding performances of the main participants in the oil lease auctions. We first document the bidding activity and returns of the individual firms. Both are shown to differ widely across firms. We then conduct two experiments to determine whether part of the variation in returns is explained by behavioral differences among firms, and find affirmative evidence. Some firms did not behave optimally, and in at least one case, a firm consistently overestimated the value of tracts.

A large number of firms participated in the OCS auctions. Table IV provides a list of the main participants together with some information summarizing their activity and returns. In constructing this classification of firms, we treated subsidiaries of a parent firm as belonging to the same firm. A "fringe" firm is defined as one which bid on fewer than 99 tracts. The first 12 bidding units were all firms which bid on at least 99 tracts either as a solo bidder or jointly with a fringe firm. The thirteenth bidding unit consists of all bids involving Socony-Mobil, a firm which bid mostly with other "large" firms, and only occasionally by itself or with a fringe firm. In addition, there were three consortia of firms which bid on a large number of tracts. For our current purposes, it is notable that, for almost all sales, the member firms of each consortium rarely bid against one another in sales where the consortium was active. This suggests that we can aggregate the participating firms and treat them as a single unit. Joint ventures among the 16 main bidding units constitutes the residual category.

The gross profit columns of Table IV, $\pi - B1$ and $(\pi - B1)/(\#\text{wins})$, show that there is significant variation in returns across firms, even when one controls for the number of tracts won. However, there is little variation in hit rates (number of productive tracts per number of tracts drilled), or in the ratio of number of tries (i.e. tracts drilled) to number of wins. An exception is Sunoco, whose low returns are attributable both to a low hit rate, and to a low try rate. The low returns of some firms, and the relatively high returns of other firms, are less readily explained, and so we examined each firm's bidding behavior more closely to see whether it was possible to identify the causes.

Our first test examines whether the variation in net profits can be explained by the fact that some firms were better at evaluating tracts and identifying the productive ones. The test consists of computing the average net profits which a firm would have earned, had it won every tract that it bid on at the price that it submitted. If the firm's estimates are unbiased, this figure should be positive. Furthermore, "winner's curse" considerations imply that the number should not be small relative to the value of the bid. The average bid is \$2.26 million. The results of these calculations are reported in the $(\pi - B)/(\#\text{Bids})$ column of Table IV. In almost all instances the average return that the firm would have earned exceeds \$2 million per tract. The exception is Texaco, which would have lost \$1.18 million per tract. Texaco's low returns were not due to poor site selection, since average gross profits were positive for both the set of tracts won and the set of tracts bid on. The problem was that it consistently overestimated the value of tracts, and as a consequence, overbid on most of them.

A comparison of the $(\pi - B)/(\#\text{Bids})$ column and the $(\pi - B1)/(\#\text{Wins})$ column reveals a strong correlation between the return figures in these two columns. This suggests that luck is not the only determinant of the variation in net profits. Differences in the firms' evaluation procedures and/or bidding strategies are also important. It is apparent from these columns that the average value of $(\pi - B)$ for each firm is substantially lower on the set of tracts which it wins than on the set of tracts which it bids on. This fact is consistent with the common values model of auctions, which predicts that the estimates of a firm on the tracts it wins are biased upward. In the independent values model, this result would occur only if firms bid more aggressively when their valuations are high. However, given the magnitude of the differences in returns in Table III, this is an unlikely explanation.

Our second test of the firms' bidding behavior consists of calculating the revenues which a firm would have earned had it rescaled all its bids by a factor of θ, holding constant the bids of all other firms. More formally, for any firm i, let K_i denote the set of tracts on which firm i submitted a bid. We will index these tracts by k, and denote the bid of firm i by b_{ik}. Let $\bar{B}_{ik}$ represent the maximum bid submitted by all other firms on that tract or, if firm i was the only bidder, the stipulated minimum acceptable bid. Now suppose that firm i varies all its bids by a factor θ, holding constant the vector $(\bar{B}_{ik})_{k \in K_i}$ and holding constant the set K_i of tracts bid on. If π_k is the discounted value of *ex post* gross profits on tract k (net of royalty payments, but not the bonus bid), then the expected net return associated with bid variation strategy θ is

$$(2) \qquad R_i(\theta) = \sum_{k \in K_i} (\pi_k - \theta b_{ik}) I_{\{\theta b_{ik} - \bar{B}_{ik}\}}$$

where $I_{\{x\}} = 1$ if $x \geqslant 0$ and $I_{\{x\}} = 0$ if $x < 0$. Thus, I is an indicator function which equals one when firm i wins tract k.

Our experiment consisted of varying the value of θ on the interval $(0, 2)$, employing a step size of 0.05 and holding K_i fixed for each firm. The outcomes of these experiments are reported in the last two columns of Table IV.

They give, for each firm i, the value of θ which maximizes $R_i(\theta)$ and the value of $R_i(\theta)$ evaluated at this point. Note that $R_i(1)$ is just the *ex post* net profit of firm i displayed in the $(\pi - B1)$ column of the Table. Similarly, $R_i(2)$ represents the net profits that firm i would have earned had it doubled all the bids it submitted, holding constant the bids of all other firms. Obviously, firm i would not have known either π_k or $\bar{B}_{ik}$ at the time it submitted its bid. However, by summing over all the tracts in K_i, we can examine broadly the appropriateness of firm i's bidding strategy.

If firms pursue a mark-down strategy, with bids being proportional to their estimates of π_k, as is suggested by anecdotal evidence and by the model of Rothkopf [1969], and if all firms choose their bid factors according to risk-neutral Nash equilibrium behavior, then θ^* should equal one. Since we are examining realizations of net returns, values of θ^* close to one are also acceptable. However, Table IV reveals that the value of θ^* for most firms is significantly less than one, so they would have been better off had they bid less. By significant, we mean that a large increase in net returns was possible with a relatively small decrease in θ. (Compare $R_i(\theta)$ with $\pi - B1$.) This result suggests that some firms may have systematically overvalued the tracts and/or failed to fully anticipate the impact of the "winner's curse".

Another possible explanation for this finding is that firms are risk-averse. In his survey paper, Milgrom [1985, pp. 272–273] points out that in auctions where each firm's valuation is certain and independent of the valuations of other firms, risk averse firms bid more than they would have if they were risk neutral and maximizing net profit. It is not clear, however, that this result extends to oil lease auctions, since the distribution of income which a firm faces in making a bid does not have all of its mass concentrated at two values (that is, 0 if it loses, and $\pi_i - B_i > 0$ if it wins, where π_i denotes firm i's valuation). Uncertainty about the value of the tract, and in particular, the fact that this value is negative on at least 60 per cent of the wildcat tracts, may cause a risk-averse firm to bid more cautiously than a risk-neutral firm in oil lease auctions.

In any event, there is little evidence of collusion in bidding, which presumably would entail some firms jointly reducing their bids, and so imply gains to unilaterally increasing one's bid (that is, θ^* would be greater than one). Collusion is not a likely explanation for the low returns of firms with θ^* greater than one, since they lost money. Of course, it is possible that some firms colluded through a bid rotation mechanism or joint venture activity on some tracts.

In conducting the two experiments, it was apparent that the number of wins was frequently not large enough to eliminate all of the idiosyncratic noise in the relationship between a firm's bids and profits. For example, there were a few instances in which the optimal value of θ^* was somewhat sensitive to the outcomes on one or two tracts. The presence of randomness reinforces the suspicion that some firms, such as Forest, may have done poorly because they were unlucky. Forest appears to have pursued a relatively good bidding strategy. Its average value of $(\pi - B)$ was higher than over half of the other firms, and its bid factor was only slightly below its optimal value. Nevertheless, its net profits per tract were among the lowest, which suggests that it may have been in the wrong place at the wrong time. Some firms, such as Texaco and Phillips, appear to have pursued inappropriate bidding strategies. For these firms, there are essentially no values of θ which would have resulted in positive net profits.

A final caveat is in order. Our comparisons of returns across firms, as well as our calculations of optimal bidding factors, necessarily rely on the assumption that the *ex post* gross profit of a tract is independent of the identity of the firm which wins the tract. Thus, we are implicitly assuming that firms have identical or similar cost functions. Since the hit rate and the ratio of tries to tracts won is relatively constant across firms, this assumption may be acceptable. In any case, it is unlikely that all the observable differences in returns and bidding can be attributed either to heterogeneity in costs, or to luck.

V. INFORMATION AND THE BIDDING DECISION

In this section we examine several hypotheses about the joint distribution of valuations and gross profits on wildcat tracts by analyzing the joint distribution of bids and gross profits. The statistical evidence indicates that there is significant variation in the joint distribution of values and gross profits across geographical areas and across sale dates, but not across firms. We suggest that the differences in these distributions across areas and sale dates are mostly due to the differences in the drilling histories of the areas. This result is crucial for estimating bidding strategies, since it means that the econometrician can use the history of an area to obtain information about the firms' unobserved prior valuations, and hence about whether and how much they will bid.

We also suggest that differences in the distributions of bids across firms are caused primarily by differences in the firms' participation rates across areas and sales, and not by differences in their bidding strategies. Furthermore, the factors which account for most of the variation in participation rates are not area- or sale-specific, but are common to all of the firms' bidding decisions. Thus, factors such as the quality of the firm's geologists or its budget constraints are likely to be more important than factors such as area-specific components of the firms' private information about tracts in a sale.

We first examine whether the underlying distributions of gross profits per acre on wildcat tracts varies across sales and areas. We restrict our attention to wildcat tracts, where the quality of the firms' information is similar. The tracts in our data are drawn from 26 separate geographical areas off the coast of Louisiana, and 7 areas off the coast of Texas. Since the tracts from many of these areas are, for practical purposes, within the same region, we have reduced this classification to 14 categories, 10 off Louisiana and 4 off Texas. We also grouped three early sales and aggregated the 1962 sales, leaving 5 sale dates. We first regressed gross profit per acre on a set of sale and area dummies. The F-statistic for this regression was 2.57 with (17, 1039) degrees of freedom, which establishes that area and sale effects are jointly significant at the one per cent level. (The R^2 of this regression was 0.038.) We then alternately set each set of coefficients equal to zero to test whether that set has significant explanatory power. The F-statistics were 4.74 for the sale dummies and 2.28 for the area dummies with (4, 1039) and (12, 1039) degrees of freedom, respectively. These statistics are significant at the one per cent level. Of course, these results may simply reflect differences in the selection rules determining which tracts are to be auctioned in each area. In any event, it is apparent that there are some differences between areas and sales in the set of tracts auctioned.

We then ask whether the distribution of bids on wildcat tracts possesses a firm-, area-, and sale-specific component. Since bid per acre is approximately lognormally distributed, we regressed the logarithm of this variable, using the entire sample of wildcat bids, on the set of firm-, area-, and sale-specific dummies. (The R^2 is 0.18 for this regression.) We then alternately set each set of coefficients equal to zero in order to test whether that set has significant explanatory power. The F-statistics were 14.3 for the firm dummies, 13.4 for thd area dummies, and 63.0 for the sale dummies, with (17, 3623), (12, 3623), and (4, 3623) degrees of freedom, respectively. These results provide evidence in support of firm, area, and sale effects on the distribution of bids.

The significance of area and sale effects on bids can be explained in part by the differences in the average gross profits across areas and sales. However, this cannot be the entire story since both of these factors appear to be more important for bids than for gross profits. The probable cause is the importance of area- and sale-specific information that is publicly available at the time of the sale. To test this implication we regressed gross profit per acre minus bid per acre ($(\pi - B)/A$) on firm-, area-, and sale-specific dummies. In this way, we attempted to control for any differences in the underlying distribution of gross profits across areas and sales. We find that the sale and area effects remain highly significant, lending support to the hypothesis that firms share common area- and sale-specific information that is imperfectly correlated with *ex post* gross profits. The F-statistics measuring the marginal contributions of these two sets of dummies were 27 and 15.5, with (4, 3623) and (12, 3623) degrees of freedom respectively.

Somewhat surprisingly, the firm effects in these regressions were not significant. The F-statistic for the firm dummies was 0.74, with (17, 3623) degrees of freedom. From the evidence in Table IV, which we discussed in the previous section, we know that average net returns do vary significantly across firms. Apparently, area and sale effects can account for most of this variation. This suggests that there must be significant interfirm differences in participation rates across areas and sales.

To pursue this point somewhat further, we regressed the logarithm of bid per acre on the firm dummies for each (area, sale) pair separately and compared the sum of the *SSE* of these regressions to the *SSE* of the regression for all areas and sales together. This comparison tests whether there is significant variation in bids by individual firms across (area, sale) pairs. The F-statistic for this test was 2.73, with (334, 3455) degrees of freedom, which is marginally significant at the one per cent level of significance. This is only weak evidence of between (area, sale) variation in firm-specific bids. Thus, the variation in bids across firms is greater than the variation of individual firm bids across areas or sales. The interpretation of this finding is that the firm-specific factors which are common to all of a firm's bidding decisions (e.g. the quality of its geologists) are much more important in explaining differences between the firms' bids than the firm-specific factors which vary across (area, sale) pairs (e.g. the private information which a firm possesses about an area in a sale).

In summary, the statistical evidence presented in this section suggests that, as a first approximation, one can make the following distributional assumptions in developing a model of bidding for oil leases on wildcat tracts in OCS auctions: (1) that the joint distribution of valuations and tract values differs across areas and sales, but not across firms; (2) that the information which firms share about the different areas prior to obtaining private seismic reports appears to have a significant impact on their valuations; (3) that the private reports of firms are individually informative, but provide quite noisy estimates of the value of tracts. The substantive differences between firms lies in their criteria for selecting which tracts to explore and bid on. Our future research on bidding functions will attempt to identify these differences and the significant area- and sale-specific factors, and to determine whether they remain significant when one appropriately accounts for other factors (i.e. the number of bidders) that are likely to affect firms' bids.

VI. INFORMATION AND THE DRILLING DECISION

This section provides some evidence on drilling decisions and the impact of local information externalities on these decisions. We establish that firms adopt sequential drilling programs in which the tracts that are believed to be of higher value are drilled first. Overall 27 per cent of the leases were allowed to expire without any wells being drilled. We also provide some evidence that firms which have won only a few tracts in an area delay drilling their tracts until after the firms which have won more tracts in that area have drilled some of their tracts.

Table V provides a decomposition of tracts according to the number of years after the date of acquisition that the first well is drilled. Year 0

TABLE V

DECOMPOSITION OF TRACTS BY LEASE YEAR IN WHICH FIRST WELL IS DRILLED

	Number of Years After Acquisition That First Well Is Drilled							
	0	*1*	*2*	*3*	*4*	*5*	*Never*	*Total*
(i) Wildcat								
No. of Tracts	234	138	93	109	116	58	308	1056
No. of Hits	122	71	51	54	53	34	0	385
Average B1	6.56	3.21	2.23	1.67	1.07	1.42	0.80	2.67
Average B1 − B2	2.93	1.54	1.25	0.86	0.53	0.80	0.34	1.31
Average $\pi - B1$	2.18	1.58	1.37	4.05	1.27	1.50	−0.80	1.22
Average V	11.75	6.66	4.95	7.65	3.31	3.77	0	5.27

	0	*1–5*	*Never*	*Total*
(ii) Drainage				
No. of Tracts	90	34	20	144
No. of Hits	68	18	0	86
Average B1	8.13	2.13	1.27	5.76
Average B1–B2	3.88	1.25	0.99	2.86
Average $\pi - B1$	7.46	0.60	−1.27	4.63
Average V	20.22	3.71	0	13.51

represents the 12 month period immediately following the *month* in which the tract was purchased, Year 1 represents the next 12 month period, and so on. The Year 5 column is comprised mainly of tracts which received their first well in the sixth or seventh year of the lease, but where exploration presumably began previously. This column also includes about 10 productive tracts which were never drilled, and about 5 tracts in which production began prior to recorded drilling. In both cases, some production may have resulted from drilling in adjacent tracts, so these tracts are not necessarily misclassified. As a result, the Year 5 column is best viewed as a residual category for the tracts that were drilled.

Table V reveals several interesting facts. First, the firms clearly use sequential drilling programs. These programs have the property that 29 per cent of the wildcat tracts and 14 per cent of the drainage tracts are never drilled. This suggests that firms acquire post sale information about tracts which causes them to choose not to drill certain tracts. Furthermore, the likelihood of acquiring such information is higher on wildcat tracts than on drainage tracts. Second, the average winning bid of a tract is a decreasing function of the time until the first well is drilled. This indicates that tracts which are expected to be more valuable, as reflected by the firms' bids, are drilled before the lower value tracts. Third, with the exception of drainage tracts that are drilled immediately, the hit rate is independent of when the tract is drilled and of whether it is a drainage or a wildcat tract, and it is slightly above 50 per cent. This invariance with respect to the date of drilling may be attributed either to the acquisition of information from prior drilling that offsets the decline in the average quality of the tracts, or to the fact that geologists are better at predicting the amount of oil on a tract, conditional on the tract containing an oil deposit, than at predicting whether a tract contains an oil deposit. However, evidence presented in a later table suggests that the latter explanation is not correct.

Two other facts are worth noting. In all categories the ratio of "money left on the table" to the winning bid is about 50 per cent. Also, net profit on drainage tracts drilled in Year 0 is a great deal higher than on any other tracts, as is the percentage of social rents which accrue to the winning firm (that is, $(\pi - B1)/V$). In our sample, social rents on the 1056 wildcat tracts totalled \$5.57 billion (in 1972\$), and the firms' share was \$1.28 billion. Thus, the winning firms on wildcat tracts captured an average of 23 per cent of total social rents. This figure is similar to Smiley's [1979] estimates for some sales in the 1970s, which were computed by a different method. On the 144 drainage tracts, social rents totalled \$1.95 billion, and the firms' share was \$0.67 billion, or 34 per cent. This higher share accrues primarily to firms which drill immediately, and, as we shall see in the next section, it is a rent which is captured by firms which own leases on adjacent tracts.

It is important to recall that these numbers are biased for two reasons. First, as mentioned previously, some costs are omitted, which will bias the firm share upward. However, these costs should be relatively constant across tracts, so that comparisons of shares is a valid exercise. Second, we are using a predicted price sequence which is much lower than actual prices. This will bias these share numbers downward. This is especially important for the later sales in our sample. Since these tended to be drainage sales, we have probably understated the difference in realized firm shares between wildcat and drainage sales.

The presence of information externalities implies that firms have an incentive to delay drilling their tracts in order to free ride on the information generated by the drilling outcomes of other firms. To examine this implication, we compared the drilling programs of firms which had won different numbers of tracts in an (area, sale) pair. The hypothesis being tested is that the probability that a particular tract is drilled in year v of the lease depends on the number of tracts which its leaseowner won in that area. The reasoning is as follows. If the drilling decisions of firms are independent of the information generated by the exploration activity of other firms, then a firm which won only one or two tracts in an area should drill these tracts immediately. It gains nothing by waiting, and to delay is costly. Firms which won many tracts, however, may choose to delay drilling a particular tract until after it obtains information from the drilling outcomes of other tracts in its portfolio.

We compute the frequency of tracts drilled in year v for each firm with a portfolio of m tracts in a particular (area, sale) pair. Aggregating over (area, sale) pairs, let $n_{v,m}$ denote the total number of tracts that were drilled in

TABLE VI

COMPARISON OF DRILLING PROGRAMS OF FIRMS WITH DIFFERENT TRACT HOLDINGS IN AN (AREA, SALE) PAIR*

	Number of Years After Acquisition That First Well Is Drilled								
m	*0*	*1*	*2*	*3*	*4*	*5*	*Never*	*No. of Tracts*	*Av. Rent*
1	0.25	0.21	0.08	0.07	0.16	0.05	0.18	76	5.83
2	0.27	0.13	0.13	0.09	0.12	0.06	0.21	120	9.51
3	0.21	0.15	0.16	0.15	0.14	0.01	0.17	66	6.64
4	0.18	0.17	0.09	0.14	0.09	0.03	0.30	88	5.55
5	0.24	0.15	0.04	0.12	0.19	0.12	0.15	75	5.92
6–9	0.20	0.14	0.14	0.14	0.14	0.07	0.18	199	6.07
$\geqslant 10$	0.24	0.12	0.09	0.12	0.16	0.05	0.26	218	7.54

* The number of tracts won by a leaseowner in a particular (area, sale) pair is denoted by *m*. The entries of the table are, for each value of *m*, the fraction of the leaseowner's tracts in that area drilled each year after the sale date. Thus the first 6 columns of each row sum to one, modulo rounding errors.

lease year v and whose leaseowners had won m tracts in an (area, sale) pair. Let $n_m = \sum_{v=0}^{6} n_{m,v}$ denote the total number of tracts whose leaseowners won m tracts in the (area, sale) pair that the tract is sold. Here v equals six for tracts which are never drilled. The frequency ratio is then given by $(n_{v,m}/n_m)$. Table VI reports these ratios for lease years $v = 0$ through 5 and the category "never drilled", and for area portfolio sizes $m = 1, \ldots, 5, 6$–9, and greater than 9.

The striking feature of this table is that the probability that a particular tract is drilled in year v does not depend on the value of m. In the case of solo winners, for example, only 40 per cent of the tracts were drilled in the first two years of the lease. Over half of these tracts were either drilled in the later years of the lease or not drilled at all. A similar story holds for values of m greater than one. Thus, firms frequently delay their drilling decisions on tracts, even when no new information may be forthcoming from its own drilling activity. Furthermore, as the last column shows, the values of the tracts were similar across categories. This suggests that the reason why firms may be waiting is because they intend to free ride on the information generated by the drilling outcomes of other firms. In particular, the firms which possess a relatively large portfolio of tracts cannot afford to wait too long to begin drilling their tracts, or they will run into the five year lease tenure constraint. Firms with smaller holdings can exploit the information generated by this drilling activity. We therefore conclude that firms appear to behave strategically in deciding when to drill marginal tracts.

There are two important implications which follow from these results. First, it means that a firm's evaluation of a tract depends in part on the potential of neighboring tracts, and the probability that the firm will win these tracts. Winning tracts which are dispersed within an area is not as valuable as winning the same number of tracts when they are adjacent to each other. It is worth noting that the optimal bidding strategies for these kinds of auctions have not been studied in detail. Second, the government must be concerned with exploration incentives when designing an auction, since there is a strong possibility that a tract may not be drilled. For example, in auctions where the bidding variable is the royalty rate rather than the bonus payment, the number of wells drilled is likely to be smaller, since the expected marginal revenue to a firm from drilling a well is lower when it has to share more of the revenues with the government.

VII. INFORMATION, COMPETITION, AND RETURNS

In this section we examine the effects of competition on bids and profits. A complete analysis of this relationship requires the estimation of bidding strategies, which is the subject of a subsequent paper. Nevertheless, a number of theoretical predictions about bidding behavior and the pattern of returns can be tested by simply examining variable means conditional on the number of bidders. In particular, we find that the differences between the returns on drainage leases and those on wildcat leases can be explained in terms of asymmetries in the quality of information among bidders on drainage tracts. We identify which bidders possess better information on drainage leases, and contrast their behavior and returns with those of relatively uninformed bidders.

Only a fraction of the set of potential bidders typically choose to submit bids in any auction. In some instances, the absence of a bid from a firm is the result of that firm's decision not to be active in the auction, but in other instances it is because the firm's valuation of the tract following its seismic survey would lead it to bid below the reservation price. Consequently, the number of bidders is likely to be a crude measure of both the quality of the tract and the level of competition.

Table VII decomposes wildcat and drainage tracts according to the number of bidders. Both the percentage of tracts that are drilled and the value of the social rent are increasing functions of the number of bidders, with both sequences being significantly higher on drainage tracts than on wildcat tracts. Evidently, firms are more likely to bid on high value tracts, and are more likely to drill these tracts. This follows from Table V, which shows that high value tracts are on average drilled before low value tracts. This confirms our hypothesis that the number of bidders is positively correlated with the value of a tract.

Somewhat surprisingly, the hit rate on wildcat tracts is virtually constant at 50 per cent. This is also true of drainage tracts with one or two bidders, although the hit rate increases to 80 per cent when there are 3 or more bidders. Since the number of bidders is correlated with tract value, this

TABLE VII
DECOMPOSITION OF TRACTS BY NUMBER OF BIDDERS

	Number of Bidders					
	1	*2*	*3*	*4*	*5–6*	*≥ 7*
A. Wildcat						
No. of Tracts	339	213	106	103	126	169
No. of Tries	183	135	81	83	109	156
No. of Hits	86	75	39	42	51	92
Average B1	0.49	1.03	1.70	2.35	3.47	9.32
Average B1 − B2	0.40	0.72	1.11	1.46	1.63	3.32
Average $\pi - B1$	1.64	1.68	0.87	3.95	2.55	−2.66
Average V	2.87	3.64	3.65	8.37	8.04	9.21
Average $V\|Hit$	12.20	11.09	11.21	22.05	21.50	18.34
	1	*2*	*3*	*4*	*≥ 5*	
B. Drainage						
No. of Tracts	49	32	24	21	18	
No. of Tries	33	29	24	21	17	
No. of Hits	22	13	20	18	14	
Average B1	2.01	3.08	8.03	10.07	12.69	
Average B1 − B2	1.94	2.25	4.43	3.52	3.57	
Average $\pi - B1$	3.50	1.74	4.08	8.60	8.93	
Average V	7.08	6.27	16.01	24.07	28.24	
Average $V\|Hit$	16.14	16.69	19.43	21.87	36.64	

implies that firms which win tracts with a small number of bidders delay their drilling decision until after the drilling outcomes on the high value tracts are known. As a result, the try rate on lower value tracts is lower, thereby offsetting the decline in the quality of the tracts and leading to a hit rate which is more or less constant. Notice, however, that the expected value of social rent conditional on a hit is not constant (Average $V|Hit$). For both wildcat and drainage tracts, it is almost twice as high on tracts with many bidders as on tracts with one or two bidders. This indicates that the geological data which firms acquire on a tract yields information about both the probability of a hit and the size of the deposit conditional on a hit.

Both winning bid and money left on the table are increasing functions of the number of bidders.[3] However, the ratio of money left on the table to the winning bid is a rapidly decreasing function. On wildcat tracts, it falls from 0.81 when N equals one to 0.36 when N exceeds six. On drainage tracts, it falls

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[3] For tracts with one bid, money left on the table is the difference between that bid and the stipulated minimum bid. On drainage sales with no minimum bid, we continued to use as a lower bound $25 per acre, the minimum bid on the other drainage sales. Our justification is that firms probably expected the government would reject any bid that was below $25 per acre. In any case, no bids in these drainage sales were less than this figure.

from 0.96 when N is one to 0.28 when N exceeds four. This is consistent with the model of Wilson [1975], in which this ratio falls monotonically to zero as the number of bidders increases. (In that model, firms know the number of actual bidders.) By this measure, auctions with more bidders are more competitive, for both wildcat and drainage tracts.

Net profits on wildcat tracts are (roughly) a decreasing function of the number of bidders, and more so when expressed as a fraction of social rents. Indeed, when there are seven or more bidders, net profits are *negative*, even though the tracts themselves are quite valuable. For these results to be consistent with the Wilson model, one would have to assume that our measure underestimates net profits and that the number of *active* firms is positively correlated with the number of bidders. However, if the latter condition is true, one would have to explain why competition varies across tracts. Arbitrage would seem to imply that the number of active firms should be constant across tracts, for otherwise the *ex ante* expected profits from bidding on different tracts are not equalized.

A more plausible explanation for this result centers on firm uncertainty about the number of firms which are active on a given tract. Recall that a firm is denoted as active on a tract if it conducts or purchases a seismic survey on that tract prior to the sale. Now suppose that a firm's decisions to survey tracts are private. Then, in calculating the expected value of a tract conditional on its own information and on winning the tract, a prospective bidder needs to distinguish between the valuations of inactive and active firms, since the latter are more informative. But if the number of active firms is random and unobservable, then each firm's estimate of the magnitude of the "winner's curse" is biased downward on tracts where there are relatively many active firms, and is biased upward on tracts where there are relatively few active firms. In that case, one would expect profits to decline as the actual number of bidders increases, and it would be increasingly likely that average profits are negative when the number of bidders is very large.

Another explanation is, of course, that firms did not adequately account for the "winner's curse" in their bidding strategies. The analysis of section IV suggests that this may be true of a subset of the major participants. Yet another possible explanation is that firms collude via some type of bid rotation mechanism, and on tracts with fewer bidders earn higher profits. However, it is not obvious why they should choose to collude on less valuable tracts. Nor can these results be explained by lack of experience. When we classified tracts by sale, net profits in the later sales were significantly lower for tracts with many bidders, relative to tracts with few bidders.[4]

The problem in trying to test these explanations is that one needs to

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[4] It is worth noting that gross profits were generally lower in the later wildcat sales. Consequently, it may be the case that firms bid relatively conservatively in earlier sales, saw that their net returns were high, and then bid too aggressively in the sales of the late 1960s. It would be interesting to see whether this trend persisted or reversed itself in the sales of the 1970s.

compute variable means conditional on the number of active firms rather than the number of bidders. The latter is an endogenous variable, as is clear from the fact that the number of bidders increases with tract value. Hence, more sophisticated econometrics is required to discriminate between the different behavioral hypotheses. This is the subject of our next paper.

In contrast, net profit on drainage tracts increases with the number of bidders. The obvious explanation for this finding, as well as other differences in the pattern of returns between wildcat and drainage leases, is the presence of asymmetric information on drainage tracts. Firms which own adjacent tracts are better informed, in the sense of more precise priors, than other firms. Theory (see Milgrom and Weber [1982b]) then predicts that uninformed firms should bid more cautiously, lest they be afflicted with the winner's curse, and informed firms should shade down their bids accordingly, thereby earning an information premium. Indeed, Milgrom and Weber show that this premium does not vanish in the limit, but that an informed bidder will earn positive profits even as the number of uninformed bidders increases without bound.

To verify the asymmetric information story, we partitioned drainage tracts according to whether the winning bid was submitted by an informed firm or an uninformed firm. A bidder is designated as informed if it won the lease on an adjacent *federal* tract in a previous auction. The largest possible number of informed bidders is eight, since each tract has at most eight neighbors. In many cases, this number was smaller because some of the tracts adjacent to a drainage tract were on state lands, for which we had no information. When this is the case, we may have misidentified some informed bids as uninformed. These would be bids that were submitted by a firm which had won one of the adjacent state leases and no adjacent federal lease. In addition, we classified bids by fringe firms as uninformed. In what follows, therefore, we may be understating the true differences between the returns to informed and uninformed firms.

Twenty-eight leases had to be dropped from the sample, since they possessed no informed firms by our definition. All but two of these leases were on the boundary of state leases. Of the 116 remaining leases for which we were able to identify at least one informed firm, 26 received no bids by informed firms, 76 received one informed bid, 13 received two informed bids, and only one lease received more than two informed bids. Of the 90 leases with at least one informed bid, 61 were won by an informed bidder. This is a remarkably high figure, given the likelihood that our list of informed firms on many of these tracts is incomplete. Nevertheless, informed bidders won 61 of these 116 drainage leases. This is consistent with the theory of auctions with asymmetric information, which would predict that the relatively uninformed bidders should win half of the tracts. This conclusion is valid for any specification of the underlying distributions. (See, for example, Milgrom and Weber [1982b].)

TABLE VIII
INFORMED VS UNINFORMED BIDDING ON DRAINAGE TRACTS
DECOMPOSITION BY NUMBER OF BIDDERS

	Number of Bidders			
	1	*2*	$\geqslant 3$	*Total*
A. Informed Winner				
No. of Tracts	31	10	14	55
No. of Tries	19	10	14	43
No. of Hits	13	7	13	33
Average B1	2.41	3.91	16.87	6.36
Average B1 − B2	2.34	2.62	5.88	3.29
Average $\pi - B1$	5.32	8.88	11.41	7.52
Average V	9.72	16.20	36.98	17.84
B. Uninformed Winner				
No. of Tracts	12	17	32	61
No. of Tries	11	15	31	57
No. of Hits	8	3	24	35
Average B1	1.34	2.43	7.78	5.02
Average B1 − B2	1.25	2.11	2.62	2.21
Average $\pi - B1$	−1.98	−3.15	3.23	0.43
Average V	−0.27	−0.58	14.57	7.43

Table VIII separately considers drainage tracts won by informed bidders and uninformed bidders, and provides for each set of tracts a decomposition of returns by number of bidders. The results are clearly in accord with the predictions of the theoretical models of asymmetrically informed bidders. Both social rents and net profits are much higher on tracts won by an informed bidder. For both variables, the amounts increase with the number of bidders. (To avoid small sample problems, we restrict our attention to only 3 categories for the number of bidders.) Uninformed bidders which won on tracts receiving one or two bids obviously suffered from an acute attack of the winner's curse. Notice, however, that average net profits on all drainage tracts won by uninformed firms are zero. Thus, the uninformed firms won profitable tracts often enough to keep them interested in participating in the drainage auctions. These results on returns are consistent with those of Mead *et al.* [1984], who calculated internal rates of returns for informed and uninformed bidders on OCS drainage sales from 1959 to 1969.

The basic message of this table seems to be that it pays to be better informed.[5] On tracts won by informed firms, 42 per cent of social rents accrue as profits to the firms. This is in contrast to 6 per cent on drainage tracts won

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[5] Notice that, while it is true that economies of scale in production is consistent with some of these findings (e.g. the fact that neighboring firms are more likely to win drainage tracts when they bid), it does not explain why average net profits to the non-neighboring firms are zero.

by uninformed firms, and 23 per cent on wildcat tracts. Note that this implies that we may be understating the true return on wildcat tracts, since firms may earn large profits on the subsequent sale of adjacent tracts. As a practical matter, this is unlikely to be important, since the number of wildcat tracts that turn out to be adjacent to tracts that are later auctioned off as drainage tracts is quite small. Furthermore, it is clear that the number of bidders is not a very good measure of competitiveness on drainage leases, since it is usually not a good proxy for the number of informed bidders. One task which we will pursue in future research is a detailed investigation of the bidding behavior of informed versus uninformed bidders on drainage tracts.

An important question prompted by the findings on differential returns to informed and uninformed firms is the extent to which joint venture activity on drainage leases represent collusion, or at least information sharing, by informed firms. To study this question, we decomposed the joint venture bids on drainage tracts according to the information status of the member firms. Of the forty-nine joint venture bids submitted, twenty-four were by joint ventures whose member firms were not informed. Of the remaining twenty-five informed bids, four were submitted by joint ventures with one informed member, and twelve were submitted by joint ventures which had won an adjacent tract in a previous sale. Thus, there were only 9 instances of winning firms of adjacent tracts forming a joint venture on drainage tracts. Since there were 75 tracts on which such an event could have taken place, this does not provide strong evidence for collusive joint venture activity. Of course, we may be understating the actual number of informed firms, as we noted previously.

The results of this section suggest that the government ought to adopt a different auction mechanism for drainage sales. Since the probability of drilling a drainage tract is close to unity, the government does not need to worry as much about the moral hazard problem. The optimal auction literature (see, for example, Riley and Samuelson [1981] and McAfee and McMillan [1986]) suggests that a higher royalty rate is warranted for drainage sales.

VIII. CONCLUDING REMARKS

The statistical analysis of the preceding sections provides considerable support for the common values model as a description of the bidding behavior of firms in OCS oil and gas auctions. We find that the data are consistent with both the assumptions and predictions of the model, or at least some variant of it. One extension of the theoretical model which needs to be investigated is to allow for interdependencies in the valuations of tracts due to economies of scale in exploration.

In many respects, however, our analysis is only suggestive, and not definitive. A detailed econometric analysis of the bidding behavior of participant firms is clearly needed to provide more precise answers to some of the questions posed in this paper. This is the subject of some of our related research projects, where we estimate auction participation decisions, bidding strategies, the determinants and effects of joint venture formation, and post-auction drilling decisions. This econometric work is intended to determine whether the statistical regularities documented in this paper are indeed consistent with existing theoretical models, or whether they can be otherwise explained.

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