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

by

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1. INTRODUCTION

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

The auction literature has been motivated primarily by substantive policy issues; namely, how should the government optimally lease mineral or timber rights, sell treasury bonds, or procure services. The theories of strategic behavior in auction markets, and of optimal auction design, are strongly influenced by these concerns. (McAfee and McMillan (1987), Milgrom (1985, 1987), and Wilson (1990) ably summarize the literature.) Accordingly, existing theory often directly addresses issues of utmost concern to empirical researchers.

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

The most notable auction, in terms of attention in the literature, has been the U.S. offshore oil and gas lease sales conducted by the Department of the Interior. Since the program's inception in 1954, the United States government has auctioned the oil and gas rights to the offshore federal lands, or Outer Continental Shelf (OCS hereafter). By the end of 1990, 12,288 tracts were sold, covering more than 63 million acres, and data on bids, tract characteristics, and post-sale drilling and production history are publicly available. The purpose of this paper is to discuss the role of information in the OCS leasing program. I survey my recent research with Ken Hendricks. Our research investigates whether equilibrium models that emphasize informational and strategic issues, and account for institutional features of the OCS leasing program, have predictive accuracy.

To concentrate on a relatively narrow topic may seem self-indulgent. There are (at least) two reasons for doing so. First, the OCS data set is quite detailed, and permits the study of strategic behavior under imperfect or incomplete information in several settings. Second, game theory emphasizes the importance of the rules of the game, and the characteristics of the economic environment, in the positive description of equilibrium behavior. The strategic environment of the OCS lease sales is relatively simple to describe, and so specific equilibrium predictions can be derived. There is no presumption, however, that these specific predictions will apply to other strategic situations, or even to other auction markets. On the contrary, detailed study of institutions, and of the economic environment, is necessary before game theoretic models can be applied to data. What follows, then, is a description of a case study of a specific market. Correctly specified equilibrium models incorporating rational strategic behavior under imperfect information provide accurate predictions of outcomes in the OCS leasing environment, and therefore game theoretic models may be used as a basis for policy analysis of the OCS leasing program, as well as in other situations.

2. THE AUCTION MECHANISM AND THE DATA SET

The U.S. federal government holds the mineral rights to the offshore lands more than three miles from the coast, out to the 200 mile limit. The adjacent state owns the rights out to the three mile mark. The federal government began auctioning mineral rights in 1954. (Texas and Louisiana held auctions prior to 1954 for lands that were subsequently ruled to be federal by the courts, and these lands came under federal control in 1953.) Rights to oil, condensate, natural gas, salt, sulphur and phosphates have subsequently been sold. This paper focuses on the oil, condensate and gas auctions off Texas and Louisiana. Approximately 80 percent of the offshore acres that have been sold are in this region of the Gulf of Mexico, and they account for a higher fraction of offshore production. Production from offshore federal lands currently accounts for about 12 percent of U.S. oil production, and 25 percent of gas production. A similar fraction of estimated U.S. reserves are located on federal offshore lands. From 1953 through 1990, the federal government has collected about $40.3 billion in royalties and $55.8 billion in bonuses paid. The offshore leasing program has earned almost $97 billion in total. In 1981 alone, $3.29 billion in royalties and $6.65 billion in bonuses were collected. (For more detail, see Barbagallo et.al. (1991).)

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

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

Based on pre-sale exploration, firms nominate tracts for sale, and the government constructs a final list. A sale must satisfy environmental impact requirements, which became more stringent in the 1970s. Tracts are then sold to the public in a first-price, sealed bid auction. A sale consists of the simultaneous auction of the nominated tracts. In the 98 offshore oil and gas sales from 1954 until 1990, 12,288 tracts were sold, or 125 tracts in an average sale. A participating bidder submits a separate bid on each tract that it has an interest in acquiring. A bid is a dollar figure, known as a bonus, that the firm pays at the date of the sale if it is awarded the tract. (There was limited experimentation with alternative bidding rules, such as royalty rate bidding, from 1978 to 1983.) The highest bidder is awarded the tract, unless the government chooses to reject the bid as insufficient. There may be an announced minimum bid, especially in early sales, but higher bids can be rejected. Announced reserve prices were $15 or $25 per acre on wildcat sales, and $25 per acre on drainage sales. Reserve prices vary from sale to sale, but not across tracts within a sale. The government's rejection decision takes into account its private estimate of the value of the tract. This estimate is based in part upon the geological and seismic information that firms are required to submit, and on the bids themselves when more than three bids are submitted. High bids were rejected on 1,040 oil and gas leases between 1954 and 1990, or 7.8 percent of the 13,328 tracts receiving bids. Tracts with rejected high bids can be reoffered at some future sale. The results of the bidding on all tracts, as well as the identities of all the bidders and the amounts of their bids, are announced at a public meeting. It is not possible to alter bids during a sale.

When a tract is won, a firm has 5 years to explore it. (A few tracts in relatively risky areas were sold with 10 year terms.) If no work is done during the lease term, the tract reverts to the government, and the tract may subsequently be reoffered. A nominal rental fee, typically $3 per acre on wildcat tracts or $10 on drainage or developmental tracts, is paid each year until either the lease is relinquished or production begins. If oil and/or gas is discovered in sufficient quantities to begin production, the lease is automatically renewed for as long as hydrocarbon production occurs. A fixed fraction of the revenues from extraction accrues to the government as royalty payments, often subject to some minimum, such as $3 to $10 per acre. The royalty rate is one sixth of revenues on the vast majority of tracts. A royalty rate of 1/8th is also employed in areas that are perceived as risky, such as in deep water. There was some experimentation with royalties collected on estimated profits, where costs were estimated according to industry standards.

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

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

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

3. BIDDING ON WILDCAT LEASES

This section describes bidding for wildcat tracts, which are located in regions where no exploratory drilling has previously occurred. The government decision of whether to accept the winning bid is characterized, as is the fate of tracts with rejected bids. The role of joint bids, where several firms form a bidding consortium, is also described.

Table 1 summarizes all OCS oil and gas sales, including sales outside the Gulf of Mexico where the data are divided into five periods between 1954 and 1990. In the earliest period, sales were held sporadically, with gaps of as much as four years. Later sales were more frequent, essentially quarterly. By the end of the 1960s, the OCS was established as a major producer of oil and gas, and in 1968-1974 there was an increase in the number of bidders and in bid levels. Tracts sold after this period tended to be less productive, and attracted fewer bidders, although bid levels remained high because of increases in the real prices of oil and gas. After 1982, there was a dramatic increase in the number of tracts offered for sale, as relatively marginal areas were offered, and there was a corresponding decrease in the number of tracts receiving bids, and in the number of bids and bid levels on tracts receiving bids. In the remainder of this paper, attention shall be restricted to the set of tracts in the Gulf of Mexico off Texas and Louisiana, and all dollar figures will be denominated in 1972 dollars.

There is considerable dispersion in submitted bids. The distribution of bids is approximately lognormal. (See Smiley (1979), for example.) Consider the set of wildcat tracts offered for sale from 1954 through 1979. Let B_{it} denote the ith highest bid in 1972 dollars on tract t, $i = 1, \ldots, n_t$, where n_t is the number of bids on tract t. In a regression of log B_{it} on a vector of tract specific dummies, where there are 8,833 bids on the 2,510 wildcat tracts, the R^2 statistic is 0.583. That is, only 58.3 percent of the variation in log bids can be explained by across tract variation, as accounted for by the 2,510 tract dummies, and the remaining 41.7 percent is due to within tract variation in bids. Within tract variation can be described by the estimated standard error of the regression equation, which equals 1.33. The sample mean log bid is 14.28, or $1.59 million in 1972 dollars. Therefore, a 68 percent confidence interval for log bids about the tract specific mean log bid is plus or minus 1.33, or bid levels between $420 thousand and $6.02 million at the sample mean.

An alternative measure of dispersion is the amount overpaid by the winning bidder. Table 2 documents money left on the table, as a function of the number of bidders, for wildcat tracts receiving two or more bids. A measure of money left on the table for tract t is $(B_{1t} - B_{2t})/B_{1t}$, where B_{1t} denotes the highest bid on tract t and B_{2t} the second highest bid. This measure is analogous to a percentage markup, for it is the amount overpaid as a fraction of the winning bid. The amount of money left on the table is a significantly decreasing function of the number of bidders. Moreover, its magnitude is economically significant, for the average amount left on the table is 44 percent of the winning bid, and the winning bid averages $7.92 million on the 1,608 tracts with two or more bids. Therefore, this measure also indicates that there is considerable dispersion in submitted bids. Even on the 180 tracts receiving between 10 and 18 bids, on average 30 percent of the winning bid is left on the table, where the mean winning bid is $21.78 million.

The measures of dispersion suggest that OCS wildcat auctions are essentially common value auctions. There are active markets for extracted oil and gas, so that heterogeneities in valuations arise from differences in exploration and drilling costs. But the magnitude of the dispersion in bids swamps likely cost differences. Therefore, the wildcat auctions may be regarded as common value, where firms are uncertain about deposit sizes or common extraction costs, or about future prices.

Table 2 shows that there is also substantial dispersion in the number of submitted bids. The number of bids ranges from 1 to 18, with mean 3.52. For several categories of numbers of bids, Table 2 indicates how many tracts were sold, and what became of purchased tracts. Bids are much more likely to be accepted on tracts with several bids, and for a given number of bidders winning or accepted bids were larger than rejected high bids. In this sample, there was exploratory drilling on 77.9 percent of the 2,255 purchased tracts, and the likelihood of exploration increases with the number of bidders. 50.1 percent of the 1,757 explored tracts are productive, with sufficient deposits so that hydrocarbons are extracted. Conditional on being explored, tracts receiving more bids are more likely to be productive, and deposits on productive tracts are larger. Here deposits are measured by discounted revenues, where outputs are evaluated at real wellhead prices as of the date of the lease auction, and a five percent real discount rate is employed. (See Hendricks, Porter, and Boudreau (1987), or HPB, for further detail.) It is difficult to infer ex post profits for this sample, because after 1973 real oil and gas prices increased dramatically, and bids would have reflected expectations concerning future prices. Nevertheless, Table 2 is consistent with the findings in HPB, that realized returns are lowest on tracts receiving the most bids. For example, compared to tracts with 7 to 9 bids, in the 10 to 18 category accepted bids are 54 percent higher, yet tracts are 10 percent more likely to be drilled, 9 percent more likely to be productive if drilled, and 16 percent more valuable if productive, or only 35 percent more valuable on average, ignoring drilling costs. This finding might be consistent with a winner's curse effect.

A few investigators of OCS auctions have attempted to test for the presence of collusion, or whether joint bidding facilitates collusion or enhances efficiency by reducing uncertainty, but the majority of empirical papers have tried to determine whether bidding was rational. The seminal article by Capen, Clapp, and Campbell (1971) asserted that firms did not account for the winner's curse. (See Thaler (1988) for a summary of more recent evidence.) Suppose agents bid for an item that they value similarly (as in a common value auction), where their information about this value is imperfect. Then they should realize that if they win the bidding, they must have been relatively optimistic about the true value, and should lower their expectations and therefore their bids accordingly. Of course, they should make their rivals aware of this phenomenon, so that the rivals also lower their bids.

An onslaught of theoretical papers has sought to characterize rational non-cooperative bidding, with increasingly general assumptions about preferences and information. A number of empirical papers have been guided by this theoretical literature in their attempts to corroborate Capen et.al. Many of the theoretical predictions employed by the empirical papers have been comparative statics results about the relationship between the number of bidders and optimal bidding. As this number increases, winner's curse considerations are magnified, and so eventually bidding should be less aggressive. (When there are only a few bidders, more bidders may imply more aggressive bidding, as competitive effects predominate.) For the offshore bidding data, there is a fundamental difficulty with this empirical approach. The comparative statics results in the theoretical literature refer to the potential, as opposed to the actual, number of bidders. Yet only the actual number is available in the data. Unfortunately, the actual number of bidders in OCS auctions is endogenous, and the participation rate is less than 50 percent for all firms. That is, all firms submit bids on less than half of the tracts offered for sale. The presence of a positive reserve price, and the large fraction of tracts with negative ex post returns, imply that some of the firms that actively consider bidding (by obtaining a seismic survey, in the typical case) will choose not to do so a significant fraction of the time. Of course, low participation rates may also result from exposure constraints. The likelihood of participation is a function of the firm's prior estimate of tract profitability, and, to the extent that these prior beliefs are positively correlated with ex post profits, is therefore higher on more valuable tracts. Table 2 indicates that the decision to submit a bid is correlated with ex post returns, and more profitable tracts do receive more bids on average. Researchers who ignore this endogeneity have found that bids are an increasing function of the number of bidders, which is not surprising given that prior beliefs are not observed and difficult to proxy exactly. It is important, then, to treat the number of bidders as endogenous. The difficulty is that it is virtually impossible to obtain adequate instruments. Any variable that is correlated with ex ante beliefs, and so is a candidate instrument, should also be included in the bid function. We cannot observe ex ante beliefs directly, and any variable that is correlated with them should be influential in bidding and participation decisions.

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

The relatively low returns on tracts receiving 10 to 18 bids are consistent with the winner's curse, but they are also consistent with equilibrium bidding when there is uncertainty on the part of the firms concerning the number of potential rivals present. In the latter case, the prior estimate of the value of a tract conditional on submitting the winning bid is too low on average if the realized number of competitors is below average, and too high if the number is above average.

HPB investigate bidding strategies in further detail, by conducting the following exercise. For a sample of tracts sold from 1954 to 1969, in which returns data are more reliable, HPB consider the set of tracts a given firm submits bids on. Assume that the bids of rival firms and ex post returns gross of the winning bid are fixed. (Costs estimates are derived using the annual survey of drilling costs by the American Petroleum Institute.) Then proportionately vary the vector of bids submitted by the firm in question. That is, if all of the firm's bids are increased by 50 percent, it will win more tracts but earn less per tract. HPB calculate the bid proportion that maximizes ex post returns. They find that a few firms did not behave optimally and overbid, and that, in at least one case, some consistently overvalued the value of tracts. However, most firms appear to follow approximately optimal bidding strategies, conditional on the set of tracts selected, especially if ex post return variability is taken into account.

HPB also calculate divisions of rent for the 1954-1969 sample. On wildcat tracts, they estimate that firms capture 23 percent of ex post tract value (i.e., discounted revenues less costs), with the remainder accruing to the government as bonus bids and royalty payments. This figure accords with industry lore, and with the noncooperative equilibrium of a common value auction where values are distributed lognormal with an appropriate level of variance. (For further detail, see Wilson (1990).)

I now describe the rejection policy of the government in more detail. Table 3 documents the frequency distribution of the number of bids, as well as the fraction of tracts where high bids were rejected as inadequate by the government for different numbers of bidders. Table 3 also differentiates between the periods before and after 1970. Between 1954 and 1969, all tracts with four or more bids were sold, and the likelihood of rejection was very low for tracts with two or three bids. (No high bids were rejected before 1960.) The number of bids per tract increased after 1970, although most of this increase is attributable to higher participation in the 1970 and 1972 sales. After 1970, the government was more likely to reject the high bid, for any number of bidders, and overall rejection rates increased from 7.1 to 12.7 percent.

Table 3 compares tracts that were sold to those where the high bid was rejected. Apart from the previously noted difference in the number of submitted bids, there is more than a seven-fold difference in the level of the high bid.

The data identifies whether tracts are reoffered, and the history of bidding on reoffered tracts can be constructed. Of the 2,510 wildcat tracts, 160 were reofferings. 51 tracts were reoffered after the lease was sold and relinquished, either because no exploratory drilling was conducted or because deposits were insufficient to justify production. Hence 2,401 tracts were sold de novo or following relinquishment. A total of 233 high bids were rejected on these tracts, or 9.7 percent. Of the 233 tracts with rejected bids, 109 were subsequently reoffered, or 46.8 percent. Reofferings following rejection occurred an average of 2.7 years after the initial sale. One of the tracts was reoffered with an altered boundary. On the remaining 108, the average number of bidders increased from 1.56 to 2.07, and mean bids increased from $1.31 million to $3.27 million. Nevertheless, 22 high bids were rejected, or 20.4 percent.

In summary, the intention of government's rejection policy seems to have been to discourage low bids on tracts with little competition, as measured by the number of bids. The long time between rejection and resale, and the low fraction of reofferings, are not consistent with revenue maximization. In addition, McAfee and Vincent (1992) argue that the announced reserve price before 1972 was too low, and that it should have been increased from $15 per acre to more than $200 per acre, or $1 million in total. The government may have been reluctant to do so, because a high reserve price would preclude the sale of marginal tracts. If so, it should not have announced a common reserve price for all tracts in a sale, but instead opted for a higher reserve on more valuable (ex ante) tracts. Optimal auction design models also suggest that the seller should reveal any relevant information prior to the sale, such as the true reserve price. In fairness to the government, there may have also been a concern about collusion, in which case it might be preferable to keep the reserve price secret.

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

An obstacle to successful collusion is uncertainty about which rivals are serious potential competitors, for there is an incentive for firms to free ride on the informational investments of other firms. Prior to a lease sale, firms acquire information by investing in seismic surveys and a staff of geologists. The quality of these investments is not publicly observable. Firms would like to communicate and coordinate with all serious rivals, but they may be unable to distinguish serious rivals from free riders beforehand. A joint bid with a non-serious rival dilutes the ex post returns from investments in information. Therefore, solo bidding is likely to occur in equilibrium.

Table 4 lists the bidding activities of the twelve largest firms and bidding consortia for the sample of 2,510 wildcat tracts receiving bids from 1954 through 1979. Three bidding consortia pooled their exploration budgets, thereby overcoming free rider problems via ex ante agreements, and for practical purposes can be thought of as single firms. The twelve firms and consortia listed in Table 4 are designated as large firms, and all other firms are referred to as fringe firms. Table 4 indicates how many solo bids each large firm submitted, as well as their joint bids. The Table distinguishes between joint bids with other large firms alone (L Only), and those including fringe firms (L&F). In 1975, Congress outlawed joint bids involving two or more of eight designated companies, in order to limit collusion. Large firms affected by this ruling are indicated by an asterisk (*). Table 4 indicates that a substantial fraction of bids submitted by each large firm are joint, although there is significant variation across firms in the number and in the type of joint bids. There are relatively few solo bids by fringe firms, or joint bids involving only fringe firms. Less than 20 percent of high bids on wildcat tracts involved only fringe firms.

Hendricks and Porter (1992a) show that most of the joint "L&F" bids involve one large firm and one or more fringe firms. 67 percent of the "L Only" joint bids entail equal shares for the participants, yet only 37 percent of L&F bids have equal shares. Instead, the large firm in an L&F bid typically holds a larger share. Large firms appear to bid jointly with relatively inexperienced partners in L&F bids, so that expertise and information is being traded for capital, and the large firm may hold a disproportionate share to mitigate adverse selection problems. Consistent with this view of L&F bids, L&F bids tend to occur on hotly contested tracts with many bids and a high winning bid, where a large firm might seek to relax capital constraints. Further, among high bid tracts, large firms earn much higher returns on their solo bids, so they appear to seek outside partners on tracts with lower expected profits. Because they retain an ownership share, L&F joint bids should be expected to earn non-negative profits. Most of the L&F bids occurred after 1970, when the OCS was established as a productive and profitable area for exploration, and after average bids increased substantially. In summary, L&F joint bids probably enhance competition by allowing large firms to bid more aggressively, and to bid on more tracts.

Gaskins has argued that, in the process of forming a joint venture, participating firms reveal their bidding intentions on all of the tracts under discussion. The concern, therefore, is that L Only joint bids allow firms to win leases on more favorable terms, either by bidding jointly or by modifying their solo bids. The joint bidding ban led to fewer L Only joint bids, but these joint bids remained significant. Profits for L Only joint bids were similar to those for solo bids by large firms, and higher than those for L&F joint bids.

4. EXPLORATION OF WILDCAT LEASES

This section analyzes exploratory drilling on wildcat tracts after their sale. Purchase of a tract does not obligate the buyer to conduct exploration. Firms have five years to begin exploration, and if they do not the lease is relinquished and reverts to the government. Indeed, Hendricks and Porter

(1992b), in their study of tracts off the coasts of Texas and Louisiana sold between 1954 and 1990, document that thirty percent of wildcat leases were allowed to expire without any wells being drilled. For the period 1954-1979, 24 percent of the leases were not explored, and the tracts with expired leases received bids averaging $2.51 million in 1972 dollars. In addition, there is a clear deadline effect, as the fraction of remaining tracts where drilling begins (the hazard rate for initial drilling) falls over time, but then increases rapidly as the five year deadline approaches.

Two alternative explanations of abandonment rates suggest themselves. First, firms may have unintentionally acquired more tracts in the auction than they were feasibly capable of drilling, because of limited drilling rig availability. This seems unlikely, to the extent that there is an active worldwide rental market in drilling rigs. (In the early 1980s, 15 leases were relinquished immediately after their sale, at a cost of the deposit of 20 percent of the bonus bid, perhaps because of capital or exposure constraints.) Alternatively, firms may acquire information after the auction that causes them to revise their forecasts about tract profitability. This must entail a fairly dramatic shift in beliefs, since bonus bids are sunk once the auction is over, and a tract should be drilled if expected gross profits (rather than profits net of the bid) are positive.

There are two potential sources of ex post information. One is the revelation of the bids of other active firms. For example, if other firms bid much less than anticipated, or not at all, even accounting for winner's curse considerations, then a reevaluation may be in order. To the extent that ex post heterogeneity of beliefs arises from differential interpretations of the same seismic data, such a reevaluation may not be sizable. A second source of ex post information is the drilling outcomes on previously explored tracts in the same area. Production information on neighboring tracts is publicly available. This information will be influential if local drilling results are more reliable predictors of tract profitability than seismic data.

If information externalities are important, a game of timing similar to that modelled by Hendricks and Kovenock (1989) will ensue. In particular, in considering whether and when to drill, firms must modify the costs and benefits of waiting appropriately. The costs of waiting arise from discounting, as expected profits are deferred. These costs are directly proportional to expected gross profits. The benefits arise from events in which other firms drill neighboring tracts during the wait, thereby permitting more precise inferences concerning own drilling outcomes. Such information could be valuable if there is then a lower probability of drilling a dry hole. Another benefit to delay occurs if a firm has acquired many tracts, and average drilling costs are increasing in the number of wells drilled. It may then be better to defer drilling some of these tracts, apart from any strategic considerations. Not all drilling should necessarily be deferred, as early results on some tracts provide useful information regarding other holdings. However, if tract holdings are dispersed across several firms, there is an information externality, and noncooperative drilling games may result in too little drilling at the beginning of the lease term. The benefits of delay are also a function of the degree of uncertainty about the tract in question, or how influential new information is likely to be. The degree of uncertainty may be proxied by the number of tracts previously drilled in the area. If these costs and benefits are important, firms will follow sequential drilling programs, in which tracts that are viewed as more valuable ex ante are explored first.

The data are consistent with this theory. Tracts average about 5,000 acres, a size large by onshore standards, but not necessarily by the standards of typical oil or gas field. Almost all of the leases in the sample had five year terms. It takes about two or three months to initiate exploratory drilling. 29.6 percent of the wildcat leases with five year leases sold between 1954 and 1990 were relinquished without exploratory drilling. In order to examine the incidence and timing issue, Figure 1 plots quarterly hazard rates for the 4,112 wildcat leases with five year leases, and royalty rates of 1/6, sold between 1954 and 1990. The horizontal axis measures the length of time, in quarters, since the tract was sold. The vertical axis measures the hazard rate; that is, the fraction of tracts that had not been drilled previously where exploratory drilling began in that quarter. The same picture could be drawn for subperiods of the data, with similar results. The hazard rate is initially high, levels off at a lower rate for most of the remainder of the term, and then turns up again in the last quarter.

The initial burst of drilling activity occurs on tracts where the owner is relatively confident of success, and indeed both hit rates and discounted revenues are higher on tracts drilled in the first year, as indicated in Table 5 for the 1954-1979 sample. The final surge is a deadline effect, and, I would argue, the by-product of a timing game played by the firms owning leases in a particular area. To the extent that wildcat tracts lie in a (geologically) compact area, drilling outcomes on a given tract will be informative about the prospects on neighboring tracts. Drilling itself is costly, to the tune of several million dollars, and so a classic war of attrition arises. Firms prefer that their neighbor drill first, and the equilibrium of a game of incomplete information predicts a relatively high incidence of drilling concentrated at the deadline, as long as discount rates are not too high. There are many incentives for firms to pool exploratory activities, and unitization agreements offer a mechanism to implement side payments, yet the U-shaped pattern evident in the hazard rates is difficult to reconcile with a model of coordinated drilling. Instead, it is consistent with the noncooperative outcome of a war of attrition.

Table 5 provides tangential evidence that firms do respond to post-sale information. First, tracts drilled early in the lease term had higher bids on average, which is consistent with nontrivial discounting. Presumably, bids are an increasing function of ex ante evaluations, as suggested by equilibrium bidding models. In addition, consider the variable BIDDIF, the difference in the logarithm of the bids for tracts that are drilled in a particular year after a sale, compared to the average log bid on tracts that have not yet been drilled, and are sold in the same year. Clearly, an important early determinant of whether a tract is drilled is pre-sale information, for which the bid serves as a proxy. However, as the drilling history unfolds, pre-sale information, as exemplified by the bid, becomes increasingly less important. Hendricks and Porter (1992b) report some regressions on the determinants of the drilling decision as time unfolds, that is whether a tract is drilled in a given year if it has not yet been drilled. The pattern of the importance of the bid is replicated, and statistics capturing the drilling outcome on tracts in the same area are important after the first year. There is a particular tendency after the first year of the lease to drill in areas where there have been large strikes since the sale date.

Table 5 contains some other informative statistics. Hit rates, or the percentage of productive tracts, are roughly constant across initial drilling time at 50 percent, suggesting that drilling information externalities may be substantial. That is, tracts drilled later in the lease term are almost as likely to be productive, and productive tracts have similar average discounted revenues, especially after the first year. In addition, average bids are lower on tracts drilled later in the term, so that ex post profits are higher.

Furthermore, HPB show that the probability of drilling a given tract in a particular year is independent of the number of tracts held in that area by a leaseholder, suggesting that firms are playing a game of timing, rather than spreading exploration activity over time. (Most firms hold fewer than 20 leases in an area.) The only advantage to delay for firms with a few tracts is information acquisition. However, their timing patterns are similar to those for firms with many tracts, suggesting that all leaseholders have similar tradeoffs from delay. Therefore, informational concerns may be more important than those of production smoothing.

A firm contemplating drilling a tract is interested in the probability that the tract is productive, and in the amount of oil or gas to be found in that event. At the time of a wildcat auction, a firm's prior expectations concerning these random variables are formed from its seismic survey, and perhaps from previous drilling activity in the area. (Recall that what distinguishes wildcat tracts is the lack of drilling activity in the immediately adjacent area.) Under plausible assumptions about the distribution of oil and gas revenues on offshore tracts (e.g., lognormal with a mass point at zero), the results of prior drilling activity (or, once the local area has been explored, of recent local drilling activity) can be summarized by three sufficient statistics: the number of tracts drilled, the number of productive tracts, and the mean of the logarithm of discounted revenues on productive tracts. If prior- and post-sale drilling activity are equally precise predictors for undrilled tracts, then these statistics can be updated straightforwardly. Alternatively, if activity prior to the sale in question is relatively uninformative, then the statistics capturing post-sale drilling outcomes should enter differentially. The idea is that, for each of the five years of the tract lease, a vector of statistics can be constructed to summarize the available information. These statistics, together with the bidding for the tract in question, are proxies for the firm's evaluation of tract profitability, and are therefore directly related to the costs and benefits of delaying drilling. Furthermore, the summary statistics can be checked for their reliability, by seeing how well they forecast actual drilling outcomes (i.e., the probability of a hit, and log revenues conditional on a hit).

The econometric work of Hendricks and Porter (1992b) suggests that the economic significance of ex post drilling information is large, insofar that drilling programs are responsive to this information, but that there is little learning from (or, more accurately, little impact on drilling decisions of) information about rivals' bids.

The possibilities of useful post-sale information revelation should not be underestimated. Hit rates are approximately 50 percent, and conditioning on a hit, the standard error of log discounted revenues is large (more than 1.5). These are risky prospects, drilling costs are non-negligible (about $4.5 million in 1972 dollars on average), and so any useful information is potentially decisive.

5. BIDDING ON DRAINAGE LEASES

It is possible to circumvent the difficulties of testing equilibrium bidding models by examining drainage leases, in which information is asymmetric. In these cases, some firms own previously leased adjacent wildcat tracts, and they are likely to have better information than other firms. Further, the data indicate how many "neighbor" firms there are. The comparative static results from the theory of bidding under asymmetric information show that the key strategic variable is the number of well-informed firms, and that the number of other potential bidders is irrelevant (provided that they have no private information). Indeed, a number of theoretical predictions lend themselves to direct tests with the available data. These results are relatively robust, and do not rely excessively on functional form assumptions. It is also possible to determine whether bidding by neighbor firms is relatively competitive or collusive.

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

The Bayesian Nash equilibrium strategies of a first-price, sealed bid auction are as follows. The uninformed firm will follow a mixed strategy. Why should it participate, given its informational disadvantage? If it did not bid, the best response of the informed firm would be to bid R if $v \geq R$, and to not bid otherwise. But then the uninformed firm should bid slightly higher than the reserve price, say R + \$1, win the object for sure, and earn E[V]-R-\$1, which is greater than zero by assumption. However, the uninformed bidder should not follow a pure strategy. If it did, then it would bid a known amount B for a given realization of the public information. But the best response of the informed firm, if it knows B, is to bid B + \$1 if $v > B$, and to not bid otherwise. Then the uninformed firm will win the object only if $v \leq B$. This is an extreme case of the winner's curse, because the uninformed firm wins the lease only if its bid exceeds the value. Therefore, the uninformed firm will participate, but it must follow a mixed, or unpredictable, strategy, denoted by the distribution function $G_\alpha(b) = Pr\{B<b\}$.

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

$$\beta(v) = \begin{cases} E[V|V\leq v] & \text{for } v \geq v', \\ R & \text{for } R \leq v \leq v', \text{ and} \\ 0 & \text{for } v < R. \end{cases}$$

Here v' is the solution to $E[V|V\leq v] = R$. (If the distribution of V contained any mass points, then the informed firm might pursue a mixed strategy.) This is a markdown strategy, for the bid is less than the valuation v, and the markdown is increasing in v. In the limit, as $v\rightarrow\infty$, $\beta(v)\rightarrow E[V]$. There will be a mass point in the distribution of the informed firm's bids at R, and β is monotone increasing above R. The uninformed firm pursues a mixed strategy, and the bidding of the informed firm is constructed so that the uninformed firm earns zero expected profits for all bids it submits with positive probability. (If the uninformed firm earned negative expected profits, it would prefer not to bid, and this cannot be an equilibrium. Similarly, it cannot earn positive expected profits in equilibrium, for then the informed firm is not maximizing profits. See Hendricks, Porter, and Wilson (1991), or HPW, for more detail.) Consider Figure 2a, where V is assumed to be distributed according to an exponential distribution with mean 6, and the reserve price R equals 1. If the uninformed firm bids above the range of the informed firm's bid, it surely wins the lease, with expected value E[V] less than its bid. If it bids between zero and R, or doesn't submit a bid, it earns zero. If its bid b is between R and E[V], then it wins the object only if $\beta(v) < b$, or if v is less than $\beta^{-1}(b)$. But then the expected value of the lease, conditioning on the event of winning the auction with bid b, is given by $E[V|V \leq \beta^{-1}(b)] = b$. Thus bids between R and E[V] break even in expectation, by construction. Bids at R earn negative expected profits, as indicated in the Figure, because $\beta(v)$ lies to the right of $E[V|V \leq v]$ for v in the interval (1, v').

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

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

2. The distribution functions of the bids of the two firms will coincide above the reserve price. The distribution functions differ because the informed firm distribution has a mass point at the reserve price, and because its bid is correlated with the true value (whereas the uninformed bid is randomly selected, conditional on publicly available information).

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

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

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

The example sketched above makes a number of strong assumptions. The assumption that there is only one uninformed bidder is not important, provided that all uninformed bidders observe only public information. Then the bid distribution function $G_\alpha(b)$ would characterize the highest bid submitted by the uninformed bidders. If uninformed bidders had access to informative private signals of V, then winning would be an informative event for the informed bidder (if it had less than perfect information concerning V), and so the strategy of the informed bidder would depend on the potential number of (relatively) uninformed bidders. The mixed strategy equilibrium described above is the limit of the equilibrium in which the uninformed bidder observes a private signal concerning V, where the limit is taken as the precision of the signal as an indicator of V goes to zero. Nevertheless, the modelling assumption, that the firms without access to drilling records from neighboring tracts have little private information of value, appears to be reasonable for predictive purposes. One indication is that ex post tract profitability, on tracts sold between 1959 and 1969 (where one can reasonably proxy price expectations as static) is highly correlated with publicly available information and the bidding behavior of firms owning neighboring leases, but it is not correlated with the bidding behavior of uninformed firms, conditional on the publicly available information. (See Hendricks and Porter (1988).)

A second strong assumption is that there is only one informed bidder on drainage leases. In fact, there are on average 3.87 neighboring leases, as indicated in Table 6. However, there are both institutional and empirical reasons to believe that the informed bidders will coordinate their actions, and effectively bid as one. There are two institutional reasons. First, joint bids are legal, as described above in Section 3. Second, tracts sharing a common pool are typically unitized, to avoid inefficiencies associated with overdrilling. (See Libecap and Wiggins (1985) for more detail.) A unitization agreement allocates revenues from a common pool according to a pre-specified scheme, typically on the basis of acreage above the pool, and serves as an institution to facilitate side payments. (In addition, there is the threat to end the unitization agreement and overdrill, should anyone break an agreement.)

The empirical reasons are several, as well. First, multiple informed bids on a tract were relatively uncommon, as indicated in Table 6. Table 6 reports the frequency distribution of the number of neighboring leases, where there is at least one adjacent lease, as well as the number of bids submitted by firms owning neighboring leases (informed bids), and by non-neighbors (uninformed bids). Note that the frequency distribution of the number of neighbor bids is almost the same before and after 1970, with mean about one, despite the increase in the average number of adjacent tracts after 1970. Second, multiple neighbor bids tended to occur on high value tracts, and ex post returns were higher than on single bid tracts, rather than lower, as might be expected from competitive bidding. Finally, the potential winner's curse problems faced by uninformed bidders are augmented by the presence of multiple competing informed bidders. If uninformed bidders have access to public signals alone, they should not participate. Yet the bidding of uninformed bidders appears to be independent of the number of firms owning neighboring leases. All three of these facts are consistent with coordinated bidding by informed firms, where multiple bids are occasionally submitted to create the appearance of competition. (See Porter and Zona (1992) for an account of a collusive scheme that similarly relied on non-serious bids.) The facts are also consistent with one of the informed bidders having superior information, and the others being akin to the uninformed firms, with the same empirical predictions.

The third and fourth predictions, concerning profits, are borne out by the data, as demonstrated in Table 7, which differentiates between tracts won by neighbors and non-neighbors, and within those categories depending on whether the other type of firm submitted a bid. Profits are reported only for the 1959-1973 subsample, where the figures are more reliable. Consistent with the third prediction above, uninformed firms break even approximately, and lose money on tracts where no informed firm bids.

On drainage tracts, HPB calculate that firms capture about a third of social rents, compared to a quarter on wildcat tracts. Nevertheless, fewer bids are submitted on average (2.45 on drainage leases versus 3.52 on wildcat leases, in the 1954-1979 sample). Entry appears to be inhibited by informational barriers to entry, and non-neighboring firms break even on average.

As for the first two predictions, as illustrated in Figure 2b, only the first is borne out, as Figure 3 demonstrates. Figure 3 depicts the empirical distribution function of the highest informed and uninformed bid submitted on the 295 drainage tracts that were offered for sale and received bids in the period 1959-1979. The informed firms indeed bid more often, as indicated by the height of the distribution functions at zero, and submit the highest bid more often (on 61.4 percent of the leases). However, there is no evidence of a mass point at the announced reserve price, which is about $62,500 (at $25 per acre for 2,500 acres, the average drainage tract size). Nor do the distribution functions coincide above the reserve price, although they are similar above $4 million. The striking aspect of Figure 3 is not that uninformed firms submit bids less often, but rather that when they bid, they tend to submit high bids.

Another assumption of the preceding theory is that the government accepts all bids above the announced reserve price. On the contrary, they rejected 58 of the 295 high bids submitted on drainage tracts, or 19.7 percent. Table 8 compares bidding on accepted and rejected drainage tracts. Two aspects are of note. First, a higher fraction of rejected bids are by informed firms. Second, the government is much more likely to reject a bid if it is low, in an absolute sense. (This is analogous to the rejection policy on wildcat tracts, as described in Section 3.)

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

The theory is too simple in that it assumes that the government has no private information of its own, and because the bidders do not account for the possibility of a reoffering in the event that the low bid is rejected. On the latter point, it is notable that less than a third of the tracts with rejected bids were reoffered, and reofferings occurred a year and a half later on average. (See Hendricks, Porter, and Spady (1989).) Therefore, it is not unreasonable to assume that firms ignore the possible repercussions of their bidding for future reofferings. On the former point, the government also has access only to seismic information before the auction, and submitted bids do not seem to influence reserve prices, except when more than three bids are submitted. (The informed firms may submit multiple bids on valuable tracts precisely to manipulate bid adequacy decisions in these cases.) As HPW demonstrate, if one accounts for private information observed by the government, then the theoretical predictions of the example above continue to hold. They show that the distribution of the informed bid should stochastically dominate that of the maximum uninformed bid, and the distributions should coincide above the support of the reserve price. These predictions are satisfied by the empirical distribution in Figure 3.

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

6. AN ASSESSMENT OF THE MECHANISM

Is the OCS auction mechanism optimal? Essentially, the issues are: whether undue rents are being captured by the firms in the bidding game, either because of lack of competition, capital constraints, or insufficient (or asymmetric) information; whether rents are dissipated via excess drilling, due to costly duplication of effort in generating common information; and whether the rate at which tracts have been offered for sale has been sensible.

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

Owners of adjacent leases extract sizable information rents in drainage lease sales. To the extent that profits in subsequent drainage sales are anticipated, expected future drainage rents are likely to be reflected in bidding for wildcat leases. If subsequent profits are not anticipated, perhaps because drainage sales do not always follow wildcat sales, then the government could increase royalty rates on drainage leases. The Bayesian Nash equilibrium of the asymmetric bidding game predicts that non-neighbors earn zero expected profits, if they have access only to public information. Then a higher royalty rate serves as a tax solely on the firms owning neighboring leases, and with access to superior information. The problem is that for tracts with relatively small deposits, it would no longer pay to bid at all. In addition, a higher royalty rate exacerbates the moral hazard problem of less ex post exploration than is socially optimal. These arguments assume that a royalty on revenues would be employed, given the difficulties in measuring costs. Alternatively, royalties might apply only to revenues above some prespecified estimate of likely drilling costs, based on industry averages. Nevertheless, some caution is in order, since changing the rules of drainage auctions would probably alter bidding and exploration decisions on wildcat leases, which are qualitatively much more important.

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

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

Another issue is whether more information could be made available prior to wildcat sales. Under current practice, firms acquire a risky prospect, and royalty schemes do not provide much insurance. In particular, they do not provide any insurance for drilling costs, since royalties apply only to revenues. As on drainage sales, royalties on wildcat leases should also only apply to revenues above a predetermined level. One reason why the government sells leases is so that it does not get into the drilling business itself. However, the theory of optimal auction design when there is noncooperative bidding suggests that the government should make public as much information as possible. If collusive bidding is a concern, then a random reservation price policy, or else higher announced reserve prices on valuable tracts, can be used.

It is clear from Table 1 that there was a fundamental policy change in the 1980s, as the rate at which tracts were offered for sale increased dramatically. This increase coincided with a fall in the real price of oil and gas, and so may have been mistimed. One might argue that any tract with positive net present value should be leased as quickly as possible, given that the U.S. is probably a price taker on world oil markets (at least with respect to offshore supply). In addition, there are clear political motives to bring revenues forward. Nevertheless, the U.S. may want to delay some lease sales. The public sector has a monopoly position on offshore oil and gas rights, and may be able to raise the price it receives by restricting supply. There may have been a problem in the 1980s, as the number of tracts offered for sale may have exceeded industry capacity to explore them. Also, with so many tracts on the market, it might be easier for firms to subdivide the OCS lands, say by geographic regions, and suppress competition. The preceding discussion is speculative, but there has been much less bidding on offshore prospects since 1983.

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

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Table 1: Summary of Offshore Oil and Gas Lease Sales, 1954-1990*

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

*Dollar figures are nominal, and in millions of dollars.

Table 2: Characteristics of Wildcat Tracts 1954-1979, by Number of Bidders*

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

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

Table 3: Number of Bids and Rejection Decisions on Wildcat Tracts*

	Number of Bidders								Mean # of Bids	Mean Bid
	1	2	3	4	5-6	7-9	10-18	Total		
1954-1969										
Accepted Bids	339 (.819)	213 (.982)	106 (.982)	103 (1.0)	126 (1.0)	114 (1.0)	55 (1.0)	1056 (.929)	3.46 (0.09)	2.671 (0.159)
Rejected Bids	75 (.181)	4 (.018)	2 (.018)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	81 (.071)	1.10 (0.04)	0.219 (0.021)
All Tracts	414	217	108	103	126	114	55	1137	3.29 (0.08)	2.496 (0.149)
1970-1979										
Accepted Bids	368 (.754)	211 (.858)	135 (.918)	104 (.954)	137 (.993)	119 (.992)	125 (1.0)	1199 (.873)	4.03 (0.10)	9.067 (0.393)
Rejected Bids	120 (.246)	35 (.142)	12 (.082)	5 (.046)	1 (.007)	1 (.008)	0 (0.0)	174 (.127)	1.49 (0.07)	1.095 (0.112)
All Tracts	488	246	147	109	138	120	125	1373	3.71 (0.09)	8.056 (0.345)
1954-1979										
Accepted Bids	707 (.784)	424 (.916)	241 (.945)	207 (.976)	263 (.996)	233 (.996)	180 (1.0)	2255 (.898)	3.76 (0.07)	6.071 (0.232)
Rejected Bids	195 (.216)	39 (.084)	14 (.055)	5 (.024)	1 (.004)	1 (.004)	0 (0.0)	255 (.102)	1.36 (0.05)	0.816 (0.081)
All Tracts	902	463	255	212	264	234	180	2510	3.52 (0.06)	5.538 (0.211)

*The numbers in parentheses are the fraction of the total, except for the mean number of bids and the mean high bid, where they are standard errors of the sample means. Bids are in millions of 1972 dollars.

Table 4: Wildcat Bidding by Large Firms, 1954-1979*

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

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

Figure 1: Hazard Rate for Exploratory Drilling on Wildcat Tracts, 1954-1990

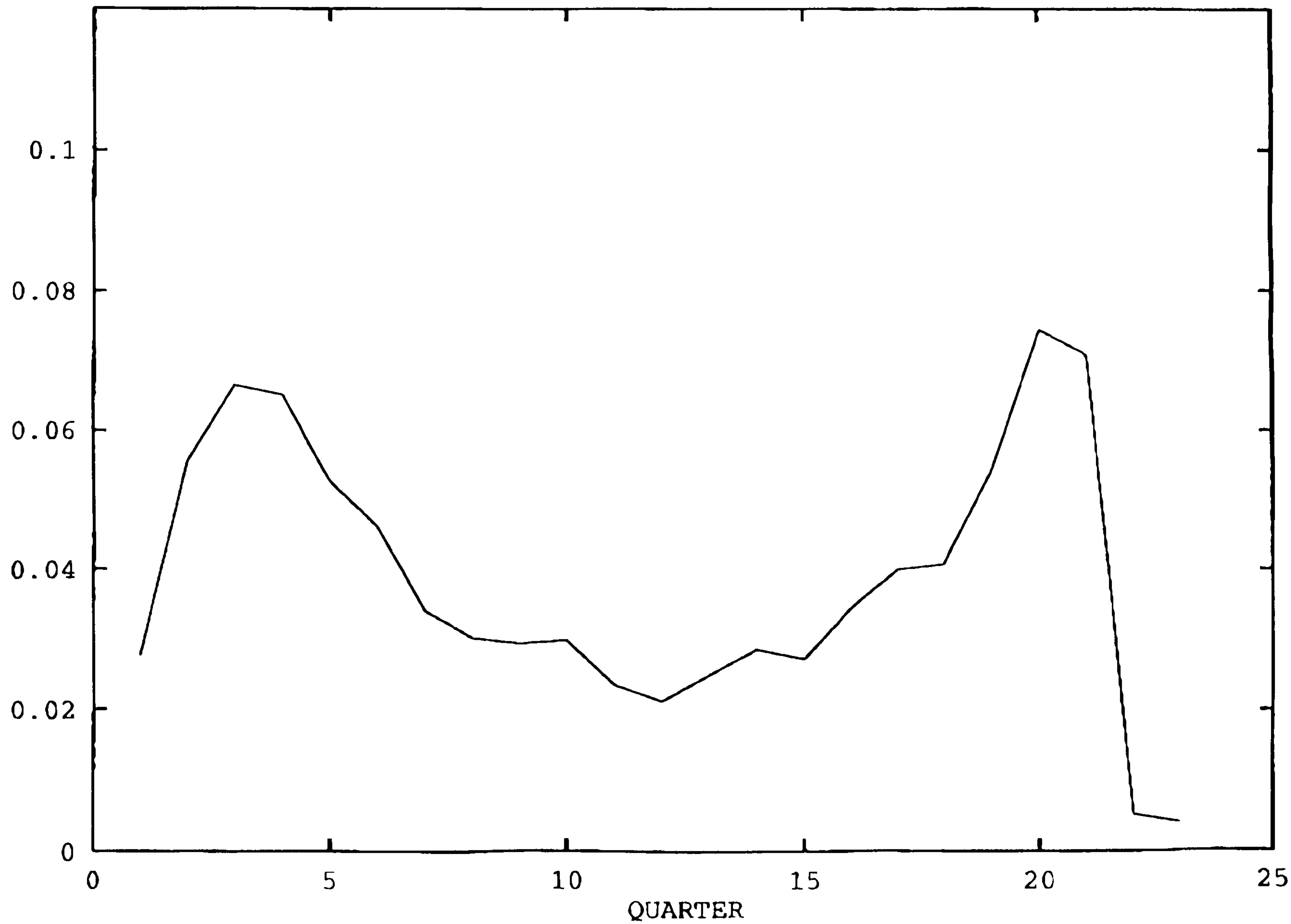


Table 5: Wildcat Tract Characteristics 1954-1979, by Year of Initial Drilling*

	Year After Acquisition				
	1	2	3	4	5
Risk Set					
Number	218[illegible]	1456	1075	879	732
BID	14.50	13.93	13.62	13.47	13.40
	(1.62)	(1.47)	(1.40)	(1.40)	(1.41)
No. of Bids	3.81	2.87	2.46	2.31	2.18
	(3.28)	(2.44)	(2.04)	(1.94)	(1.81)
Tracts Drilled					
Number	728	381	196	147	217
(fraction)	(0.333)	(0.262)	(0.182)	(0.167)	(0.298)
BID	15.65	14.80	14.29	13.82	13.48
	(1.26)	(1.30)	(1.21)	(1.28)	(1.21)
BIDDIF	0.769	0.679	0.579	0.525	0.213
	(0.041)	(0.058)	(0.078)	(0.098)	(0.075)
No. of Bids	5.68	4.05	3.11	2.99	2.37
	(3.90)	(3.02)	(2.35)	(2.36)	(1.81)
HIT	413	172	91	66	85
(fraction)	(0.567)	(0.451)	(0.464)	(0.449)	(0.392)
REV	16.32	15.54	15.60	15.57	15.17
	(1.50)	(1.72)	(1.72)	(1.98)	(1.53)

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

Figure 2a
Bid Function for Example with Fixed Reserve Price

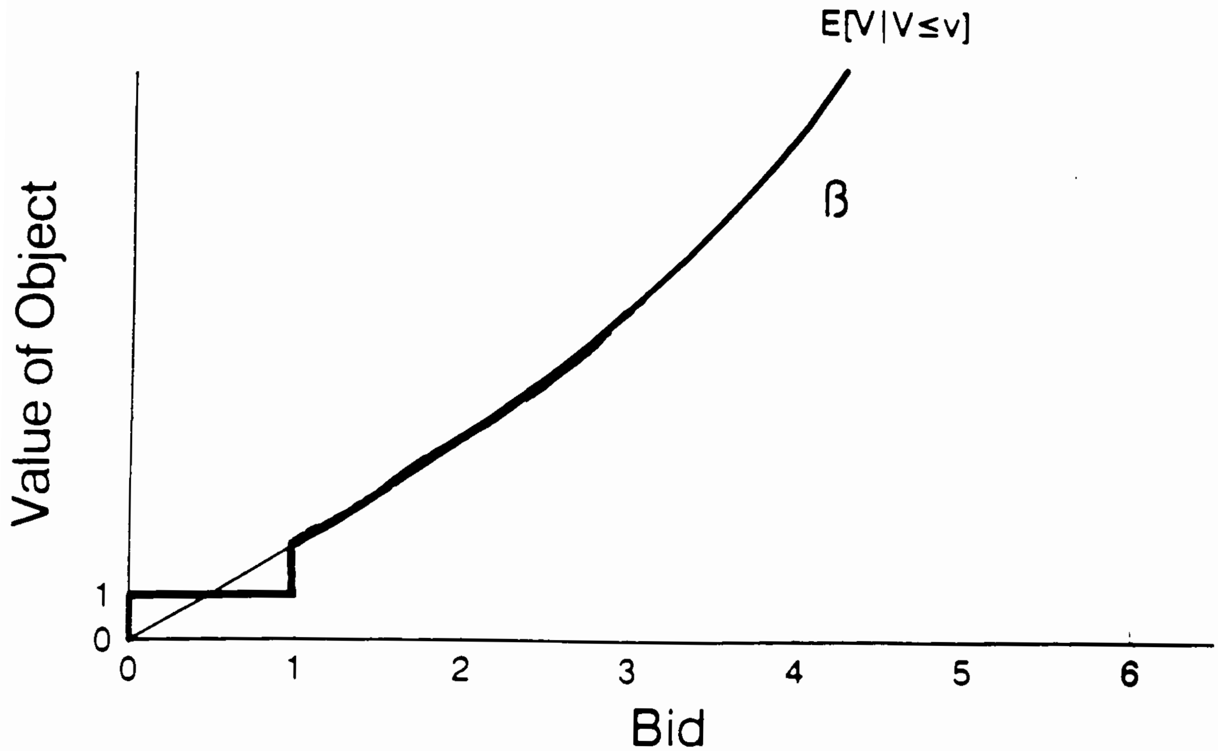


Figure 2b
Bid Distribution Functions for Example with Fixed Reserve Price

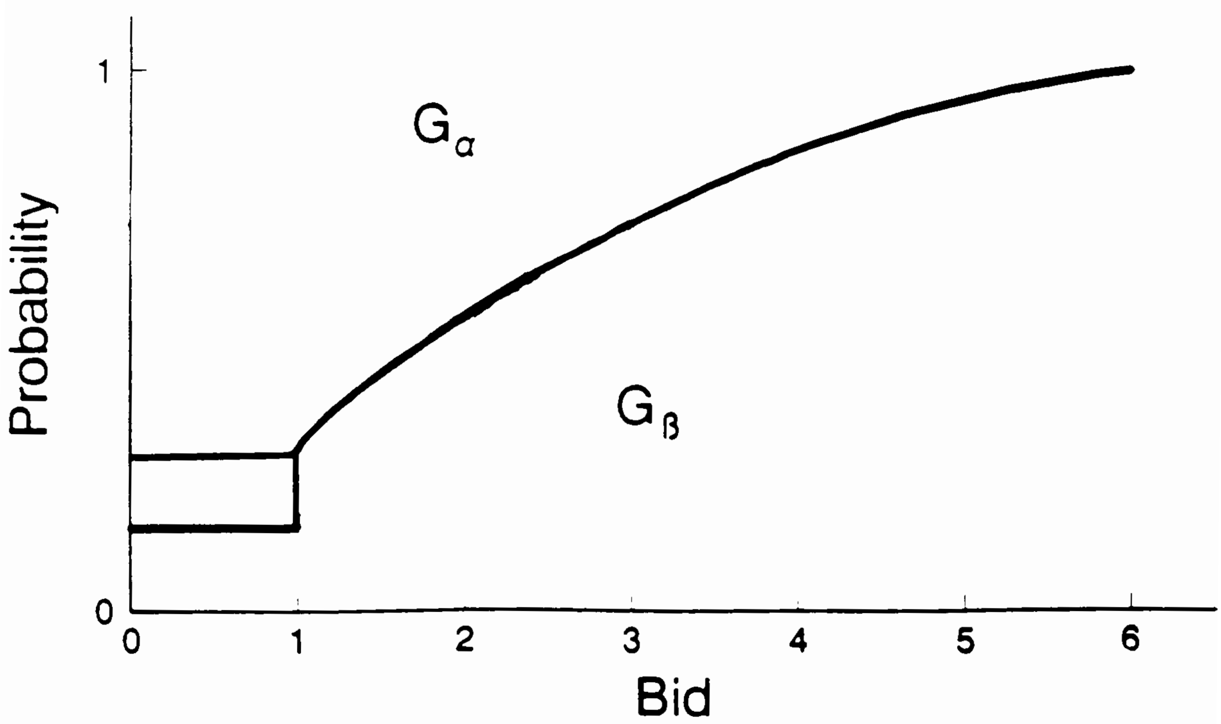


Table 6: Frequency Distributions on Drainage Tracts

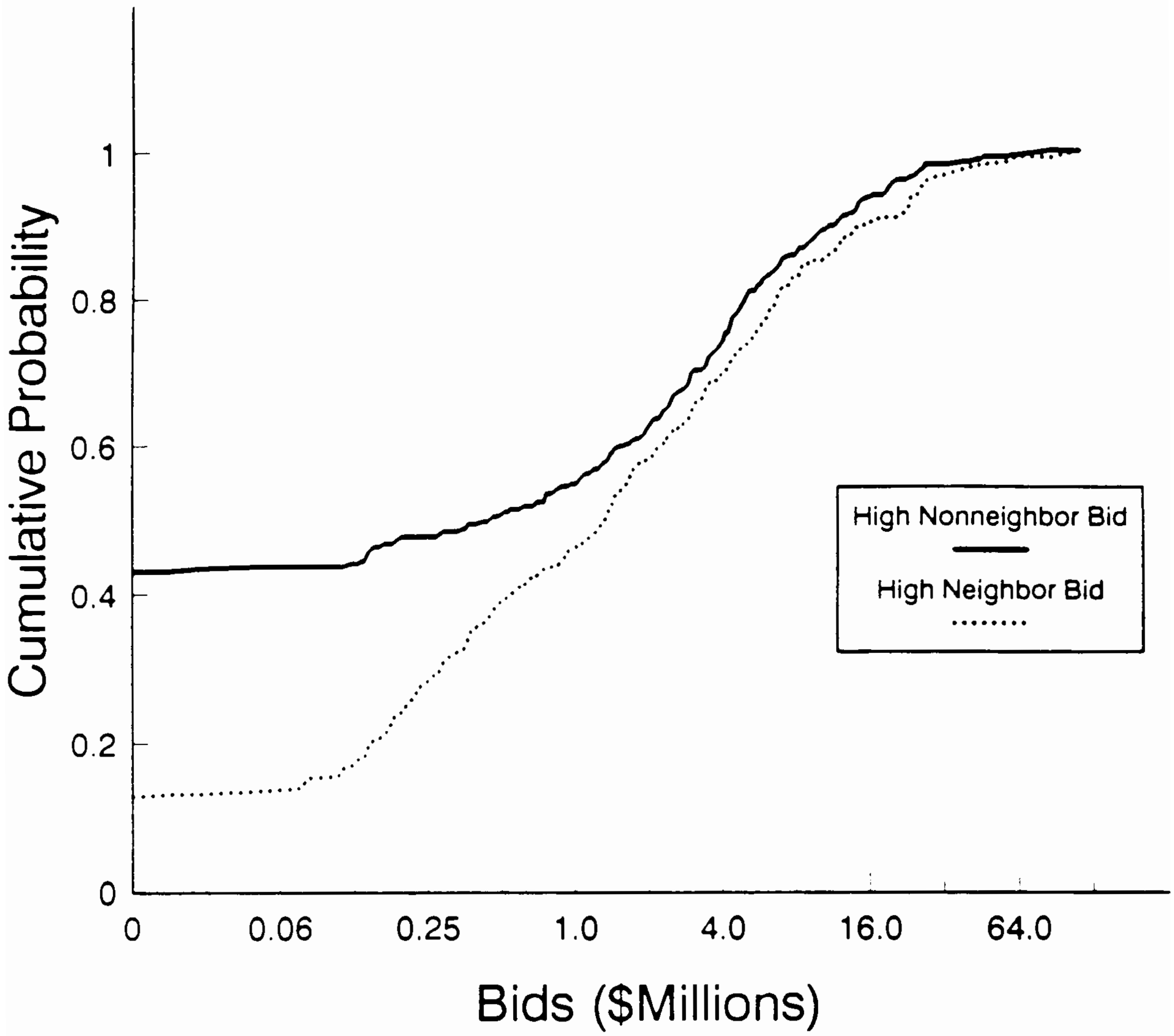
	Number							Mean
	0	1	2	3	4	5-6	7-12	
1959-1969:								
Neighbor Tracts	0	19	36	19	12	14	7	3.04
Neighbor Bids	12	80	14	0	1	0	0	1.05
Non-Neighbor Bids	46	31	11	11	2	2	4	1.35
1970-1979:								
Neighbor Tracts	0	14	34	40	26	43	31	4.21
Neighbor Bids	30	118	33	6	1	0	0	1.10
Non-Neighbor Bids	76	46	36	11	6	9	4	1.38
1959-1979:								
Neighbor Tracts	0	33	70	59	38	57	38	3.78
Neighbor Bids	42	198	47	6	2	0	0	1.08
Non-Neighbor Bids	122	77	47	22	8	11	8	1.37

Table 7: Bidding on Drainage Tracts, by Type of Bidder*

	Wins by Neighbor Firms		Wins by Non-Neighbor Firms		
	No N-N Bid	Total	No N Bid	N Bid	Total
1954-1979:					
No. of Tracts	77	135	32	70	102
No. Drilled	60	117	27	67	94
No. Productive	46	95	12	40	52
(fraction of total)	(0.60)	(0.70)	(0.38)	(0.57)	(0.51)
Mean Winning Bid	5.19	10.16	3.31	8.90	7.14
	(1.09)	(1.55)	(0.85)	(1.30)	(0.96)
Mean Disc. Revenues	11.67	19.83	4.24	18.29	13.88
	(2.60)	(3.14)	(1.57)	(4.16)	(2.96)
1954-1973:					
No. of Tracts	43	75	12	37	49
Mean Net Profits	1.56	4.93	-2.00	1.83	0.89
	(1.82)	(2.41)	(0.92)	(3.23)	(2.45)

*Dollars figures are in millions of 1972 dollars. Except where noted, standard errors of sample means are displayed in parentheses.

Figure 3
Distribution of Bids on Drainage Tracts, 1959-1979



All bids are represented in 1972 dollars.

Table 8: Comparison of Accepted and Rejected Drainage Bids, 1959-1979*

	Accepted	Rejected
Largest Neighbor Bid	7.047 (0.971)	1.165 (0.310)
Largest Non-Neighbor Bid	5.088 (0.667)	0.319 (0.116)
High Bid	8.861 (0.978)	1.453 (0.312)
No. of Neighbor Bids	1.11 (0.04)	0.93 (0.07)
No. of Non-Neighbor Bids	1.62 (0.13)	0.33 (0.09)
No. of Bids	2.73 (0.14)	1.26 (0.30)
No. of Neighbor Tracts	3.73 (0.14)	4.00 (0.30)
Fraction with High Bid by Neighbor	0.57	0.79
No. of Tracts	237	58

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

Figure 4a

Bid Functions for Example with Unknown Reserve Price

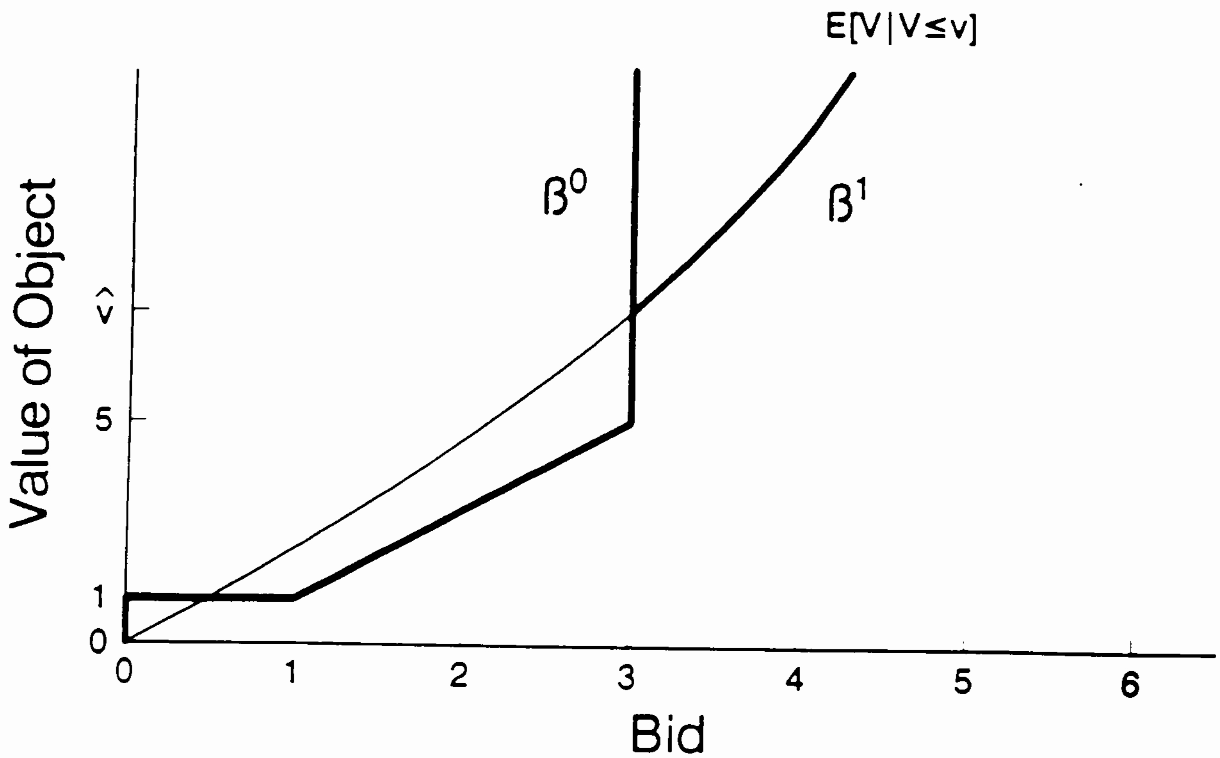


Figure 4b

Bid Distribution Functions for Example with Unknown Reserve Price