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Risk Aversion and Bidding Behavior for Offshore Petroleum Leases

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Summary

This paper examines economic determinants of bidding behavior in offshore petroleum lease sales. Multiple regression analysis is used to measure the explanatory influence of various firm-specific and tract-specific characteristics that enter the bidding decision. The principal finding is that most bidders display significant aversion to risk. An additional finding is that the magnitude of tendered bids is directly related to the number of competitors in the market. The hypothesis that firms which are relatively short of petroleum reserves bid more aggressively is not supported by the data.

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RISK AVERSION AND BIDDING BEHAVIOR FOR OFFSHORE PETROLEUM LEASES

1. Introduction

The present paper examines economic determinants of bidding behavior in petroleum lease sales on the United States Outer Continental Shelf (OCS). Factors which presumably condition the magnitude of a firm's bid include: the expected economic value of the potential resource; the degree of uncertainty which surrounds this value; the anticipated degree of competition to acquire the tract in question; and the firm's capacity to bear significant financial risks. We show below that systematic differences in these factors do significantly account for observed fluctuations in the magnitude of tendered bids.

Economic factors that impact bidding behavior are of considerable interest to auction participants and to the federal government, which administers the auction procedure. The interest of participants stems from their desire to formulate successful bidding strategies appropriate to their individual circumstances. The government's interest derives from the legal responsibility to design an auction procedure and adopt policies that elicit "fair" bids from the participants. Many of the leasing policy alternatives that we presently face (e.g., royalty bidding, profit-share bidding, and bonus bidding with sliding-scale royalties) can be expected to affect significantly the underlying factors (i.e., prospective risks and resource values, and the degree of competition) that influence bidding behavior. An informed choice between current policy options requires some empirical knowledge of the impact which these factors exert on the strategic bidding behavior of firms.

2. Theoretical Ambiguities

Theoretical research has helped to clarify the influence which various economic factors exert on the bidding behavior of profit-maximizing firms. A summary of results is provided in the recent survey article by Englebrecht-Wiggans. However, theoretical formulations leave several ambiguities that cannot be resolved without empirical analysis of the particular market in question.

For example, it is well known that an increase in the number of bidders for an item of certain value will cause all bidders to raise their bids. Unfortunately, very few auctions offer the chance to bid for an item whose value is known, so this simple and intuitive result rarely applies. In the presence of uncertainty, the choice of a competitive bidding strategy is complicated by the phenomenon of "winner's curse"; i.e., the possibility that any particular firm will outbid its competitors as a result of having over-valued the item in question. To avoid this outcome each firm will adopt a less aggressive bidding strategy than is indicated by the certainty model. As Smith has shown, pronounced uncertainty may even cause the firm to reduce its bid as the number of competitors increases. Capen, Clapp, and Campbell have previously advocated the use of such "non-aggressive" strategies in the context of OCS lease sales, but the prevalence of this behavior has not been determined.

We are also relatively ignorant of the effect of risk aversion in OCS lease sales. The nature of petroleum exploration imposes significant risks on auction participants. The traditional hypothesis of decreasing absolute risk aversion states that the premium required to induce a firm to accept such risks is inversely related to the size of firm in question. This implies, ceterus paribus, that larger firms would tender larger bids than their smaller counterparts. The applicability of the hypothesis of decreasing risk aversion is supported by Ramsey's and Millsaps and Ott's observation that bankruptcy risks are systematically related to the size of OCS participants. However, to the extent that nearly all participants are large, widely-held concerns, the risk of bankruptcy may be small in absolute terms. Consequently, it is not clear whether we should expect to observe systematic bidding differentials among firms of varied size.

The theory of risk aversion also suggests that bids are discounted in proportion to the perceived financial risk attending respective tracts. The most risky tracts would then be expected, ceterus paribus, to receive relatively low bids. However, Tourihno's recent extension of option pricing theory, in conjunction with the hypothesis of risk neutrality, establishes that if an effective futures market exists for petroleum reserves (including the option to sell short), then a higher variance in prospective value will increase the expected price at which the option (i.e., resource development) is exercised; thus leading to a higher bid for the riskier tract.

In the remainder of this paper, we explore the empirical validity of these and related hypotheses regarding OCS bidding behavior.

3. The Empirical Method

Multiple regression analysis is used to measure the explanatory influence and statistical significance of various factors that account for observed fluctuations in OCS bids, both among firms and among tracts. The estimated equations consist of linear and log-linear relationships between the amount of each firm's bid and a set of firm-specific and tract-specific variables. The basic model includes three factors which are thought to be of fundamental importance: (1) a prospective estimate of tract value; (2) the size of the bidding firm; and (3) the number of bidders competing for the tract. The simplest equation is of the form:

(1) $$\ln(Bid_{ij}) = a + b_1 \cdot \ln(NW_i) + b_2 \cdot \ln(N_j) + b_3 \cdot \ln(V_j) + e_{ij};$$

where Bid_{ij} = bid of the i^{th} firm on the j^{th} tract,

NW_i = net worth of the i^{th} firm,

N_j = number of bids on the j^{th} tract,

V_j = expected value of the j^{th} tract,

e_{ij} = a normally distributed random disturbance.

Subsequently, additional variables are added whose relevance to the bidding decision is more speculative. These variables include: (1) the degree of the firm's self-sufficiency in crude oil production; (2) the degree of the firm's self-sufficiency in petroleum refining; and (3) two measures of tract-specific financial risks.

The implications of Equation 1 are straightforward where solo bids are concerned. However, where a single bid is tendered collectively by members of a bidding consortium (a joint bid), there is some question regarding how the equation should be interpreted. In fact, it is possible to treat joint bids in the analysis, and the method for doing so opens several interesting lines of inquiry.

We apply a method of decomposition to split each joint bid into "imputed" solo bids which describe the financial stake and potential reward of each consortium member. Let the equity share of the k^{th} member be represented by the symbol δ_k (e.g., 35%). For that member it is as if a solo bid were tendered in the amount of $Bid^*_{ijk} = \delta_k \cdot Bid_{ij}$ on a tract whose prospective value is $V^*_{jk} = \delta_k \cdot V_j$. We assume the consortium formulates a joint bid that imputes individual bids consistent with the bidding preferences of each member (cf. Equation 1):

$$(2) \qquad \ln(Bid^*_{ijk}) = a + b_1 \cdot \ln(NW_k) + b_2 \cdot \ln(N_j) + b_3 \cdot \ln(V^*_{jk}) + e_{ijk}.$$

If this were not true, the consortium would have saddled some member with an effective bid that is inconsistent with its conception of appropriate behavior, and we would not expect that firm to remain a member of the consortium. Indeed it is common to see individual consortium members selectively withdraw from bidding on particular tracts.

Our method of joint bid decomposition does not imply that the magnitude of an OCS bid is independent of whether the bid is tendered jointly. If $b_3 < 1$, the resulting concavity of Equation 2 implies that the joint bid of the consortium exceeds the amount that individual members would tender if bidding alone. Thus, the "diversification effect" of joint bidding is represented implicitly in Equation 2.

To assess the validity of the bid decomposition procedure, we separate all bids into two groups -- solo versus imputed joint bids -- from which Equations 1 and 2 are estimated separately.

4. The Data

The primary source of tract-specific data is the U.S. Geological Survey (USGS), which prepares pre-sale evaluations of all offered tracts. Since 1973 the method of pre-sale evaluation has been linked to a Monte Carlo simulation model of offshore exploration and reservoir development. The simulation model is designed to calculate the expected net present value of each tract, while incorporating explicit probability judgments regarding the volume and value of recoverable petroleum reserves. Three elements of the simulation analysis are of interest here:

(1) Dry-hole Risk; a tract-specific parameter that reflects the probability that no petroleum is present.

(2) Expected Value; the average simulated net present value of the tract, incorporating the probability of dry holes.

(3) Development Risk; the standard deviation of simulated net present value, conditional on the presence of petroleum.

The USGS "expected value" is the estimate of prospective tract value that enters our regression analysis. "Dry-hole risk" and "development risk" together summarize the degree of uncertainty regarding prospective value.

The USGS also provides miscellaneous accounting information regarding OCS lease sales. The number of bids received on each tract, the amount of each bid, and the identity of each bidding party are recorded in the Lease Production and Revenue Database: System LPR-5. If a bid is tendered by a consortium, the membership composition is indicated on the basis of equity shares.

There is no administrative counterpart to the USGS that maintains a comprehensive record of firm-specific information. Reports available in the public domain provide only partial coverage of firms recently active in OCS sales. The sample is both small and unrepresentative, with only the operations of major companies being well documented.[1]

Accordingly, we have extracted from corporate annual reports a data set that represents financial and operating characteristics of approximately 100 firms. The sample is not exhaustive, but it is believed to be representative of the group of OCS bidders. It includes all major companies plus many small and intermediate-sized firms. The information collected for each consists of annual observations over six years (1971-76) on eight operating variables:

(1) total assets
(2) net worth
(3) crude oil production
(4) natural gas production
(5) crude oil proved reserves
(6) natural gas proved reserves
(7) rated refinery capacity
(8) actual refinery runs

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[1]The annual National Petroleum News Factbook Issue compiles data taken from the annual reports of approximately thirty petroleum companies; only major companies are included. The Oil and Gas Journal periodically reports similar operating data, but coverage is again limited to major oil companies. The International Petroleum Encyclopedia extends the sample to roughly fifty major companies, but reports on a restricted number of data items. The Financial Post Survey of Oils compiles statistical abstracts of most Canadian oil companies based on corporate annual reports and other information. The Federal Energy Administration (FEA) has published (1976) the most comprehensive account of the operations of integrated U.S. petroleum refiners, forty in number, but no financial data are included in the FEA report. Separately, the FEA (1975) reports the refining capacity of 154 U.S. refiners, but no other operating information is included. John S. Herold, Inc., a private investment analysis company, provides broader operating information on 130 U.S. and foreign firms that are engaged in various phases of the petroleum industry. The major limitation of this data source is that objective and subjective appraisals of firms' operating positions are intermingled.

The variable names are mostly self-explanatory. Production and reserve volumes are taken in physical units; i.e., barrels of oil and cubic feet of gas. The complete data set is available on request from the author.

We have selected seven recent OCS sales for analysis. The particular sales are described in Table 1. Among the many lease sales that have been held since 1954, analysis was confined to these seven for three reasons:

(1) Each sale occurred after 1973, when tract-specific data from the USGS simulation model became available.

(2) Each sale is classified as a "wildcat" offering of previously unexplored territory. Consequently, we avoid informational asymmetries that might otherwise arise among firms due to prior experience in the area of the sale.

(3) Each sale drew bids on seventy or more tracts of widely varied value. This provides a large and fairly rich bidding record to support statistical analysis.

5. Empirical Results

The Basic Model

We initially present results pertaining to the basic explanatory variables: net worth, tract value, and number of bidders. These variables appear to exert a strong influence on the magnitude of tendered bids, and establish a benchmark for judging the contribution of other variables to be considered subsequently.

Estimated coefficients of Equation 1 based on the set of solo bids are presented in Table 2. Corresponding estimates of Equation 2 based

TABLE 1

OCS LEASE SALES INCLUDED IN THE ANALYSIS

Sale Date	Sale Number	Geographical Region	Number of Tracts Receiving Bids	Number of Bids Tendered	
				Solo	Joint	Number of Bidding Participants

Sale Date	Sale Number	Geographical Region	Number of Tracts Receiving Bids	Number of Bids Tendered: Solo	Number of Bids Tendered: Joint	Number of Bidding Participants
03/28/74	33	Louisiana	114	129	273	82
05/29/74	34	South Texas	123	141	210	76
12/11/75	35	California	70	92	74	42
10/16/74	36	Louisiana	157	178	209	80
02/04/75	37	South Texas	143	135	146	48
04/13/76	39	Alaska	81	88	158	39
08/17/76	40	Mid-Atlantic	101	143	267	51

TABLE 2

SOLO BID EQUATIONS--BASIC MODEL

(t-statistics in parentheses)

	constant	ln NW	ln N	ln V	
OCS 33	5.74 (12.26)**	0.16 (2.17)*	0.76 (5.72)**	0.01 (0.20)	R^2 = .367 df = 74
OCS 34	3.82 (4.79)**	0.21 (3.88)**	0.64 (4.46)**	0.25 (2.15)*	R^2 = .363 df = 82
OCS 35	5.58 (15.32)**	-0.09 (1.35)	0.81 (5.33)**	0.10 (1.78)	R^2 = .406 df = 86
OCS 36	4.15 (7.14)**	0.17 (1.55)	0.51 (2.88)**	0.26 (4.15)**	R^2 = .208 df = 114
OCS 37	4.86 (10.58)**	-0.07 (1.24)	0.62 (4.09)**	0.17 (2.40)*	R^2 = 0.201 df = 131
OCS 39	2.69 (4.15)**	0.44 (3.18)**	1.03 (5.36)**	0.18 (2.56)*	R^2 = .483 df = 77
OCS 40	2.79 (7.96)**	0.34 (6.30)**	0.50 (3.06)**	0.31 (5.36)**	R^2 = .489 df = 136

*significant at 5% level.
**significant at 1% level.

Net worth is measured in $ million.
Bid and tract value are measured in $1.

on the set of imputed joint bids are presented in Table 3.[1] The most striking feature of the results is the significance of the three variables in accounting for observed fluctuations in the magnitude of bids. Each of the three factors is apparently of fundamental importance to the firm's behavior.

The number of competitors enters thirteen of fourteen equations at the 1% significance level, always with a positive sign. The magnitude of the coefficient ranges widely between 0.23 and 1.09, averaging roughly 0.65. This indicates that a 100% increase in the degree of competition has been associated historically with a 65% increase in the magnitude of tendered bids, ceterus paribus. Neither set of results (solo versus joint bids) produces a response elasticity that is significantly higher than the other, although the dispersion of results admittedly leaves much uncertainty regarding the precise magnitude of the stimulative effect of competition. There can be no doubt, however, that the effect is positive. None of the fourteen equations supports the hypothesis that the phenomenon of winner's curse has caused widespread use of non-aggressive bidding strategies. This may indicate that bidders have been misinformed regarding the optimal formulation of bidding strategies. However, the industry's long experience with this particular auction market creates a strong presumption to the contrary; i.e., that the phenomenon of winner's curse does not play a role so pronounced to require the adoption of non-aggressive behavior.

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[1] All coefficient estimates presented in this paper were obtained by the method of ordinary least squares.

TABLE 3

JOINT BID EQUATIONS--BASIC MODEL

(t-statistics in parentheses)

	constant	ln NW	ln N	ln V	
OCS 33	3.73 (33.77)**	0.42 (16.60)**	1.09 (18.95)**	0.10 (5.02)**	R^2 = .566 df = 647
OCS 34	3.21 (15.93)**	0.24 (7.29)**	0.49 (8.58)**	0.33 (8.83)**	R^2 = .390 df = 505
OCS 35	3.07 (12.38)**	0.30 (6.61)**	0.30 (2.52)*	0.29 (5.67)**	R^2 = .429 df = 250
OCS 36	3.56 (25.44)**	0.34 (11.58)**	0.52 (5.94)**	0.23 (8.11)**	R^2 = .390 df = 552
OCS 37	4.30 (26.29)**	0.21 (7.42)**	0.23 (3.38)**	0.10 (3.48)**	R^2 = .149 df = 502
OCS 39	2.76 (14.08)**	0.49 (9.12)**	0.97 (9.26)**	0.16 (6.69)**	R^2 = .368 df = 564
OCS 40	2.09 (17.04)**	0.31 (9.85)**	0.58 (6.06)**	0.39 (18.64)**	R^2 = .462 df = 1,094

*significant at 5% level.
**significant at 1% level.

Net worth is measured in $ million.
Bid and tract value are measured in $1.

The influence of tract value is very much as expected. Tract value enters all fourteen equations with a positive sign, significant in twelve cases at the 5% level. The finding that bids are monotonically increasing in tract value confirms the theoretical results of Matthews, Vickrey, and Wilson. Of greater interest is the finding that none of the fourteen coefficients exceeds unity, which is the pivotal value for determining the effect of diversification. As discussed in Section 3, the concavity implied by $b_3 < 1$ is sufficient to demonstrate that joint bids are of greater magnitude than would be tendered by individual consortium members. The joint bid is evidently an effective institutional device for diversifying risks that are by nature indivisible. The direct effect of diversification is reflected in higher bids; the indirect effect is reflected in the rapid historical growth of consortia formation relative to the practice of solo bidding.[1]

The evidence regarding diversification is one indication that OCS bidders are risk averse. This conclusion is supported further by the performance of net worth in Tables 2 and 3. The coefficient of net worth enters positively in twelve of the fourteen equations, significant eleven times at the 5% level. Large firms have bid significantly more than small firms, after controlling for tract value and the degree of competition. This finding is consistent with the hypothesis of decreasing absolute risk aversion. An alternative explanation is that large firms are more efficient in the development of OCS reserves and therefore

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[1]The percentage of all bids tendered jointly, and of winning bids tendered jointly, increased from 32% in the late 1950's to nearly 70% by the early 1970's.

place higher values on the potential resource. However, all firms typically contract with drilling specialists who provide development services, so this explanation is not compelling. It would appear more likely, a priori, that the bids of small firms reflect higher premia required as compensation for bearing a relatively large risk. This interpretation is reinforced by additional corroborating evidence (presented later) that firms systematically discount bids on relatively risky tracts.

It is not coincidental that the influence of net worth is more erratic among solo bids (Table 2) than among joint bids (Table 3). In the solo bid equations, net worth enters significantly in only four of the seven cases; and actually enters with a negative sign on two occasions (but without statistical significance). This result should not be considered to be a statistical aberration, but to accurately reflect an important difference between the sets of solo and joint bids. The solo bids in our sample were tendered primarily by the largest firms in the industry, whereas the joint bids have been tendered by a wide range of small and large firms. Consequently, there is considerably less sample variation in the size of firms represented in the solo bid equations (see Table 4). This difference, in conjunction with smaller sample sizes, would account for the weaker statistical significance of solo bid results.

Moreover, if we adopt the working hypothesis of decreasing risk aversion, the disparate performance of net worth between solo and joint bids follows as a logical consequence of the behavioral model. The

TABLE 4

SAMPLE VARIATION IN FIRMS' NET WORTH

OCS Sale		Net Worth ($ billion) Mean	Minimum	Maximum
Sale 33:	Solo Bids	5.274	0.039	15.634
	Joint Bids	1.571	0.005	8.394
Sale 34:	Solo Bids	4.001	0.008	15.634
	Joint Bids	1.650	0.005	15.634
Sale 35:	Solo Bids	7.859	0.051	15.634
	Joint Bids	2.033	0.001	8.394
Sale 36:	Solo Bids	5.762	0.164	15.634
	Joint Bids	1.630	0.005	15.634
Sale 37:	Solo Bids	7.870	0.021	15.634
	Joint Bids	1.213	0.005	6.089
Sale 39:	Solo Bids	13.272	0.817	18.470
	Joint Bids	2.621	0.078	9.002
Sale 40:	Solo Bids	9.810	0.090	18.470
	Joint Bids	2.310	0.035	9.002

average size of firms tendering solo bids ranges across sales from $4 billion to $13 billion, as compared to roughly $2 billion for firms tendering joint bids. It is not surprising, then, that fluctuations in net worth have been less influential in the determination of solo bids, since the firms involved there are, by hypothesis, less averse to risk.

The preceeding argument suggests that the log-linear specification (which implies a constant response elasticity) may be inappropriate as a model of bidding behavior. To further explore this question we re-specify the basic estimating equation as a quadratic relationship that permits the relative influence of net worth to diminish and eventually disappear where larger firms are concerned:

$$(3) \qquad Bid_{ij} = a + b_1 \cdot NW_i + b_2 \cdot NW_i^2 + b_3 \cdot N_j + b_4 \cdot V_j + e_{ij}.$$

Consistent with the hypothesis of decreasing risk aversion, the expected signs of b_1 and b_2 are positive and negative, respectively. Moreover, the "critical" firm size to attain risk neutrality (NW_c) is determined by: $NW_c = -\frac{1}{2}b_1/b_2$. Increments to wealth beyond NW_c fail to increase the tendered bid.

Estimates of Equation 3 based on solo and imputed joint bids are presented in Tables 5 and 6, respectively. Both tables lend considerable support to the hypothesis of decreasing risk aversion. Among joint bid equations, the anticipated sign pattern occurs in six of seven cases. Although the quadratic term is statistically significant in only four instances, a consistent pattern is established across the seven sales. Evaluation of the critical size to attain risk neutrality yields the estimates reported in Table 7. None of the seven sales generates an estimate that falls below $5 billion.

TABLE 5

SOLO BID EQUATIONS--QUADRATIC FORM

(t-statistics in parentheses)

	constant	NW	NW^2	N	V	
OCS 33	-2.91e6 (0.79)	8.90e1 (0.09)	3.64e-2 (0.60)	2.10e6 (5.13)**	-1.50e-1 (1.05)	R^2 = 0.365 df = 73
OCS 34	-1.81e6 (0.92)	1.03e3 (1.59)	-6.68e-2 (1.66)	1.44e6 (6.40)**	4.88e-2 (0.43)	R^2 = 0.356 df = 81
OCS 35	7.90e4 (0.07)	-4.88e1 (0.18)	8.50e-3 (0.58)	5.61e5 (4.57)**	9.04e-2 (2.63)**	R^2 = 0.356 df = 85
OCS 36	1.59e6 (0.66)	-4.01e2 (0.62)	2.60e-2 (0.71)	7.02e5 (1.69)	1.31e0 (5.60)**	R^2 = 0.278 df = 113
OCS 37	3.54e5 (0.42)	1.21e2 (0.46)	-8.78e-3 (0.62)	2.50e5 (1.91)	2.53e-1 (2.23)*	R^2 = 0.077 df = 130
OCS 39	-4.78e6 (3.50)**	1.19e3 (2.90)**	-5.01e-2 (2.65)**	6.50e5 (4.65)**	1.41e-1 (4.52)**	R^2 = 0.532 df = 76
OCS 40	-6.25e6 (2.48)*	1.28e3 (1.08)	-4.25e-2 (0.70)	9.85e5 (2.54)*	3.15e-1 (3.31)**	R^2 = 0.292 df = 135

*significant at 5% level.
**significant at 1% level.

Net worth is measured in $ million.
Bid and tract value are measured in $1.

TABLE 6

JOINT BID EQUATIONS--QUADRATIC FORM

(t-statistics in parentheses)

	constant	NW	NW^2	N	V	
OCS 33	-2.58e6 (5.88)**	2.49e3 (8.00)**	-2.42e-1 (5.47)**	5.62e5 (9.58)**	4.66e-1 (7.35)**	R^2 = .366 df = 646
OCS 34	-9.34e5 (2.43)*	1.32e3 (7.43)**	-3.40e-2 (2.07)*	3.17e5 (7.44)**	1.03e-1 (1.70)	R^2 = .306 df = 504
OCS 35	-5.06e4 (0.09)	2.08e2 (0.51)	2.79e-2 (0.52)	1.81e5 (1.94)	4.08e-1 (5.07)**	R^2 = .211 df = 249
OCS 36	-3.36e5 (0.93)	1.11e3 (6.20)**	-8.64e-2 (3.61)**	2.36e5 (2.95)**	8.61e-1 (7.11)**	R^2 = .228 df = 551
OCS 37	2.21e5 (2.73)**	2.23e2 (2.98)**	-2.21e-2 (1.75)	3.31e4 (2.40)*	8.35e-2 (1.76)	R^2 = .069 df = 501
OCS 39	-2.10e6 (4.16)**	8.87e2 (4.07)**	-6.46e-2 (2.48)*	3.36e5 (5.34)**	3.92e-1 (15.22)**	R^2 = .435 df = 563
OCS 40	-9.52e5 (2.13)*	3.84e2 (2.14)*	-1.15e-2 (0.49)	1.16e5 (2.74)**	4.39e-1 (14.45)**	R^2 = .252 df = 1,093

*significant at 5% level.
**significant at 1% level.

Net worth is measured in $ million.
Bid and tract value are measured in $1.

Three of the four statistically significant estimates of NW_c range between \$5 billion and \$7 billion. The fourth exceeds \$19 billion. The one estimate that is of marginal statistical significance (OCS 37) exceeds \$5 billion only slightly.

TABLE 7: ESTIMATES OF CRITICAL FIRM SIZE
(in \$ billion)

OCS Sale	NW_c
33	\$ 5,145
34	19,412
36	6,424
37	5,045
39	6,865

For perspective, the firms in our sample range in size from less than \$5 million (Oxoco Oil Co.) to more than \$18 billion (Exxon) in terms of net worth. The seven "major" companies are of particular interest. Of the seven, four hold net worth in excess of \$7 billion (Exxon, Texaco, Mobil, and Standard of California). Net worth of the remaining three (Gulf, Standard of Indiana, and Shell) ranges between \$4.6 billion and \$6.9 billion. Thus, the seven majors are the only firms that can reasonably be said to have attained risk neutrality. This conclusion is reinforced by the analysis of solo bids (Table 5), where the behavior of the seven majors is dominant and where the influence of fluctuation in net worth is of limited statistical significance.

Vertical Integration and Self-Sufficiency

Many participants in the OCS leasing market are vertically integrated companies that engage in both production and refining of petroleum. It is frequently alleged that firms relatively short of crude oil supplies bid more aggressively to acquire petroleum development rights.[1] We are not aware of any bidding models that establish this result formally; rather, the assertion is usually supported by general references to "security of supply" and "enhanced coordination" between different segments of the industry. These justifications are most seriously questioned because they ignore what many believe to be superior mechanisms for ensuring and coordinating supply; i.e., the many allocative mechanisms which comprise the world petroleum market.

We have tested the "self-sufficiency hypothesis" by including two additional variables in the basic estimating equation. The first variable measures the ratio of the firm's production to proved reserves. The second variable measures the ratio of the firm's refining throughput to production. Both measures are taken from corporate annual reports.[2] The resulting estimating equation takes the following form:

$$(4)\quad Bid_{ij} = a + b_1 \cdot NW_i + b_2 \cdot NW_i^2 + b_3 \cdot N_j + b_4 \cdot V_j + b_5 \cdot \frac{Prod}{Res_i} + b_6 \cdot \frac{Ref}{Prod_i} + e_{ij}$$

If self-sufficiency is advantageous to firms, then both ratios should enter Equation 4 with positive coefficients.

The estimated coefficients are presented in Tables 7 and 8, which reflect solo and imputed joint bids, respectively. Although these estimates are not strictly comparable to those presented earlier (the

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[1]A recent example of this argument appears in the October 13, 1980 issue of Business Week.

[2]Self-sufficiency ratios used here refer to proved reserves, production, and refining throughput in the North American Region. Alternative specifications which include proved plus provable reserves and which incorporate world-wide operations were not found to materially alter the results.

TABLE 7

SOLO BID EQUATIONS—SELF-SUFFICIENCY

(t-statistics in parentheses)

	constant	NW	NW^2	N	V	Prod/Res	Ref/Prod	
OCS 33	-6.27e6 (0.25)	1.06e3 (0.49)	-2.34e-2 (0.20)	2.41e6 (4.10)**	-1.77e-1 (0.96)	1.17e1 (0.20)	-2.18e3 (0.17)	R^2 = 0.343 df = 52
OCS 34	-1.22e8 (4.29)**	3.20e3 (2.06)*	5.48e-3 (0.07)	1.81e6 (6.54)**	1.37e-1 (0.74)	-1.74e0 (0.07)	6.15e4 (4.11)**	R^2 = 0.565 df = 45
OCS 35	-6.69e6 (0.76)	1.42e2 (0.17)	9.81e-3 (0.18)	5.93e5 (3.86)**	1.01e-1 (2.44)*	-2.63e3 (0.47)	3.46e3 (0.58)	R^2 = 0.368 df = 65
OCS 36	1.63e7 (1.73)	-5.19e2 (0.48)	2.58e-2 (0.40)	7.55e5 (1.61)	1.29e0 (4.79)**	-3.36e4 (2.68)**	-3.40e3 (0.71)	R^2 = 0.327 df = 83
OCS 37	-4.69e7 (1.81)	-2.19e3 (1.87)	1.79e-1 (1.96)*	2.94e5 (2.12)*	2.89e-1 (2.37)*	2.30e4 (2.12)*	2.70e4 (1.86)	R^2 = 0.140 df = 117
OCS 39	-7.12e6 (1.47)	-9.62e2 (0.75)	4.61e-2 (0.78)	8.09e5 (4.98)**	1.69e-1 (5.49)**	-1.63e4 (2.01)*	6.77e3 (1.62)	R^2 = 0.627 df = 67
OCS 40	-9.54e6 (1.46)	2.11e2 (0.11)	8.40e0 (0.09)	1.36e6 (2.92)**	3.50e-1 (3.21)**	2.68e4 (1.90)	1.31e3 (1.47)	R^2 = 0.329 df = 114

*significant at 5% level.
**significant at 1% level.

Net worth is measured in $ million.
Bid and tract value are measured in $1.

TABLE 8

JOINT BID EQUATIONS—SELF-SUFFICIENCY
(t-statistics in parentheses)

	constant	NW	NW^2	N	V	Prod/Res	Ref/Prod	
OCS 33	-5.75e6 (2.15)*	2.90e3 (3.44)**	-2.70e-1 (2.75)**	1.12e6 (6.81)**	4.24e-1 (3.40)**	-9.68e2 (0.23)	-1.27e2 (0.26)	R^2 = 0.308 df = 214
OCS 34	-4.82e6 (2.90)**	2.01e3 (5.27)**	-7.34e-2 (2.57)**	4.55e5 (5.45)**	1.23e-1 (1.09)	7.08e3 (2.21)*	-4.59e2 (0.98)	R^2 = 0.315 df = 239
OCS 35	6.69e6 (1.63)	1.29e3 (0.70)	-4.02e-2 (0.22)	3.00e5 (1.25)	3.60e-1 (2.62)**	3.71e3 (0.47)	-7.24e3 (2.00)*	R^2 = 0.208 df = 80
OCS 36	-1.06e6 (0.59)	8.35e2 (1.99)*	-6.77e-2 (1.59)	5.23e5 (2.52)*	8.70e-1 (4.47)**	1.33e3 (0.39)	-6.67e1 (0.16)	R^2 = 0.163 df = 190
OCS 37	4.83e5 (1.16)	-3.15e1 (0.15)	2.03e-2 (0.61)	3.35e4 (1.06)	1.50e-1 (1.38)	4.94e2 (0.74)	-7.24e1 (1.45)	R^2 = 0.069 df = 174
OCS 39	-2.39e6 (2.27)*	9.75e2 (3.00)**	-7.77e-2 (2.16)*	4.06e5 (4.50)**	3.98e-1 (12.36)**	-5.45e2 (0.48)	2.87e1 (0.22)	R^2 = 0.415 df = 386
OCS 40	-1.63e5 (0.17)	3.49e2 (1.11)	-1.83e-2 (0.51)	1.63e5 (1.92)	5.51e-1 (12.84)**	-5.24e2 (0.52)	-1.93e2 (1.82)	R^2 = 0.282 df = 704

*significant at 5% level.
**significant at 1% level.

Net worth is measured in $1 million.
Bid and tract value are measured in $1.

sample has been condensed to eliminate firms for which self-sufficiency data are not available), the previous pattern and significance of coefficients is hardly affected by the added variables. However, the self-sufficiency ratios themselves perform quite erratically. In only three cases out of twenty-eight do the measures of self-sufficiency enter significantly with the expected positive coefficient. In the majority of cases the measures enter with a negative sign (three times with statistical significance), in direct contradiction to the self-sufficiency hypothesis. Public assertions aside, the hypothesis that self-sufficiency is valued *per se* does not appear consistent with the actual bidding behavior of firms in the industry.

Tract-Specific Risks

In this section we consider the influence of tract-specific risks on bidding behavior. Analysis of this factor provides another test of the hypothesis of risk aversion, and generally reinforces previous conclusions. To account for tract-specific risks we add two further variables to the basic estimating equation: (1) USGS pre-sale estimates of dry-hole risk (DHR), and (2) the standard deviation (SD) of development value ascribed to each tract by the USGS. The revised estimating equation takes the form:

$$(5)\quad Bid_{ij} = a + b_1 \cdot NW_i + b_2 \cdot NW_i^2 + b_3 \cdot N_j + b_4 \cdot V_j + b_5 \cdot DHR_j + b_6 \cdot SD_j + e_{ij}.$$

If greater financial risk is a factor that systematically depresses bid levels, we would then expect both coefficients (b_5 and b_6) to enter negatively. Alternatively, if the option pricing theory of asset valuation applies (cf. Section 2) and firms are risk-neutral, we should then expect the coefficient of development risk (b_6) to enter positively.

Estimates of Equation 5 are presented in Tables 9 and 10, which correspond to solo bids and imputed joint bids, respectively. The dry-hole risk factor enters negatively in nine of twelve cases and displays considerable statistical significance. In no case does this factor enter with a significant positive sign. Because expected tract value (inclusive of dry-hole risk) has been controlled elsewhere in the equation, our results imply that firms value small but sure prospects more highly than those that are large but risky -- even though their actuarial value is the same. What may be surprising is that this pattern is reversed in both solo and joint bid equations for OCS Sale #39 (Gulf of Alaska). Members of the industry may have their own explanation for this reversal, but it is conceivable that the significantly higher costs and harsher operating environment of the Alaskan province diminish the attractiveness of all but the largest geological structures located there.

The measure of development risk (SD) also performs consistently across equations. The variable enters five of six joint bid equations with a negative sign, four times with statistical significance. This result lends additional support to the hypothesis of risk aversion (at least among the firms that have tendered joint bids), and strongly contradicts the prediction of the option pricing model. Both measures of risk (DHR and SD) exert less influence in the sample of solo bids. Indeed, development risk enters none of the solo bid equations with statistical significance, and on only two occasions with a negative sign.

TABLE 9

SOLO BID EQUATIONS — TRACT-SPECIFIC RISKS
(t-statistics in parentheses)

	constant	NW	NW^2	N	V	DHR	SD	
OCS 33	------------ no tract-specific risk data available for Sale 33 ------------							
OCS 34	9.43e6	1.08e3	-7.28e-2	1.35e6	-7.20e-1	-2.48e4	7.48e-2	R^2 = 0.416
	(1.44)	(1.40)	(1.55)	(4.80)**	(0.94)	(1.90)	(1.14)	df = 66
OCS 35	1.39e7	-5.33e1	1.29e-2	7.02e5	2.26e-3	-2.20e4	1.29e1	R^2 = 0.467
	(2.72)**	(0.16)	(0.72)	(4.89)**	(0.03)	(3.13)**	(0.72)	df = 60
OCS 36	4.61e6	-6.03e1	1.93e-2	1.20e6	-3.28e-2	-7.61e3	-1.87e-2	R^2 = 0.431
	(1.97)*	(0.15)	(0.86)	(4.35)**	(0.10)	(2.18)*	(1.76)	df = 43
OCS 37	8.59e5	1.62e2	-1.16e-2	2.25e5	6.11e-2	-6.49e2	1.42e-1	R^2 = 0.057
	(1.84)	(1.94)*	(1.60)	(3.54)**	(2.69)**	(1.18)	(0.27)	df = 99
OCS 39	-1.32e6	9.36e2	-3.60e-2	6.84e5	1.47e-1	9.62e3	2.17e-3	R^2 = 0.541
	(1.84)	(1.94)*	(1.60)	(3.54)**	(2.69)**	(1.18)	(0.27)	df = 64
OCS 40	1.38e6	1.63e3	-5.83e-2	9.83e5	3.69e-1	-7.58e3	-6.88e-2	R^2 = 0.271
	(0.05)	(1.23)	(0.86)	(2.01)*	(1.85)	(0.23)	(0.87)	df = 119

*significant at 5% level.
**significant at 1% level.

Net worth is measured in $ million.
Bid, tract value, and SD are measured in $1.

TABLE 10

JOINT BID EQUATIONS--TRACT-SPECIFIC RISKS
(t-statistics in parentheses)

	constant	NW	NW^2	N	V	DHR	SD	
OCS 33	------------ no tract-specific risk data available for Sale 33 ----------							
OCS 34	-1.32e6 (1.66)	8.10e2 (4.47)**	2.80e-2 (1.56)	3.30e5 (6.90)**	6.04e-1 (4.30)**	1.71e3 (1.32)	-1.17e-2 (2.26)*	R^2 = 0.406 df = 427
OCS 35	2.23e7 (6.83)**	5.35e1 (0.11)	5.41e-2 (0.88)	4.38e5 (3.66)**	4.29e-1 (3.51)**	-3.56e4 (6.69)**	-6.76e-2 (3.54)**	R^2 = 0.364 df = 193
OCS 36	1.72e6 (2.27)*	4.49e1 (0.31)	2.81e-2 (1.67)	2.07e5 (2.77)**	1.78e-1 (1.54)	-1.72e3 (1.38)	-2.30e-3 (0.99)	R^2 = 0.213 df = 164
OCS 37	1.67e6 (4.66)**	2.36e2 (3.05)**	-2.48e-2 (1.89)	9.66e3 (0.63)	-3.53e-3 (0.05)	-2.07e3 (4.21)**	3.46e-2 (2.18)*	R^2 = 0.100 df = 451
OCS 39	-6.41e6 (2.45)*	7.50e2 (3.48)**	-5.78e-2 (2.25)*	3.87e5 (5.86)**	4.95e-1 (14.22)**	5.59e3 (1.87)	-5.37e-3 (2.64)**	R^2 = 0.482 df = 523
OCS 40	2.16e7 (4.79)**	3.45e2 (1.90)	-6.40e-3 (0.27)	1.21e5 (1.61)	4.27e-1 (10.45)**	-2.54e4 (5.05)**	-3.71e-2 (5.61)**	R^2 = 0.256 df = 1037

*significant at 5% level.
**significant at 1% level.

Net worth is measured in $ million.
Bid, tract value, and SD are measured in $1.

This result is again consistent with the hypothesis of decreasing risk aversion among large firms and cannot be explained by the hypothesis of differential efficiency in the development of offshore resources.

6. Summary

Bidding patterns in recent OCS lease sales provide strong evidence in support of four important hypotheses:

(1) Greater competition for OCS leases inspires all participants to bid more aggressively. There is no evidence that the phenomenon of winner's curse is sufficiently important to lead to the adoption of non-aggressive bidding strategies.

(2) The majority of firms in the industry exhibit significant aversion to risk, but the degree of risk aversion decreases among larger firms and may eventually disappear.

(3) The mechanism of joint bidding, which facilitates the pooling and diversification of risk, has enabled consortia to bid more than individual members would under a regime of solo bidding. This conclusion may not apply to the seven major firms, who appear to have attained a position of risk neutrality. Not surprisingly, it is precisely this group of firms that have been the most active solo bidders.

(4) Self-sufficiency in crude oil production is not, per se, of sufficient importance to cause "crude-short" firms to bid more aggressively for OCS development rights.

These conclusions pertain closely to the debate regarding current leasing policy options. A traditional goal of leasing policy has been to increase the degree of competition for leases. Our results indicate that this desire is well directed; the degree of competition is the most significant determinant of bidding behavior in our analysis. Of course, the analysis does not directly indicate which policy actions, if any, would encourage greater competition. However, the finding that most OCS participants exhibit significant aversion to risk suggests that any policy that is effective in mitigating OCS risks might induce more extensive and aggressive competition for leases.

The current thrust of leasing policy reform appears to be moving in this direction. Numerous auction methods currently in experimental use (e.g., royalty and profit-share bidding) are designed to substitute production-related payments for the present lump-sum bonus. By effecting this substitution the government would assume a significant portion of exploration risk, and presumably permit the companies to compete more aggressively. A disadvantage is that the government's new vehicle for collecting mineral rents may interfere with subsequent resource development by distorting marginal costs, but this carries us beyond the scope of the present paper.

Finally, an informed policy regarding joint bidding must reflect the benefits of risk-sharing. Because OCS risks are by nature indivisible, and because most firms display considerable aversion to bearing risk, the benefits of joint bidding appear to be significant. Current policy, which prohibits joint bidding among the seven largest U.S. oil companies, but permits it elsewhere, is well-supported by our finding of decreasing risk aversion. The largest companies have not behaved as if the problem of indivisibilities were a serious one, but almost everyone else has.

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M/D/317