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DETERMINANTS OF THE TIMING AND INCIDENCE OF EXPLORATORY DRILLING ON OFFSHORE WILDCAT TRACTS

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ABSTRACT

This paper documents exploratory drilling activity on offshore wildcat oil and gas leases in the Gulf of Mexico that were sold between 1954 and 1990, with emphasis on the period before 1980. For each year of the lease, we study the determinants of the decision whether or not to begin exploratory drilling, and the outcome of any drilling activity. Our results indicate that equilibrium predictions of plausible noncooperative models are reasonably accurate, and more descriptive than those of cooperative models of drilling timing. We discuss why noncooperative behavior may occur, and the potential gains from coordination.

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I. INTRODUCTION

Beginning in 1954, the United States government has auctioned the oil and gas rights to the offshore federal lands, in thousands of parcels. These parcels, known as tracts, cover five thousand acres on average. Tracts are large by onshore standards, although not necessarily by the standards of typical hydrocarbon fields. Purchase of a tract does not obligate the buyer to conduct exploratory drilling. Indeed, Kenneth Hendricks, Robert Porter and Bryan Boudreau (1987), in their study of Outer Continental Shelf (OCS) tracts off the coasts of Texas and Louisiana sold between 1954 and 1969, document that twenty-nine percent of wildcat leases expired without any wells being drilled. The tracts with expired leases received bonus bids averaging $800,000 in 1972 dollars. The lease term was five years in this period.

The oil and gas rights to OCS wildcat leases are sold simultaneously in a first price sealed bid auction. A wildcat sale consists of tracts in areas where there has not been prior exploratory drilling, and no on-site drilling is permitted prior to the sale. Firms have access only to seismic information, and as a consequence face considerable uncertainty. Typically, more than a hundred tracts are sold at once. The tracts tend to be scattered throughout the region, but clusters of tracts are not uncommon. Further, tracts within the same area often share common geological features, and a subset may be located over a common pool. In either case, the ex post value of nearby leases will be correlated. Hence, there is an information externality associated with exploratory drilling, and noncooperative drilling plans may be inefficient.

This paper documents exploratory drilling activity on wildcat OCS tracts in the Gulf of Mexico that were sold between 1954 and 1990, with particular emphasis on those sold before 1980. For each year of the lease, we study the determinants of the decision whether or not to begin exploratory drilling, and the outcome of any drilling activity. The purpose is not to estimate a structural model, but rather to provide some empirical regularities as a prelude to future structural modelling. Our results indicate, however, that "reduced form" predictions of plausible noncooperative game theoretic models are reasonably accurate.

We focus our attention on tracts with five year leases, which account for the vast majority of tracts sold in the Gulf of Mexico in our sample period. The lease term applies only to the exploration phase. A lease is relinquished if exploratory activity has not begun by the end of the lease term. However, if exploration is successful, and the tract is productive, then the lease is automatically renewed. The lease of a productive tract is terminated when production stops. The five year lease term will affect the exploration decision, but not developmental drilling or subsequent production decisions. Therefore, we focus on exploratory drilling.

The exploration decision is a costly one, in that unsuccessful drilling can cost millions of dollars. In addition, outcomes are uncertain. In our sample, only half of the tracts that were explored yielded positive revenues (i.e., production was commercially viable), and so many tracts were unprofitable, ex post. Further, revenues on productive tracts were quite variable. For example, the sample standard deviation of the logarithm of discounted revenues on productive tracts is approximately 1.5. As a result, information concerning likely drilling outcomes could have been quite valuable.

We believe that the decision to abandon tracts without exploratory drilling is a rational one, and in part reflects the arrival of post-sale information. A lease is like an option to drill, and the drilling decision akin to the (costly) exercise of an option. The option may not be exercised for one of several reasons. First, the winner of the auction discovers which rival firms bid, if any, on the tracts offered for sale, and at what level. This information is released at a public meeting held shortly after the sale. Second, a firm may acquire more tracts than anticipated, and not be capable of exploring them all within the lease term. This is unlikely to account for abandonment of leases, because there is an active rental market in drilling rigs. Third, if oil or gas prices fall unexpectedly after the lease sale, then marginally profitable tracts will be abandoned. In our sample, real wellhead prices are virtually constant prior to 1973, and the timing and incidence of drilling is similar before and after 1973. (Most oil price surprises between 1973 and 1980 were favorable to the industry.) More generally, as noted by James Paddock, Daniel Siegel and James Smith (1988), the option holder has an incentive to wait to the end of the lease if there is sufficient uncertainty concerning prices.

Finally, if exploration is delayed, the lease holder could observe drilling outcomes on neighboring tracts. In our 1988 study of drainage auctions, we argued that tract productivities are highly correlated within narrow geographic areas, and that drilling outcomes on neighboring tracts are more accurate predictors of tract productivity than seismic records. Because drilling is costly, there is a consequent incentive to delay, and free ride on any information acquisition on neighboring leases. As Hendricks and Dan Kovenock (1989) demonstrate, some equilibria of these games of timing result in delay, relative to an optimal plan. These situations are sometimes described as wars of attrition. (See also Hendricks and Charles Wilson (1989) and Mark Isaac (1987).) The symmetric (mixed strategy) equilibrium outcome of these finite horizon games of timing exhibits a deadline effect. At the end of the lease, there should be an increase in the number of tracts that are explored, relative to the number of previously unexplored tracts. In our data, both the number of tracts drilled and the hazard rate (the proportion of remaining, or not yet explored, tracts that are drilled) are declining functions of the number of quarters that the lease has been held, except in the last year, when both rates increase dramatically. That is, both the fraction of tracts drilled and the associated hazard rate follow a U-shaped pattern over the term of the lease. Such a deadline effect is also present in the data for the individual sale years in our sample, so that it cannot easily be ascribed to aggregation over dissimilar samples.

In addition, we present some evidence that firms update their information rationally. Initially, a tract is more likely to be explored the more the lease owner bid to acquire it, but as time progresses bid levels are decreasingly accurate predictors of whether drilling will be initiated. Instead, firms appear to be increasingly reliant on the information generated by post-sale drilling activity in the local geographic area. We also present some evidence that if lease holdings in an area are relatively asymmetric, then drilling is less likely to be delayed, consistent with the internalization of information externalities.

We also examine drilling outcomes, and whether they are correlated with the determinants of drilling activity. We find that the determinants are correlated with drilling outcomes, but there is some evidence of over-response to some factors.

Finally, we present a simple theoretical model of the timing decision, and compare noncooperative equilibria and optimal coordinated drilling plans. We argue that the incidence and timing patterns in our data are more consistent with noncooperative behavior. We discuss why noncooperative behavior may predominate, and we describe the potential gains from coordination.

The exploration decision has been examined previously by Dennis Epple (1985), Scott Farrow and Marshall Rose (1992), Franklin Fisher (1964), Hendricks and Alfonso Novales (1987), Frederick Peterson (1975), and Peter Reiss (1990), among others. Several of these authors have noted that information externalities may be an important factor in exploration. The empirical studies have employed more aggregate data than ours. An advantage of our data set is that we observe both actions and outcomes on individual tracts. That is, our data set contains unusually detailed information.

II. QUARTERLY HAZARD RATES, 1954-1990

Before discussing drilling decisions at annual frequencies for our comprehensive 1954-1979 data set, we begin by analyzing quarterly drilling patterns for the full 1954-1990 sample. There are 6,178 wildcat tracts in our larger sample, which includes tracts sold by March 21, 1990. A wildcat lease is in an area that has not been explored previously, and only seismic surveys are permitted prior to wildcat auctions. We restrict attention to tracts off the coasts of Texas and Louisiana, where the high bid was accepted, and firms submitted fixed bonus bids with royalty payments preset at one sixth of revenues. (Some tracts were sold under alternative auction rules, and have been deleted from our sample.) All tracts had five year leases. We aggregate the monthly drilling data to the quarterly level, because it takes about three months to set up and begin an exploratory drilling program.

Some tracts are drilled after the twentieth quarter, and are classified as such. For a few tracts, drilling records indicate that initial drilling began after the twenty-third quarter; these tracts are classified as never explored. Tracts registered as first drilled after the twentieth quarter are either misclassified, or else exploration began in time but drilling itself started after the five year clock expired. Alternatively, an extension may have been granted if the government delayed the sale of the tract, in the process of deciding whether to reject the winning bid as inadequate.

Table 1 describes the first quarter in which drilling began for each lease, as well as the number of leases that were never explored. Because our drilling information only covers up to January 1991, there is some attrition from the sample due to censoring in later quarters. For example, if a tract sold in December 1989 had not been drilled on or before January 31, 1991, we do not know whether it was drilled after the fourth quarter of its lease. The risk set includes the tracts remaining in a given quarter that had not yet been drilled. The risk set therefore falls over time as tracts are drilled, or if we can no longer observe whether they have been drilled.

The striking feature of Table 1 is the U-shaped pattern in the number of tracts drilled in a given quarter, and especially in the (Kaplan-Meier) hazard rate. The quarterly hazard rate is plotted in Figure 1. There is an increase in both numbers at the beginning of the lease term, as there is an adjustment period in setting up an exploratory drilling program. (The initial increase in the hazard rate is also characteristic of some noncooperative drilling equilibria, as we demonstrate below in Section VI.) Thereafter, the hazard rate declines monotonically until the twelfth quarter, slowly increases after that, and then jumps up in the quarters 19, 20, and 21, with a peak in quarter 20. In this sample, 30 percent of the 4,112 tracts in the potential risk set in quarter 23 were never explored. A similar pattern is evident if the drilling data are plotted at monthly or annual frequencies.

The table reports standard errors for the hazard rates. If H_t is the hazard rate in quarter t, and R_t the size of the risk set, then the variance of the hazard is $H_t(1 - H_t)/R_t$. The standard error of the difference in hazard rates over time can then be approximated by the square root of the sum of the individual variances. (This is an approximation, because the hazard rates in different periods are not independent.) By this method, the increase in the hazard rate between quarters 19 and 20 is significant, with a t-statistic of 2.34.

Tracts sold in the 1980s may be somewhat unrepresentative, because the number of tracts offered for sale increased rapidly. Therefore, the rate of exploration may have slowed, and the fraction of leases that were never explored may have increased. In this sample, 2,255 tracts were sold in the 1954-1979 period, and 3,923 during 1980-1990. As a check on whether our more detailed 1954-1979 data set is similar to the full 1954-1990 sample, Table 2 reproduces the calculations of Table 1 for the 1954-1979 period. Note that, in the 1954-1979 sample, there is no censoring of observations. As might be expected, a smaller fraction of tracts were never explored, 24 percent, but a similar pattern in the hazard rates is evident, as Figure 2 depicts.

III. THE 1954-1979 DATA

Our comprehensive data set consists of wildcat tracts off the coasts of Texas and Louisiana that were auctioned between 1954 and 1979, inclusive. In our sample period, 2,510 tracts received bids. The high bid was rejected by the government on 255 tracts, and so 2,255 leases were sold. All were five year leases, with ownership reverting to the government if exploration did not begin within that period. In 75 cases, exploratory drilling began after the five year lease horizon, according to well drilling records, and we classify these tracts as being never drilled. (The following results do not change much if these tracts are classified as having been drilled in the fifth or sixth year after acquisition.)

The government has divided this offshore region into 51 separate geographical areas. For the purposes of this paper, we consider all tracts within a given area to be potential neighbors. This is almost surely too broad a classification of the set of tracts with correlated deposit sizes, but the implementation of a finer (and more accurate) definition would be difficult. On the other hand, adjoining leases may lie in two different areas. (One could exploit spatial correlation methods, as in Anne Case (1991). The difficulty in our data set would be matching tract identification measures with tract locations, in order to compute distances. Also, the degree of spatial correlation is probably not uniform over the region we consider.) For each area, we create three variables to capture local drilling experience. They include the total number of tracts explored to date (the number drilled), the number of drilled tracts that were productive (the number of hits), and total discoveries on productive tracts (the sum of the logarithm of discounted real revenues on productive tracts -- where a 5 percent discount rate is employed, and wellhead prices in 1972 dollars as of the date of sale of individual tracts are used to evaluate oil, gas, condensate and miscellaneous production.) In our regressions, we employ the change in all three historical variables since the sale date for individual tracts for each year after they were acquired (that is, the post-sale experience in the relevant area). These post-sale variables are denoted DRPOST, HITPOST, and REVPOST. The three variables employed are the logarithm of (one plus) the total number of tracts explored since the sale date (DRPOST; it equals zero if there were no tracts drilled), the logarithm of (one plus) the number of drilled tracts that were productive (HITPOST; again, zero if there are no hits), and the mean of the logarithm of discounted revenues on productive tracts (REVPOST; it equals zero if there are no hits). For example, HITPOST in the fourth year after acquisition is the logarithm of the number of productive tracts drilled in that area in the preceding three years. The post-sale variables all equal zero in the first year after the sale date, and so do not appear in the year 1 regressions.

The data set also includes several other variables of note. BID is the logarithm of the winning bid for the tract, and represents our best measure of pre-sale beliefs about the value of the tract by the winning firm. Of course, a firm's bid is some fraction of its expectation of tract value, where this fraction depends on the perceived degree of competition as well as the precision of ex ante information. Nevertheless, a significant component of the difference across tracts in prior expectations of value is likely to be accounted for by the bid level.

To account for the level of competition, we also include the logarithm of the number of bids submitted for each tract (NBID), as well as a dummy variable that equals one if the winning bid was the only bid submitted (ONEBID). We also include a "money left on the table" variable, MLT, defined as the logarithm of the ratio of the highest to the second highest bid. In cases where there is one bid, the announced reserve price is employed instead of the second highest bid. Because money left on the table has a different connotation in this event, we also include a ONEBID x MLT interaction term. All of these "competition" variables might affect subsequent drilling decisions if firms' expectations of tract profitability change when they see whether, and how much, other firms bid. For example, they may learn to their surprise that other firms did not share their optimistic expectations, and so be less likely to begin exploration. Alternatively, if they knew beforehand that they alone were optimistic, then they will have bid less relative to their expectations and, for a given bid level, they will be more likely to initiate exploration.

In order to account for the severity of potential war of attrition problems, we also include HERF, a Herfindahl index of the dispersion of lease holdings among solo bidders in the relevant area and sale year. For this measure, bids are classified as solo if there was one bidder, or only one experienced partner (and that firm had at least a fifty percent share) in a joint bid. For each area and sale year, we compute each bidder's share of the leases acquired by solo bidders. HERF is the sum of these shares squared. It equals one if one firm acquired all the solo bid leases, and 1/N if N firms split the leases equally. Thus higher values of HERF correspond to more asymmetric lease holdings and, as we shall see later, greater coordination in the noncooperative equilibria of wars of attrition. In particular, in areas with high values of HERF, there should be less delay due to strategic information acquisition. We also include PCTJT, which is defined as the fraction of leases in the relevant area and sale year that were acquired by joint bidders (excluding those that were classified as solo for the construction of HERF). The idea is that higher values of PCTJT may be associated with situations where wars of attrition are less likely to arise.

Our data set also includes tract characteristics, such as the logarithm of tract acreage (ACRE) and the date of sale. Some blocks that are ex ante believed to be more valuable are split into two tracts for the wildcat auction. Such divisions may exacerbate war of attrition problems, unless the tracts are known to be productive, in which case tracts with smaller acreage are more likely to be drilled right away. We include the ACRE variable to capture these effects. ACRE is unlikely to reflect scale economies.

We employ a set of yearly dummy variables, to account for variations in oil and gas prices and expectations of these prices, as well as year-to-year variations in the perceived productivity of tracts offered for sale. There is substantial variability over time in the productivity of leased tracts.

We also employ a set of area dummy variables, to capture area-specific variations in perceived deposits or in drilling costs, that might not be reflected in the bids.

The dummy variable REOFFER equals one if the tract is being reoffered. Tracts may be sold a second (or third) time if the government previously rejected the high bid, or if a previous leaseholder relinquished the lease without drilling. There are 158 reoffered tracts in our sample, 107 of which were reoffered after a high bid was rejected.

Finally, Hendricks and Porter (1992) document that a substantial fraction of bids are joint bids. The incentives to conduct risky activities such as exploration may differ for bidding consortia, as suggested by Mark Wolfson (1985) for example. Accordingly, the dummy variable JOINT equals one if the winning bid is submitted by a consortium of firms. We also experimented with dummy variables for the different types of joint and solo bids, as described by Hendricks and Porter (1992), but JOINT appears to be sufficient for our purposes.

IV. AGGREGATE DRILLING ACTIVITY

We now describe our detailed annual data set, covering 1954 through 1979. Table 3 indicates, for each wildcat sale year, the timing of initial exploratory drilling, and the number of leases that were allowed to expire without any drilling. The U-shaped pattern in hazard rates is also apparent at annual frequencies, as demonstrated in the final row of the table. Also, note that a similar pattern emerges for each sale year. There is year-to-year variation, but the aggregation of constant but heterogeneous hazards over several sales does not seem to be the explanation for the U-shaped aggregate hazard rate. Heterogeneity across or within sales can account for negative duration dependence, or a decreasing hazard function, but it cannot explain the increasing hazard function at the end of the lease term.

Table 4 takes a first look at the determinants of drilling activity. For each year of the lease, it reports the number of tracts not yet explored (the risk set), and how many were drilled, as well as characteristics of the two sets. The average number of bidders is reported, together with the mean of the logarithm of the high bid in 1972 dollars (BID). HIT describes the number of explored tracts where there was subsequent production, and REV the mean of the logarithm of discounted revenues on productive tracts. (Again, production is valued at wellhead prices in 1972 dollars in the sale year, and discounted at a five percent rate. To the extent that firms anticipated any post-sale changes in real prices, this is a flawed measure of revenues. However, like the history variable REVPOST, REV captures big strikes. It may be preferable to view REV as an output measure, where relative prices at the sale date indicate how to aggregate oil, gas, condensate and miscellaneous production.) Finally, BIDDIF measures the difference between BID on tracts that were drilled, and the average level of BID on tracts in the risk set that were sold in the same year. (This is akin to accounting for sale year specific fixed effects.)

Table 4 indicates that in each lease year, tracts that were a priori judged to be more productive, as indicated by BID, were more likely to be drilled. That is, BIDDIF is significantly positive throughout. However, the magnitude and significance level of BIDDIF wanes further into the lease term. Note also that hit rates, and deposit sizes conditional on a hit, fall over the lease term, and the decreases are largest after the first year and in the final year of the lease. We believe that there are a set of tracts where the prior expectation of profits is sufficiently high that they are likely to be drilled immediately. The remainder are held in reserve, and we argue below that while prior expectations continue to matter, the early drilling experience on tracts sold in that area in the same sale is an important determinant of subsequent drilling decisions. Note also that average bids on drilled tracts fall more than hit rates or average revenues from the second year of the lease term through the fourth year, so that ex post tract profits are increasing over these three years of the lease term for the set of tracts that are drilled. This pattern is consistent with the acquisition of payoff relevant information. Finally, the quality of tracts drilled in the last year of the lease is significantly lower, as reflected by the hit rate and REV.

In this sample, the mean winning bid on the 602 unexplored tracts is $2.86 million dollars (in 1972 dollars). (The mean winning bid for the entire sample of 2,255 wildcat tracts is $6.07 million.) It is worth repeating that abandonment of a tract, without conducting exploratory drilling, entails walking away from substantial sunk costs on average. As a matter of comparison, the average drilling costs on the 897 unproductive tracts in our sample are $1.52 million, based on American Petroleum Institute estimates.

We now turn to a regression based examination of the determinants of the incidence of initial drilling activity, for each year of the lease. Tables 5A and 5B report the estimates from a linear probability model and a probit regression, respectively. For each year of the lease term, the sample is the risk set, the set of tracts not yet explored. The dependent variable in both Tables is a dummy variable equalling one if exploratory drilling began in that year. The explanatory variables are described in Section 3, and include separate sets of dummy variables for each sale year and each area. (Because only 15 tracts were sold in 1976, there is one dummy variable for 1976 and 1977.) The post-sale changes in the area-specific drilling history variables are relevant, and reported, only for the last four years of the lease. All non-qualitative variables are expressed in logarithms, so that the coefficients in the linear probability model of Table 5A can be interpreted as the change in the probability of drilling a tract in the risk set that year associated with a one per cent change in the independent variable, evaluated at the sample means. (To obtain an elasticity measure, divide by the appropriate annual hazard rate.)

Note that the BID coefficient is initially large and significant, but also that it falls over the lease term, and is negative and insignificant by the final year. The coefficients of the other bidding variables indicate that leaseholders do not respond much to the information revealed by their rivals' bids. In particular, the coefficient of the variable measuring money left on the table, MLT, is an order of magnitude smaller than that of BID, and insignificant. Alternatively, this information may have been anticipated by the winning firm when it submitted its bid, and hence is included in BID.

In the first year of the lease term, HERF is positive and significant. This is consistent with asymmetries of lease holdings mitigating any information externalities an enhancing coordination, and therefore reducing any incentive to delay.

Finally, DRPOST is positive and significant throughout the lease term. That is, there is more drilling in areas with substantial post-sale activity, all else equal. If one views DRPOST as a measure of sample size, and HITPOST the number of positive outcomes, then the relative magnitudes of their coefficients is somewhat surprising. One might expect the number of positive outcomes to have a larger coefficient, and perhaps also that the DRPOST coefficient would be negative. The sum of the two coefficients is positive, as expected, indicating that proportional increases in DRPOST and HITPOST increase the likelihood of drilling. The findings suggest that there may be significant unobservable heterogeneity across areas, specific to particular sale dates, that area specific fixed effects do not capture, that are correlated with DRPOST.

The results from these tables should be viewed as suggestive. We have concentrated on relatively simple functional forms, because of uncertainty on our part about the information set facing lease holders. The issue is whether and when information becomes available publicly. We have experimented with different decision frequencies, such as quarterly, and a variety of lag structures for the information variables. The reported specification is representative, and (to our minds) plausible a priori. Firms can certainly observe when their neighbors are drilling, and hits would be difficult to disguise. (For example, developmental wells must be drilled.) More problematic is the implicit assumption that actual production levels are observable. Annual royalty payments are observable, and initial production is correlated with eventual production, so that our discounted production measure is probably a noisy proxy of what firms observe. This may explain why REVPOST does not appear to have much of an effect on drilling decisions, except in the last year of the lease.

V. DRILLING OUTCOMES AND ALTERNATIVE SPECIFICATIONS

Tables 6 and 7 report on the determinants of the probability that a drilled tract is productive, and the logarithm of discounted revenues conditional on a hit, for the set of tracts drilled in each of the five years after the sale date. The set of regressors is the same as in Tables 5A and 5B. Tables 6A and 6B describe the estimates from a linear probability model and a probit regression, respectively, where the dependent variable is a dummy variable equal to one if the tract produced positive discounted revenues, or was a hit by our nomenclature. Table 7 describes a least squares regression for the set of productive tracts. (Analogous results are obtained if the two regressions are combined into a Tobit estimating equation, but there appears to be a gain in not so restricting the mass point.)

The idea behind these regressions is to see whether the determinants of drilling activity are correlated with drilling outcomes. There is an obvious sample selection problem in that we observe outcomes only on tracts that are viewed most favorably and hence drilled. Nevertheless, within the set of drilled tracts, one can still ask how accurate ex ante information is.

For example, the BID coefficients mirror those in Tables 5A and 5B. ACRE is initially negative and (marginally) significant, consistent with smaller tracts being more productive by design. Also, HERF is not significant to begin with, as one would expect if it reflects the selection of a particular equilibrium timing pattern, rather than being correlated with actual productivity differences.

Note that the money left on the table variable, MLT, is initially negative and significant, indicating that firms may not correctly update their beliefs after the auction.

Finally, DRPOST is often negative and significant, in contrast to the coefficients in Tables 5A and 5B. (HITPOST is often positive and significant, as one might expect, and in accordance with Tables 5A and 5B.) To the extent that the positive coefficients of DRPOST in the drilling equation reflect unobservable area specific heterogeneities, the negative coefficients in the productivity equations indicate that firms are not processing information optimally. Of course, this finding should be viewed as preliminary.

Especially in the final columns of Table 7, there are not many degrees of freedom in the reported regressions. For purposes of comparison, Table 8 reports full sample estimates corresponding to the decisions modelled in Tables 5 through 7. The five years are pooled together, and the ex post drilling outcome variables dropped. The results are broadly consistent with those in the preceding Tables.

Finally, Table 9 presents estimates from a pooled logit estimator of the drilling decision. The five years are pooled together in the likelihood function, but the coefficients are not restricted to be equal in the five years, and the ex post drilling outcome variables vary over the lease horizon. Therefore, the coeffcients and a subet of the regressors are time-varying. A tract drilled in the third year of the lease (say) then enters the likelihood function three times, reflecting the decision not to drill in the first two years. Table 9 differs from its predecessors, in that area-specific dummies are not included. (A full set of year-specific dummies are included.) The results are similar to those in Tables 5A and 5B, and especially to corresponding results when area-specific dummies are not included.

We conclude that the results reported in Sections IV and V are relatively robust.

VI. A SIMPLE THEORETICAL MODEL

Suppose that OCS drilling programs are indeed the outcome of a non-cooperative game of timing. We now describe a simple, and probably too simplistic, theoretical model, in order to demonstrate the social costs of uncoordinated drilling activity.

Consider an area with two adjacent wildcat leases, where the bidding process has resulted in ownership of mineral rights by two different firms. Suppose that the lease values are perfectly correlated and equal to V, where V equals 1 with common probability p, and zero with probability 1-p. A firm must pay fixed costs c to initiate a drilling program, where these costs are independent of whether the tract is productive. The value of productive leases, here normalized to equal one, may be thought of as revenues net of royalty payments and the costs of developmental, as opposed to exploratory, wells. Then c represents the costs of exploratory drilling. Assume for the moment that c is less than p, the expected value of a lease, so that the owner of a single isolated lease would choose to conduct exploratory drilling. Also assume that each firm can observe the outcome of its rival's drilling. There is then an informational externality, since a firm can avoid incurring the drilling costs of dry holes if its rival drills first. Finally, lease terms are of length T periods, and firms discount future profits according to a common discount factor β. On the OCS, an appropriate period length is approximately a quarter, corresponding to the amount of time necessary to initiate an exploratory drilling program, and so a five year lease term translates into T equalling 20 quarters.

A strategy for each firm specifies the probability of drilling each quarter, as a function of the state of the world, conditional on not having drilled previously. Here, the state vector is easy to describe, as is a portion of the optimal strategy. There are three relevant states each period after the first (not including the length of time left in the lease term). First, the rival firm may not have drilled yet, either. Second, the rival may have drilled and come up empty. In that event, V is known to equal zero, and the firm will choose not to drill. Third, if the rival firm has drilled and the leases are productive, then the firm should drill with probability one. Therefore, in order to compute a subgame perfect Nash equilibrium, it is necessary only to solve for the probability of drilling each period, given that no one has drilled yet.

The game is solved recursively. In the last period, if there has not been any drilling, both firms will drill, with (positive) expected payoff p-c. In period T-1, if there has been no prior drilling, drilling yields expected payoff p-c. If instead a firm waits, and its rival drills with probability q, then the expected payoff is $\beta[qp(1-c) + (1-q)(p-c)]$. The first term in the square brackets corresponds to the event that the rival drills and the tract is productive, and so a payoff of 1-c is realized. The second term corresponds to the event where the rival also doesn't drill, in which case both drill in the final period. A third term, excluded because the payoff is zero, describes the event where the other firm drills a dry hole. The firm will be indifferent between drilling and waiting if and only if

$$q_{T-1} = (1-\beta)(p-c)/\beta c(1-p) = q^*.$$

Here q^* is positive by assumption, and it is less than one if $p-c < \beta p(1-c)$, or if the discounted profits from waiting one period, and then drilling in the event that the lease is productive, exceed the expected profits from drilling immediately. The game is a war of attrition if the payoffs from following (letting the other firm move first) exceed the payoff from leading, and then q^* is less than one. If p is high enough, or c low enough, then the gains from waiting are insufficient, and q^* exceeds one. In equilibrium, if both firms drill with probability q^*, their expected payoffs equal p-c.

In period T-2, if no drilling has occurred, the payoff from drilling immediately is again p-c. If the firm waits, its expected payoff is exactly the same as from waiting in period T-1, since by construction the expected payoff in period T-1, in the event that the other firm also does not drill in T-2, is p-c. Hence, in equilibrium, $q_{T-2} = q^*$ (assuming that q^* is less than one). Thus, despite the finite lease term, the game is stationary, in the sense that $q_t = q^*$ for $t = 1, 2, \dots, T-1$. As described above, q_T equals one. (Note that there are also pure strategy asymmetric equilibria. For example, one firm could drill with probability one in all periods when there is no previous drilling, and the other could choose to wait in every such period, except for period T. This pair of strategies is also a subgame perfect Nash equilibrium as long as $p-c < \beta p(1-c)$.)

The sequence of hazard rates implied by the symmetric mixed strategy equilibrium, described by the vector $(q_1, q_2, \dots, q_T)$, does not correspond to what we observe in the data. The theoretical hazard rate q^* pertains to tracts in areas with no prior drilling. Instead, we observe if a tract is drilled in a given period, whether or not there has been prior drilling. In terms of the above example, this means that tracts not yet drilled include those where adjacent tracts were explored. Tracts adjacent to successfully explored tracts will be drilled. Those next to dry holes will be abandoned, for practical purposes. The number of abandoned tracts increases over the lease term, but is included in the risk set. Therefore, the implication is that the empirical hazard rate is decreasing in periods 2 through T-1, even ignoring heterogeneities in q^* across areas. The hazard function is derived in the Appendix. If tracts are thought to be sufficiently good prospects, so that p-c is large, then q_1 equals one in those areas.

The empirical hazard rate will increase in period T as long as q^* is sufficiently small. For example, if $T = 20$, $\beta = 0.99$, $p =$

0.5, and c = 1/8, roughly consistent with our sample averages, then $q^* = 0.06$. Tedious but straightforward computation implies that the sequence of empirical hazards equals (.060, .086, .084, ... , .030, .310). These parameters imply that 21.9 percent of the tracts will never be drilled. The overall hazard rate will be U-shaped, after an increase between the first and second periods, as observed in the data. A more symmetric U-shape could be obtained by combining samples of tracts with different parameters. The hazard rate will increase between the first and second periods, because tracts drilled in the first period are productive with probability one half, and thereby induce drilling on neighboring tracts in the second period. Roughly speaking, 6 percent are drilled in period 1, half of which are productive. These successes result in another 3 percent being drilled in period 2 (their neighbors), together with 6 percent of the remaining tracts. Note that no unproductive tracts are abandoned in equilibrium.

In contrast, consider the optimal drilling program, as implemented by a single owner (or a drilling consortium). There is no reason to delay drilling beyond the second period, as profits are then deferred. The choice is between simultaneous exploration of both tracts, and sequential search, in which case one tract is drilled first. The expected profits from simultaneous search are $2(p-c)$. Sequential search yields expected profits $(p-c) + \beta p(1-c)$. Sequential search is preferable if $\beta p(1-c) > p-c$. Note that this is the condition that ensures that q^* is less than one. If

q^* equals one, then both the optimal and the Nash equilibrium drilling plans entail immediate drilling of both tracts. Otherwise, the two drilling plans differ.

It is also tedious but straightforward to show that the joint expected discounted profits in the mixed strategy Nash equilibrium equal $2(p-c)$, or the expected profits from simultaneous search, independent of the lease length T. The simple intuition underlying this result is that the probability of drilling in any period, q^*, given that nobody has drilled yet, is calculated so that in any period the leaseholders are indifferent between drilling and waiting. But drilling in the first period just yields the simultaneous search payoff. In contrast, the optimal sequential plan (assuming that q^* is less than one) yields expected discounted payoff $(p-c) + \beta p(1-c)$. For the numerical example given above, the noncooperative equilibrium is 7.2 percent less efficient than the optimal sequential plan, as measured by total expected discounted profits.

To highlight the differences, consider variations in the cost of drilling, c. Both plans entail immediate drilling of both tracts if c is less than $(1-\beta)p/(1-\beta p)$, denoted c_1, which is less than p. The duopolists will never drill if c exceeds p. However, the monopolist will drill one tract if c exceeds p, as long as c is less than $(1+\beta)p/(1+\beta p)$, denoted c_2, since the expected value is positive. Even though the optimal plan expects to lose money on the first tract drilled, the option of drilling the second tract when it is known to be productive is valuable. If c exceeds c_2, neither plan prescribes drilling. For intermediate values of c, between c_1 and c_2, the optimal plan entails sequential drilling, whereas the Nash equilibrium is a mixed strategy for the interval $[c_1, p]$, and there is no drilling for c on the interval $(p, c_2]$. For low values of q^*, or high values of c, there is insufficient drilling relative to the optimal plan prior to period T, and costly duplication in the final period. For low values of c, there is costly duplication of drilling effort relative to the optimum throughout the lease term.

To repeat, the optimal drilling plan in this simple environment never dictates delay beyond the second period, so that the U-shaped pattern of the empirical hazard rate appears to be inconsistent with optimal drilling. Further, deviations from optimality appear to be consistent with the predictions of the Nash equilibrium outcome. The model above clearly abstracts from some important features of the OCS drilling environment, but we believe that the abstractions do not dramatically affect predictions concerning the hazard rate. Of course, the empirical hazard rate could reflect optimal coordination of drilling on a subset of tracts, and noncooperative drilling on others, but then there are inefficiencies on the latter set.

In a typical OCS area there are more than two tracts, with more than two lease holders. Increasing the number of players can exacerbate the incentives for delay in the Nash equilibrium relative to the social optimum, as the informational externalities are larger. For example, suppose the above model is extended to include N tracts, all with the same value and the Bernoulli distribution described above. Suppose further that there are N independent lease owners. Then the equilibrium q^* that we derived above describes the probability that one of the N-1 rivals drills. The probability that a single firm drills falls accordingly.

Asymmetries in the distribution of leaseholdings can help firms coordinate their drilling decisions. For example, suppose that the N leases in the above example are acquired by two firms, with one firm, say firm 1, holding N-1 leases, and the other firm, say firm 2, holding only one lease. In period T-1, if there has been no prior drilling, the expected payoff to firm 1 from drilling one lease, and responding optimally in period T to the information revealed by the outcome, is $(p-c) + \beta p(N-2)(1-c)$. If firm 1 waits, and firm 2 drills in period T-1 with probability q, the expected payoff to firm 1 is $\beta(N-1)[qp(1-c) + (1-q)(p-c)]$. Firm 1 is indifferent between drilling and not drilling if

$$q = [(p-c) + \beta p(1-c) + \beta(N-1)c(1-p)] / [(N-1)\beta c(1-p)].$$

But this expression exceeds one if $(p-c) + \beta p(1-c) > 0$ or, equivalently, if c is less than c_2. Thus, conditional on reaching period T-1 without any drilling, firm 1 will drill with probability one and firm 2 will wait. A backward induction argument establishes that this is the case for every period $t = 1,\ldots,T-1$. Hence, there is no equilibrium with delay. If the value of the sequential drilling program is positive, and exceeds that of drilling all N-1 leases simultaneously, firm 1 drills one tract in period one and firm 2 waits.

A more complicated model would endow each of the firms with private information concerning the value of their leases. Then delay is an informative event, as it signals that a firm is not very optimistic. Wilson (1986) characterizes the equilibria of wars of attrition in some similar cases. Hendricks and Kovenock (1989) show that in a two period model, the equilibrium outcomes are qualitatively similar to those of the simple symmetric model sketched above. That is, there is underinvestment on tracts that are regarded as marginally profitable, and overinvestment in areas that are believed to be profitable. The effect of learning about the information held by a rival is likely to be swamped by the incentives captured in our simple model, at least on the OCS, where half of the explored tracts are not productive. In addition, Hendricks and Kovenock argue that inefficiencies are not likely to be resolved through bargaining or a resale market, due to the presence of private geological information.

VII. CONCLUSION

If our hypothesis that drilling programs on the OCS are the outcome of a noncooperative Nash equilibrium is correct, we are left with a puzzle. There are several avenues for firms to coordinate their actions on the OCS. First, joint bidding consortia are legal, except those involving two or more of eight designated firms after 1975. Second, once a common pool has been discovered, revenues from developmental wells are usually unitized. Unitization agreements, which are encouraged by the federal government, allocate revenues from a common pool according to a prespecified rule, such as acreage owned above the pool, in order to prevent overdrilling of developmental wells. (See Gary Libecap and Steven Wiggins (1985) and Wiggins and Libecap (1985).)

The puzzle is why apparently noncooperative behavior occurs in the exploratory drilling phase. Part of the answer may concern asymmetries of information. In the bidding game, informational heterogeneities are present, because firms interpret imperfect seismic information differentially. As a consequence, joint ventures between firms actively engaged in exploratory drilling are relatively uncommon. Instead, it is as common for firms to turn to outside partners to raise capital or to bid alone. An obstacle to the formation of joint bidding agreements is the incentive to free ride on the information gathering expenditures of prospective partners. (For more detail, see Hendricks and Porter (1992).) Therefore, firms do not necessarily emerge from the bidding process in strong multilateral arrangements.

Unitization agreements are common on federal lands, unlike state lands, in part because negotiations occur relatively early in the process, when information is not too asymmetric. In terms of the model above, the uncertainty regarding the presence of deposits is not resolved, and uncertainty remains about the distribution of rents between the leaseholders. Unitization on federal lands typically occurs after the leases are acquired, and prior to exploratory drilling. However, it is notable that unitization agreements pertain to common pools, and not to fields that share common geological structures. In our sample, only 383 of the 2,255 tracts were unitized.

An agreement with respect to exploratory drilling of necessity must be consummated prior to the resolution of uncertainty concerning whether a pool, or a broader area, is productive. While unitization agreements probably encourage coordination of drilling on common pools, this bargaining mechanism is not available for broader areas. In those cases, firms' expectations of their shares may be difficult to reconcile, due to differential interpretations of seismic data, and yet some sources of uncertainty are common. Then one would expect noncooperative behavior to ensue.

Finally, an obstacle to coordination in the exploration phase is that firms may fear sacrificing informational, or expertise, advantages in future auctions. For example, if in the process of coordinating drilling decisions firms must reveal how they interpret seismic data, then they may lose a competitive advantage. This is another example of potential free rider problems.

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APPENDIX

In this Appendix, we derive the hazard function for the model with symmetric firms in Section VI, corresponding to the empirical hazard function depicted in Figures 1 and 2.

Consider a sample consisting of pairs of tracts, all with the same equilibrium q, the probability of drilling in period $t = 1,...,T-1$ if there is no prior drilling. Let n_t denote the proportion of the sample that is drilled in period t, and let H_t denote the hazard rate in period t (the proportion of the risk set in period t that is drilled). Equivalently, the sample size is normalized to equal one. Then n_1 equals q, as all leaseholders drill with probability q. The risk set in period 1 is the full sample, and so H_1 also equals q.

For any pair of tracts, the probability that both firms wait in period 1 is $(1-q)^2$, and then each tract is drilled in period 2 with probability q. Both drill in period 1 with probability q^2, in which case neither tract is in the risk set in period 2. A firm waits and its neighbor drills in period 1 with probability $q(1-q)$, and the neighboring tract is productive with probability p. Thus, n_2 equals $q(1-q)^2 + pq(1-q)$. The risk set in period 2 is $1-q$, and so $H_2 = q(1-q) + pq$. Note that $H_2 > H_1$ if and only if $p > q$.

For $t = 2,...,T-1$, $n_t = [q(1-q) + pq](1-q)^{2t-3}$. That is, n_t equals n_2 times $(1-q)^{2t-4}$, the probability that neither tract in an area is drilled prior to period t-1. The hazard rate H_t equals n_t / $[1 - (n_1 + ... + n_{t-1})]$. It is straightforward to show that $H_t > H_{t+1}$ for $t = 2,...,T-2$.

In period T, all tracts are drilled if there is no prior drilling in the area. Hence $n_T = [(1-q) + pq](1-q)^{2T-3}$. A sufficient condition for $H_T > H_{T-1}$ is that $n_T > n_{T-1}$, for which sufficient conditions are $q < p$ and $q < 1/2$.

Table 1: Quarterly Hazard Rates 1954-1990[*]

Quarter	# of Tracts	Risk Set	# Drilled	Hazard Rate	Std. Error
1	6178	6178	171	0.0277	0.0021
2	6178	6007	334	0.0556	0.0030
3	6178	5673	377	0.0665	0.0033
4	5799	4917	320	0.0651	0.0035
5	5799	4597	242	0.0526	0.0033
6	5550	4106	189	0.0460	0.0033
7	5550	3917	133	0.0340	0.0029
8	5156	3390	102	0.0301	0.0029
9	5137	3269	96	0.0294	0.0030
10	4942	2978	89	0.0299	0.0031
11	4942	2889	68	0.0235	0.0028
12	4625	2504	53	0.0212	0.0029
13	4625	2451	61	0.0249	0.0032
14	4443	2208	63	0.0285	0.0035
15	4320	2022	55	0.0272	0.0036
16	4320	1967	68	0.0346	0.0041
17	4320	1899	76	0.0400	0.0045
18	4292	1795	73	0.0407	0.0047
19	4247	1677	91	0.0543	0.0055
20	4247	1586	118	0.0744	0.0066
21	4247	1468	104	0.0708	0.0067
22	4227	1344	7	0.0052	0.0020
23	4112	1222	5	0.0041	0.0018
Never	4112		1217	0.2960	

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[*] The Never category refers to tracts that were never drilled. In this case, the "Hazard Rate" equals the fraction of tracts that were never drilled, out of the set for which 23 quarters of data are available. Otherwise, the hazard rate is the fraction of tracts in the risk set that were first drilled in that quarter.

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

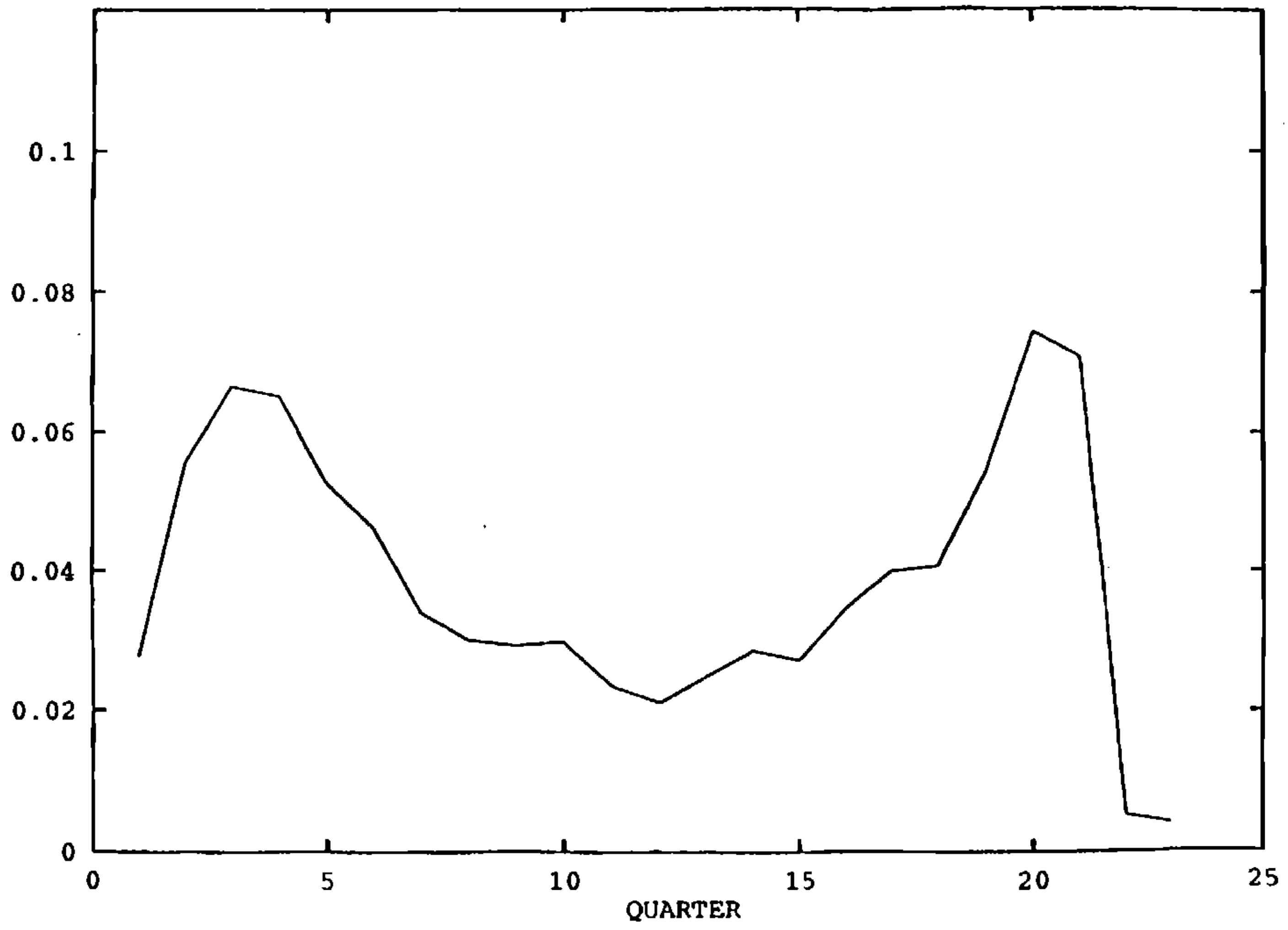

Table 2: Quarterly Hazard Rates 1954-1979*

Quarter	# of Tracts	Risk Set	# Drilled	Hazard Rate	Std. Error
1	2255	2255	155	0.0687	0.0053
2	2255	2100	223	0.1062	0.0067
3	2255	1877	191	0.1018	0.0070
4	2255	1686	164	0.0973	0.0072
5	2255	1522	134	0.0880	0.0073
6	2255	1388	106	0.0764	0.0071
7	2255	1282	62	0.0484	0.0060
8	2255	1220	61	0.0500	0.0062
9	2255	1159	63	0.0544	0.0067
10	2255	1096	49	0.0447	0.0062
11	2255	1047	41	0.0392	0.0060
12	2255	1006	35	0.0348	0.0058
13	2255	971	36	0.0371	0.0061
14	2255	935	43	0.0460	0.0069
15	2255	892	30	0.0336	0.0060
16	2255	862	46	0.0534	0.0077
17	2255	816	48	0.0588	0.0082
18	2255	768	52	0.0677	0.0091
19	2255	716	52	0.0726	0.0097
20	2255	664	62	0.0934	0.0113
21	2255	602	44	0.0731	0.0106
22	2255	558	5	0.0090	0.0040
23	2255	553	5	0.0090	0.0040
Never	2255		548	0.2430	

*See the footnote for Table 1.

Figure 2: Hazard Rate for Exploratory Drilling on Wildcat Tracts, 1954-1979

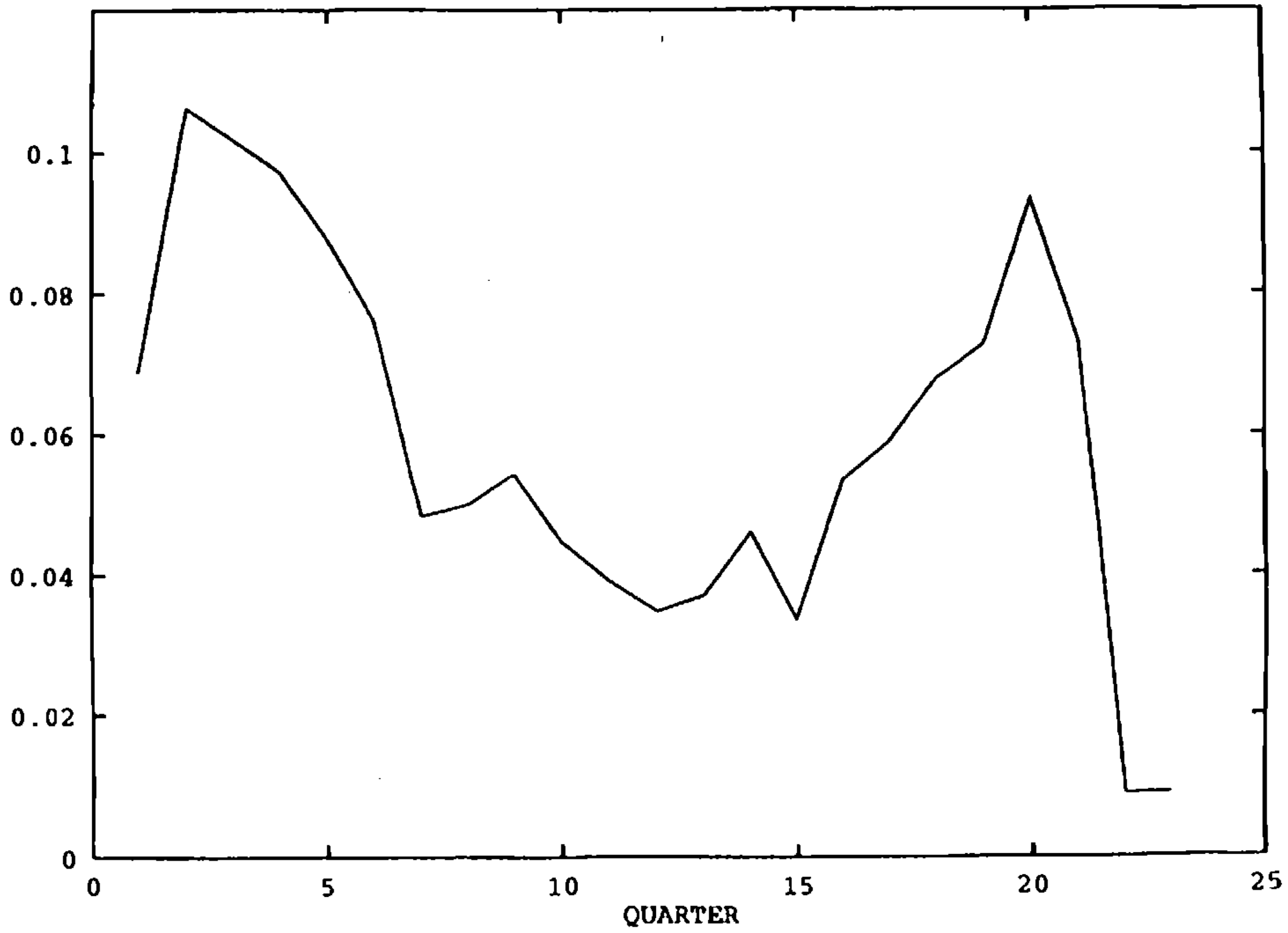

Table 3: Drilling Timing by Year of Sale*

		Year of Initial Drilling					
Year	Number of Tracts Sold	1	2	3	4	5	Never
1954	109	7	11	17	17	18	39
1955	121	5	9	5	13	25	64
1960	147	35	33	7	13	14	45
1962	411	89	62	50	53	57	100
1967	158	70	21	10	7	15	35
1968	110	44	13	6	5	2	40
1970	119	81	26	1	0	0	11
1972	178	105	22	9	5	7	30
1973	106	57	15	3	2	5	24
1974	325	119	52	28	16	24	86
1975	236	39	51	24	15	24	83
1976	15	7	1	2	0	3	2
1977	80	28	17	7	3	11	14
1978	68	21	10	14	2	6	15
1979	72	26	20	5	4	3	14
Total	2255	733	363	188	155	214	602
		(0.325)	(0.161)	(0.083)	(0.069)	(0.095)	(0.267)
		[0.325]	[0.239]	[0.162]	[0.160]	[0.262]	--

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*The number in ( ) parentheses is the number of tracts drilled in that year, as a fraction of the total number of tracts sold in the same year. The number in [ ] brackets is the hazard rate: the number of tracts drilled as a fraction of tracts sold in the same year, and not yet drilled.

Table 4: Tract Characteristics, by Year of Initial Drilling[*]

	Year After Acquisition				
	1	2	3	4	5
Risk Set					
Number	2255	1522	1159	971	816
BID	14.46	13.91	13.64	13.52	13.46
	(1.62)	(1.48)	(1.43)	(1.44)	(1.46)
# of Bids	3.76	2.87	2.51	2.41	2.30
	(3.26)	(2.47)	(2.15)	(2.13)	(2.06)
Tracts Drilled					
Number	733	363	188	155	214
(fraction)	(0.325)	(0.239)	(0.162)	(0.160)	(0.262)
BID	15.62	14.77	14.26	13.82	13.50
	(1.26)	(1.31)	(1.18)	(1.31)	(1.18)
BIDDIF	0.769	0.679	0.579	0.525	0.213
	(0.041)	(0.058)	(0.078)	(0.098)	(0.075)
# of Bids	5.62	4.00	3.06	2.99	2.33
	(3.86)	(3.03)	(2.22)	(2.37)	(1.75)
HIT	403	163	87	70	82
(fraction)	(0.550)	(0.449)	(0.463)	(0.452)	(0.383)
REV	16.29	15.52	15.55	15.52	15.22
	(1.54)	(1.64)	(1.71)	(1.96)	(1.55)

[*] 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.

Table 5A: Least Squares Estimates of the Probability of Initial Drilling, by Year After Acquisition*

Variable	Year After Acquisition 1	2	3	4	5
ACRE	-0.036	-0.001	0.069	0.099	0.074
	(0.028)	(0.031)	(0.033)	(0.034)	(0.036)
NBID	0.025	0.019	0.043	0.048	0.038
	(0.027)	(0.034)	(0.038)	(0.042)	(0.048)
ONEBID	0.126	0.126	-0.084	0.032	-0.149
	(0.046)	(0.052)	(0.055)	(0.057)	(0.063)
BID	0.148	0.101	0.025	0.020	-0.028
	(0.012)	(0.014)	(0.016)	(0.018)	(0.019)
MLT	-0.010	-0.016	-0.008	0.019	-0.026
	(0.013)	(0.017)	(0.019)	(0.021)	(0.023)
ONEBID*MLT	-0.030	-0.042	0.028	-0.029	0.058
	(0.018)	(0.022)	(0.024)	(0.026)	(0.028)
JOINT	0.009	0.005	-0.006	0.016	0.003
	(0.019)	(0.022)	(0.024)	(0.026)	(0.029)
REOFFER	0.024	0.008	0.155	-0.055	0.152
	(0.041)	(0.046)	(0.051)	(0.061)	(0.065)
HERF	0.141	0.077	0.044	-0.045	-0.259
	(0.070)	(0.079)	(0.084)	(0.090)	(0.100)
PCTJT	0.098	0.007	0.095	-0.022	-0.086
	(0.066)	(0.080)	(0.089)	(0.095)	(0.107)
DRPOST		0.083	0.083	0.127	0.100
		(0.026)	(0.026)	(0.029)	(0.036)
HITPOST		0.116	0.060	0.040	0.012
		(0.037)	(0.037)	(0.038)	(0.041)
REVPOST		-0.002	-0.005	-0.002	0.028
		(0.002)	(0.003)	(0.004)	(0.005)
Sample Size	2255	1522	1159	971	816
Adjusted R^2	0.310	0.260	0.157	0.190	0.441
Area Dummies:					
Number	50	48	47	47	47
F-statistic	2.58	2.09	1.61	1.64	4.55
% of SSR	11.90	16.46	26.20	25.66	29.86

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[*] Standard errors are displayed in parentheses. Each regression includes a set of 14 year-specific dummy variables, as well as a full set of area dummy variables. The sample is the set of tracts not yet drilled by the year in question. The dependent variable equals one if the tract was first drilled in that year.

Table 5B: Probit Estimates of the Probability of Initial Drilling, by Year After Acquisition[*]

	Year After Acquisition				
Variable	1	2	3	4	5
ACRE	-0.076	0.206	0.633	0.916	0.329
	(0.119)	(0.150)	(0.257)	(0.292)	(0.245)
NBID	0.046	0.101	0.188	0.090	0.093
	(0.103)	(0.146)	(0.178)	(0.219)	(0.280)
ONEBID	-0.039	0.411	-0.619	0.128	-0.876
	(0.230)	(0.258)	(0.312)	(0.338)	(0.385)
BID	0.575	0.440	0.155	0.216	-0.124
	(0.050)	(0.066)	(0.079)	(0.093)	(0.110)
MLT	-0.037	-0.090	-0.059	-0.001	-0.199
	(0.047)	(0.079)	(0.095)	(0.103)	(0.141)
ONEBID*MLT	0.042	-0.097	0.211	-0.096	0.340
	(0.077)	(0.101)	(0.127)	(0.142)	(0.177)
JOINT	0.029	0.002	-0.068	0.131	0.086
	(0.075)	(0.099)	(0.125)	(0.150)	(0.165)
REOFFER	0.174	0.096	0.555	-0.179	0.620
	(0.151)	(0.187)	(0.224)	(0.334)	(0.301)
HERF	0.750	0.520	-0.008	0.048	-0.324
	(0.293)	(0.356)	(0.484)	(0.523)	(0.554)
PCTJT	0.490	0.060	0.558	-0.012	0.140
	(0.266)	(0.346)	(0.336)	(0.516)	(0.594)
DRPOST		0.391	0.567	0.766	0.846
		(0.115)	(0.143)	(0.170)	(0.204)
HITPOST		0.346	0.055	0.066	-0.464
		(0.153)	(0.182)	(0.212)	(0.232)
REVPOST		0.006	0.001	0.015	0.139
		(0.010)	(0.016)	(0.023)	(0.028)
Sample Size	2255	1522	1159	971	816
Area Dummies:					
Number	50	48	47	47	47
Chi-squared	145.3	98.6	65.8	80.9	105.0

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[*] Standard errors are displayed in parentheses. Each regression includes a set of 14 year-specific dummy variables, as well as a full set of area dummy variables. The sample is the set of tracts not yet drilled by that year. The dependent variable equals one if the tract was first drilled in that year.

Table 6A: Least Squares Estimates of the Probability of Tract Productivity, by Year of Initial Drilling*

	Year After Acquisition				
Variable	1	2	3	4	5
ACRE	-0.109	-0.161	-0.325	0.477	-0.084
	(0.070)	(0.087)	(0.264)	(0.294)	(0.149)
NBID	0.042	0.112	-0.184	0.296	-0.070
	(0.053)	(0.090)	(0.131)	(0.167)	(0.165)
ONEBID	-0.128	-0.151	0.040	0.107	-0.021
	(0.164)	(0.189)	(0.282)	(0.285)	(0.235)
BID	0.111	-0.017	0.068	-0.086	0.031
	(0.027)	(0.042)	(0.058)	(0.082)	(0.067)
MLT	-0.046	0.069	-0.024	0.222	0.197
	(0.023)	(0.048)	(0.075)	(0.105)	(0.095)
ONEBID*MLT	0.079	-0.011	-0.072	-0.038	-0.190
	(0.047)	(0.070)	(0.097)	(0.132)	(0.101)
JOINT	0.022	-0.013	0.006	-0.008	0.087
	(0.040)	(0.064)	(0.088)	(0.105)	(0.098)
REOFFER	0.204	0.016	0.018	0.307	-0.020
	(0.092)	(0.123)	(0.147)	(0.311)	(0.173)
HERF	-0.024	-0.100	-0.331	1.074	0.688
	(0.176)	(0.252)	(0.373)	(0.555)	(0.323)
PCTJT	0.054	-0.023	-0.533	0.617	0.172
	(0.138)	(0.217)	(0.406)	(0.424)	(0.305)
DRPOST		-0.137	-0.151	-0.083	0.002
		(0.087)	(0.161)	(0.208)	(0.140)
HITPOST		0.200	0.193	0.022	0.136
		(0.097)	(0.175)	(0.217)	(0.173)
REVPOST		0.006	-0.008	-0.013	-0.014
		(0.008)	(0.017)	(0.030)	(0.020)
Sample Size	733	363	188	155	214
Adjusted R^2	0.151	0.111	0.134	0.103	0.028
Area Dummies:					
Number	41	38	34	35	35
F-statistic	1.20	1.09	1.35	1.03	0.57
% of SSR	25.31	38.10	51.77	46.18	30.06

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*Standard errors are displayed in parentheses. Each regression includes a set of 14 year-specific dummy variables, as well as a full set of area dummy variables. The sample is the set of tracts drilled in that year. The dependent variable equals one if there has been oil or gas production on that tract.

Table 6B: Probit Estimates of the Probability of Tract Productivity, by Year of Initial Drilling*

	Year After Acquisition				
Variable	1	2	3	4	5
ACRE	-0.375	-0.730	-1.723	1.601	-0.242
	(0.214)	(0.439)	(0.977)	(1.014)	(0.438)
NBID	0.121	0.354	-0.806	0.893	-0.130
	(0.160)	(0.270)	(0.442)	(0.542)	(0.525)
ONEBID	-0.421	-0.457	0.147	0.490	0.146
	(0.514)	(0.581)	(0.869)	(0.959)	(0.721)
BID	0.343	-0.041	0.384	-0.049	0.154
	(0.081)	(0.123)	(0.217)	(0.268)	(0.209)
MLT	-0.153	0.205	-0.502	0.619	0.777
	(0.072)	(0.140)	(0.277)	(0.378)	(0.344)
ONEBID*MLT	0.264	-0.033	0.059	-0.076	-0.790
	(0.151)	(0.215)	(0.306)	(0.470)	(0.349)
JOINT	0.068	-0.020	0.092	0.061	0.351
	(0.120)	(0.190)	(0.273)	(0.359)	(0.303)
REOFFER	0.641	0.059	0.610	1.201	0.209
	(0.284)	(0.384)	(0.459)	(1.208)	(0.549)
HERF	-0.079	-0.311	-1.311	5.969	2.807
	(0.559)	(0.815)	(1.240)	(2.420)	(1.025)
PCTJT	0.221	-0.049	-2.298	2.360	0.015
	(0.419)	(0.685)	(1.275)	(1.558)	(0.974)
DRPOST		-0.544	-0.831	-1.112	-0.115
		(0.288)	(0.467)	(0.976)	(0.488)
HITPOST		0.828	1.047	1.312	0.970
		(0.318)	(0.546)	(0.916)	(0.569)
REVPOST		0.028	-0.028	-0.137	-0.156
		(0.027)	(0.058)	(0.110)	(0.078)
Sample Size	733	363	188	155	214
Area Dummies:					
Number	41	38	34	35	35
Chi-squared	51.7	48.9	53.7	45.6	29.7

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*Standard errors are displayed in parentheses. Each regression includes a set of 14 year-specific dummy variables. The sample is the set of tracts drilled in that year. The dependent variable equals one if there has been oil or gas production on that tract.

Table 7: Determinants of the Logarithm of Discounted Revenues on Productive Tracts, by Year of Initial Drilling*

	Year After Acquisition				
Variable	1	2	3	4	5
ACRE	-0.501 (0.281)	-0.087 (0.324)	-0.344 (1.166)	3.981 (2.335)	0.112 (1.067)
NBID	-0.386 (0.220)	0.141 (0.501)	-0.073 (0.619)	-1.702 (1.041)	0.093 (1.153)
ONEBID	-0.059 (0.878)	0.472 (1.131)	-1.497 (1.382)	-3.218 (2.206)	0.607 (1.450)
BID	0.600 (0.110)	0.400 (0.241)	0.371 (0.344)	0.152 (0.540)	0.096 (0.489)
MLT	-0.196 (0.106)	-0.539 (0.257)	-0.542 (0.502)	-0.148 (0.681)	-0.225 (0.665)
ONEBID*MLT	-0.019 (0.020)	0.036 (0.401)	0.597 (0.573)	0.946 (1.014)	-0.108 (0.606)
JOINT	-0.013 (0.177)	0.565 (0.336)	-0.581 (0.542)	2.084 (0.851)	0.210 (0.662)
REOFFER	-0.587 (0.360)	-0.780 (0.731)	-0.071 (0.857)	-1.873 (2.164)	0.263 (1.368)
HERF	-0.386 (0.827)	1.978 (1.509)	0.006 (2.294)	7.722 (6.228)	0.307 (2.002)
PCTJT	0.072 (0.628)	2.237 (1.306)	-0.668 (2.505)	2.764 (3.614)	1.064 (2.412)
DRPOST		0.230 (0.648)	0.710 (0.847)	-1.387 (2.760)	0.791 (2.326)
HITPOST		0.575 (0.688)	-1.398 (1.117)	2.444 (2.312)	-0.579 (1.793)
REVPOST		-0.083 (0.050)	0.111 (0.115)	-0.436 (0.322)	0.097 (0.238)
Sample Size	403	163	87	70	82
Adjusted R^2	0.190	0.152	0.302	0.164	-0.109
Area Dummies:					
Number	38	29	25	24	24
F-statistic	1.78	1.06	2.31	1.05	0.63
% of SSR	43.57	36.49	67.79	41.73	38.74

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*Standard errors are displayed in parentheses. Each regression includes a set of 14 year-specific dummy variables. The sample is the set of productive tracts drilled in that year.

Table 8: Full Sample Estimates*

	Pr{Drill}		Pr{Hit|Drill}		E[Rev|Hit]
Variable	OLS	Probit	OLS	Probit	OLS
ACRE	0.120	0.325	-0.110	-0.348	-0.366
	(0.026)	(0.103)	(0.046)	(0.141)	(0.187)
NBID	0.028	0.170	0.043	0.113	-0.265
	(0.026)	(0.111)	(0.037)	(0.107)	(0.173)
ONEBID	-0.128	-0.055	0.054	0.154	-0.057
	(0.044)	(0.174)	(0.073)	(0.209)	(0.368)
BID	0.083	0.359	0.080	0.231	0.499
	(0.011)	(0.047)	(0.017)	(0.048)	(0.077)
MLT	-0.005	-0.028	-0.010	-0.032	-0.265
	(0.012)	(0.050)	(0.018)	(0.052)	(0.091)
ONEBID*MLT	0.032	0.023	-0.005	-0.015	0.072
	(0.017)	(0.070)	(0.027)	(0.076)	(0.127)
JOINT	0.004	0.020	0.016	0.045	0.203
	(0.018)	(0.076)	(0.027)	(0.076)	(0.130)
REOFFER	0.096	0.374	0.059	0.160	-0.370
	(0.039)	(0.168)	(0.055)	(0.153)	(0.253)
HERF	-0.040	0.084	0.143	0.403	0.764
	(0.066)	(0.259)	(0.103)	(0.295)	(0.505)
PCTJT	0.049	0.366	0.056	0.164	0.410
	(0.063)	(0.263)	(0.090)	(0.255)	(0.439)
Sample Size	2255	2255	1653	1653	805
Adjusted R^2	0.303	NA	0.122	NA	0.182
Area Dummies:					
Number	50	50	44	44	41
Test statistic	7.72	157.7	2.42	108.3	2.21
% of SSR	36.72	NA	36.01	NA	37.31

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* Standard errors are displayed in parentheses. Each regression includes a set of 14 year-specific dummy variables, as well as a full set of area dummy variables. The sample is the full set of tracts sold, drilled, or productive, respectively. The dependent variable equals one if the tract was drilled, it equals one if it was productive, or it equals real discounted revenues, respectively.

Table 9: Pooled Logit Estimates of the Probability of Initial Drilling, by Year After Acquisition*

	Year After Acquisition				
Variable	1	2	3	4	5
ACRE	-0.133	0.069	0.948	1.249	0.557
	(0.140)	(0.211)	(0.380)	(0.386)	(0.273)
NBID	-0.042	0.102	0.205	0.315	-0.093
	(0.117)	(0.169)	(0.231)	(0.270)	(0.278)
ONEBID	-0.793	0.353	-1.191	0.499	-1.126
	(0.327)	(0.341)	(0.427)	(0.435)	(0.393)
BID	0.644	0.524	0.187	0.217	-0.044
	(0.057)	(0.080)	(0.106)	(0.118)	(0.112)
MLT	-0.032	-0.095	-0.116	-0.012	-0.352
	(0.056)	(0.091)	(0.139)	(0.113)	(0.152)
ONEBID*MLT	0.201	-0.110	0.440	-0.237	0.486
	(0.097)	(0.128)	(0.176)	(0.185)	(0.185)
JOINT	0.029	0.096	-0.060	0.191	-0.002
	(0.089)	(0.126)	(0.175)	(0.203)	(0.180)
REOFFER	0.149	0.065	0.705	-0.567	0.477
	(0.194)	(0.254)	(0.291)	(0.539)	(0.283)
HERF	0.850	1.242	0.775	1.051	0.395
	(0.326)	(0.402)	(0.552)	(0.537)	(0.506)
PCTJT	0.673	0.164	0.781	0.192	0.308
	(0.279)	(0.422)	(0.582)	(0.609)	(0.526)
DRPOST		0.798	1.026	1.042	0.863
		(0.146)	(0.185)	(0.205)	(0.216)
HITPOST		0.012	-0.235	-0.059	-0.241
		(0.173)	(0.205)	(0.209)	(0.188)
REVPOST		0.027	0.010	0.012	0.105
		(0.013)	(0.020)	(0.026)	(0.026)
Sample Size	2255				

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*Standard errors are displayed in parentheses. Each column includes a set of 14 year-specific dummy variables, but no area dummy variables. The sample is the full set of tracts. The dependent variable is the year in which the tract was first drilled.