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Abstract: We describe an ongoing research project, in which we examine recent trends in bidding for offshore oil and gas leases, and the exploration and development of leases after they are sold. We review empirical findings regarding bidder participation and bidding for the period 1954 through 1982. In 1983, the MMS adopted Area Wide Leasing (AWL), which dramatically changed the bidding environment. We provide an initial analysis of the post-1982 data, documenting a number of significant changes in behavior and outcomes. Bidding has been much less aggressive recently in comparison with the early years of the leasing program, in terms of both the number of bids submitted and the level of the submitted bids. This descriptive evidence leads to a number of questions, and we discuss a number of changes in the bidding environment since 1982, which may offer partial explanations of the observed changes.

Recent U.S. Offshore Oil and Gas Lease Bidding: A Progress Report*

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1 Introduction

The U.S. Mineral Management Service (MMS) uses auctions to allocate exploration and drilling rights for oil and gas on federal lands on the Outer Continental Shelf (OCS). The federal offshore leasing program began in 1954, and there have been few alterations in the auction mechanism. However, the environment in which firms bid in these auctions has experienced a number of substantial changes. Offshore oil and gas today accounts for about a third of U.S. production. The stakes are high, and the leasing program has generated considerable revenue for the government. Moreover, excellent data are available.

This paper describes an ongoing research project, in which we examine recent trends in bidding behavior and exploration and development of leases after they are sold. A striking feature of the data is that bidding has been much less aggressive recently in comparison with the first thirty years of the leasing program, in terms of both the number of bids submitted and the level of the submitted bids.

Our research asks positive questions concerning participation, bidding, and exploration behavior. For example, what accounts for the changes in bidding behavior? Is observed behavior consistent with equilibrium models of competitive bidding? Is there evidence of collusion in exploration or bidding? We are also interested in examining the impact of

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policy changes. For example, did the increase in lease tenures from five to ten years in the 1980s on deep water tracts lead to higher participation rates and bids? Did the "royalty relief" programs of the late 1990s induce firms to bid and drill more tracts and increase production?

We are also interested in normative issues. Could different auction rules or lease terms improve revenues or efficiency? Is an auction the appropriate allocation mechanism?

We begin in sections 2 and 3 with a discussion of the leasing program and description of the rich data available. Section 4 then provides a discussion of empirical findings regarding bidder participation and bidding for the period 1954 through 1982. This discussion reviews several papers by Hendricks and Porter, together with several coauthors. Some of these papers are summarized more extensively by Porter (1995). In 1983, the MMS adopted Area Wide Leasing (AWL), which dramatically changed the bidding environment for companies. Section 5 provides an initial analysis of the post-1982 data, documenting a number of significant changes in behavior and outcomes. This descriptive evidence leads to a number of questions, and in section 6 we discuss a number of changes in the bidding environment since 1982, at least some of which may offer partial explanations of the observed changes. We conclude with a discussion of an agenda for research.

2 The OCS Auction Mechanism

In this section we describe the OCS auction mechanism employed by the MMS from 1954 to the present.

The mechanism proceeds in several stages. The process begins when the MMS announces that a given set of areas within the federal offshore lands is available for drilling. The lands are divided into blocks or tracts so that an area consists of many tracts. The tracts are typically 5,000 or 5,760 acres, that is, up to 9 square miles. Before the sale, companies interested in bidding on tracts in unexplored areas can either hire a geophysical company to "shoot" a seismic survey of tracts in an area or conduct their own survey. They are not permitted to drill wells. Historically the interpretation of seismic data varied across companies, and typically caused them to focus on different tracts and to bid different amounts. Most of the seismic surveys conducted before 1990 were limited to two dimensions, or 2-D, vertical cross sections of strata. These data provided quite noisy information about the likelihood of a deposit containing oil or gas, or the size of any given deposit. Costs amounted to a couple hundred thousand dollars per tract and they were typically shared among several companies. In the past two decades, advances in computing power has made 3-D seismic analysis possible. 3-D surveys are both more informative and more expensive.

For tracts in areas that have been explored, most companies already possess seismic data. Furthermore, if they own (or have owned) leases in the area and have drilled wells on those leases, they also have private drilling information. Production from wells in explored areas is more or less public information.

After conducting their analysis of the data on tracts in the areas, and prior to the sale date, some firms engage in bidding consortia negotiations. Potential partners decide whether to submit a joint bid and, if so, agree on the bid level and their individual shares. Joint bidding agreements are enforced by legally binding contracts. Most joint bidding agreements are area and sale-specific, that is, firms who bid jointly in one area of a sale will not necessarily do so in other areas or other sales. Joint bidding agreements are typically struck shortly before the sale date and *after* the firms have acquired their private information about the tracts. We suspect that ex ante bidding agreements are not prevalent because firms are reluctant to divulge their methods of interpreting seismic data. All firms were allowed to bid jointly prior to 1975. After 1975, joint bids were banned involving two or more of the (then) eight largest oil and gas companies, although these firms were free to participate in joint bids with other firms.

The tracts are "sold" as leases, and many leases are offered simultaneously. Each lease is sold by first-price sealed bid auction, in which the bid is referred to as a bonus payment. There is an announced minimum bid or reserve price. The winning bidder pays the bonus on the sale date, and also pays a royalty rate on any revenues it earns from post-sale production. The government does not necessarily accept the highest bid, even one above the reserve price. If a lease is sold, the winning bidder then has the right, but not the obligation, to conduct exploratory drilling of their wildcat tract. There is a fixed lease term during which time exploration must begin to avoid having the lease revert to the government. A lease is automatically renewed if it is productive, as long as royalty payments are being made. In addition, there are small rental fees during the exploration phase.

3 The OCS Data

In this section, we describe the available data. Our sample consists of all tracts offered for sale, from the inception of the program in 1954 through the present day. In all our research, we confine our attention to leases in the Gulf of Mexico, which account for a large percentage of OCS bidding and production.

For each sale, we know the date of the sale and the prevailing auction rules, such as the minimum bid and the policy for rejecting high bids. For each tract offered in a sale, we observe the tract's location, that is, the longitude and latitude coordinates of its boundary points. We observe the date a tract sold, or all dates if the tract is sold more than once, as well as the tract's water depth and acreage. Each time the tract is sold, we observe the royalty rate, the lease term, the identity of all bidders and the amounts they bid. If a bid is joint, the participants and their shares are recorded. We observe whether the high bid was rejected. For any ownership transfer after the original sale, we see the transfer date and the identity of the new owners. We know the date, number, and depth of any wells drilled, the number of platforms, as well as monthly production data through the present day of oil, condensate, natural gas and other hydrocarbons. For the set of leases that are productive today, we forecast future output based on an econometric model of historical decay rates in lease production. American Petroleum Institute surveys of drilling costs by year, location, water depth and type of well (i.e., dry or productive) allow us to translate the information on wells drilled into estimates of drilling costs. We convert production information into revenue estimates using wellhead prices. There is an important question of how to treat firms' expectations of future oil and gas prices. Leases can be productive for as long as 50 years, and even today futures markets do not extend that far into the future. We have experimented with evaluating revenues at actual wellhead prices, and at wellhead prices at the time of the sale date. For the calculations reported in this paper, we use sale date prices.

Given the information above, we construct a measure of the ex post discounted tract value, discounted revenues minus drilling costs, and the government share of that value, the bonus bid plus royalties. The difference between tract value and the government share is a measure of ex post discounted profits. In the calculations reported in this paper, we employ a five percent real discount rate, deflating revenues and cost to the sale date using a GDP deflator, with 1982 as the base year.

For the purposes of building an econometric model, the most important information that is not available is the private information available to bidders when they are formulating their bidding strategy, especially their interpretation of the seismic data. Nevertheless, this is an excellent data set. The bidding environment consists of well specified rules, and we observe both the bids submitted as well as a measure of their ex post payoffs. It is this latter feature that distinguishes the OCS data from many other auction data sets.

4 Findings for 1954-1982

In this section we describe the workings of the auction mechanism prior to 1983 and briefly review some findings of the research by Hendricks, Porter and coauthors on bidding during this period of the OCS leasing program. Porter [11] provides a more extensive summary of the earlier papers.

In the first twenty years of the OCS leasing program, the bidding environment was quite stable. Real crude oil prices were roughly constant and the technologies for surveying and drilling did not change very much. MMS would hold at most one or two sales a year. If the area to be sold was not explored previously, the sale was called a wildcat lease sale. Firms in a wildcat sale have access only to seismic information, and not drilling records. In each wildcat sale, MMS would offer at least 100 tracts, up to 515. The tracts would lie in a relatively narrow band on the boundary of previously explored areas. The boundary would shift with each new sale into deeper waters and, by 1982, it was approximately at water depths of 200 meters. If a discovery was made in an area after a wildcat sale, there would often be a subsequent sale of tracts adjacent to the tract on which the discovery was made. These tracts are known as drainage tracts and the sales of these tracts are called drainage sales. The number of tracts offered in drainage sales was much lower than in wildcat sales, tens of tracts rather than hundreds. Most sales during the first twenty years of the program were wildcat sales. The increase in crude oil prices in the mid and late 1970s caused companies to re-evaluate the profitability of many tracts that had been offered in previous sales. As a result, MMS increased the number of sales held each year and sold many tracts that it had offered or sold in earlier sales.

Aside from a few sales held in the late 1970s in which the MMS experimented with different auction rules, the announced minimum bid or reserve price for tracts sold between 1954 and 1982 was \$15 per acre on wildcat tracts and \$25 per acre on drainage tracts. The MMS conducted a bid adequacy decision, based in part on its own independent assessment of tract value. Rejection of the high bid was not uncommon, particularly on drainage tracts. The royalty rate on any revenues earned from a tract was 1/6. The lease term was 5 years.

We begin with a discussion of the wildcat sales, which comprised the vast majority of the tracts sold. The biggest players in the auctions were the large oil companies, including Shell, ARCO, Chevron, Gulf Oil, Amoco, Exxon, Texaco and Mobil. The twelve largest bidders accounted for roughly 75% of the bids and a slightly higher percentage of wins. Bidding coalitions were frequent in wildcat sales, although less common on marginal tracts (Hendricks, Porter and Tan [8]). When more than one of the large oil companies participated, equal division sharing rules were the norm. Most joint bids with more than one large firm only involved a pair of large firms, and very few involved four or more (Hendricks and Porter [5]).

Wildcat sales exhibited considerable dispersion in bids, both across and within tracts. We present some data on bid dispersion below. Bidding patterns are consistent with a Bayesian Nash equilibrium of a bidding environment with common values (Hendricks, Pinkse and Porter [3]). Ex post returns are also consistent with competitive bidding with a significant amount of competition.

Exploratory drilling outcomes were consistent with non-cooperative plans in areas with multiple lease owners, as they exhibit inefficient delay and duplicative exploratory drilling at the lease term five year deadline (Hendricks and Porter [6]). The results of drilling a given lease are informative of the likely returns from drilling nearby leases. Hence, a cooperative plan would entail sequential, not simultaneous, drilling earlier in the lease term, given that drilling is costly and given information externalities across leases in an area.

Ex post returns indicate that the government captured a large share of rents. Both bonus bids and royalty payments were important sources of revenue, and roughly of similar magnitude.

On drainage sales, the bidding and returns data indicate that asymmetric information favors the owners of neighboring wildcat leases (Hendricks and Porter [4], and Hendricks, Porter and Wilson [9]). The government share of rents is smaller than on wildcat leases, and the beneficiaries are the neighboring owners. When there are multiple owners of neighboring leases, their bidding is consistent with the neighbors colluding and essentially bidding as one. Hendricks and Porter [4] describe a few features of the data that are consistent with collusion among the neighbors, and in this project we extend these ideas, as we describe below.

5 Patterns in the Post-1983 Data

The introduction of Area Wide Leasing (AWL) in 1983 provides an important break in the OCS bidding and exploration environment. Under AWL, most of the offshore lands were available in every sale, including thousands of tracts in deep water areas (i.e., exceeding 200 meters of water depth). Furthermore, to encourage exploration in these areas, lease tenures were lengthened to 8 or 10 years, and royalty rates on tracts with water depth of more than 400 meters were lowered to 1/8. In addition, the 1995 Deepwater Royalty Relief Act exempted deep water tracts from royalty payments on production up to a cap.[1] We discuss AWL in more detail in the next section. Here we examine the data in the post-1983 period and compare it to the findings for the 1954-1982 period.

Table 1 provides an overview of oil and gas lease sales from 1954 to 2006. ¿From 1954

[1]This "royalty relief" was generally contingent on oil prices falling below $35 per barrel, although for sales in 1998 and 1999 the upper bound on prices was omitted from the lease contract, apparently inadvertently. This led to significant public outcry (and congressional hearings), although the effects on bidding have not been carefully explored.

through 1982, 3,525 tracts were sold, or 49% of the 7,175 tracts offered for sale. The vast majority of these tracts were wildcat tracts. Among the tracts receiving bids, 64% received at least 2 bids, and there were 3.2 bids per tract on average. The government rejected 11.2% of the high bids. The mean high bid was $15.07 million. (Hereafter, all dollar figures are deflated to 1982 dollars.) In the set of tracts that were sold, winning bids totalled $53.10 billion.

In the period from 1983 through 2006, 18,142 tracts were sold, or 7% of the 241,980 tracts offered for sale. Offerings increased by more than a factor of 30 relative to the pre-1983 period, and sales more than doubled. Among the tracts receiving bids, only 25% received at least 2 bids, and the average number of bids per tract fell by more than half to 1.3. The government rejected 4.0% of the high bids, a fall of almost two thirds. The mean high bid was $0.97 million, less than 1/15 of the pre-1983 mean. When we disaggregate the AWL period into five-year subperiods (except for the last eight-year period), the bid patterns for each subperiod reflect the pattern for the period as a whole. It is not an exaggeration to say that bidding collapsed after 1983.

Table 2 compares bidding patterns for various periods where tract have been categorized by the number of bids they receive. We compare six periods: the relatively stable period before 1980; the 1980-1982 period immediately before AWL, when oil and gas prices had increased substantially after the second OPEC price shock, and there were expectations of even more increases in the future; the 1983-1987 period immediately after AWL was adopted; and three more recent five year periods, 1988-1992, 1993-1997 and 1998-2002.

One striking feature of bidding in the period before 1980 is the dispersion in bid levels, as reflected by "money left on the table," the percentage difference between the high bid and the second highest bid on a given tract. On average, the second highest bid was only 56 percent of the high bid on those tracts receiving two or more bids (since 44 percent of the winning bid was left on the table). Even on the 180 tracts that received ten or more bids, 30 percent of the winning bid was left on the table, when winning bids on these tracts averaged almost $50 million. There is much more dispersion in this data set than in other auction data sets with which we are familiar.

Bids reached an all time high in 1980-1982, probably in large part because of inflated price expectations. Bids fell immediately after AWL was adopted in 1983, in part because of increases in the number of tracts offered for sale.

The first order trend evident in the Table 2 is the fall in the number of bids received and in bid level, overall and for a given number of bidders. The cumulative shares demonstrate a substantial shift over time in the distribution of participation (in terms of first-order stochastic dominance) toward a smaller number of bids. By the 1998-2002 period, 93 percent of tracts sold attracted one or two bids, compared to 54 percent in the 1954-1970 period. In contrast, there have been relatively small changes in money left on the table, overall or for a given number of bidders. There was not a noticeable decrease in money left on the table in the recent periods, after the widespread adoption of 3-D seismic analysis. If anything, the fraction of the winning bid left on the table has increased.

Table 3 compares drilling and development patterns over time. One striking trend is the fall in the fraction of tracts drilled after 1983. There is a truncation bias for tracts sold in the 1998-2002 period, as some leases have not yet expired, e.g., those with a ten year term. Many of these are still being explored. The number of productive leases (defined as those with positive production levels) as a fraction of drilled leases, has recovered to pre-AWL levels after an initial fall. The final row reports the number of leases that were still productive in 2006, for those sold after 1983. Almost half of those sold between 1983 and 1987 that were ever productive are still productive, reflecting the long lease lives for OCS tracts.

Table 4 reports returns over time. In the pre-OPEC period, 1954-1972, discounted profits were positive, evaluated at a five percent real discount rate, but the government captured most of the value (industry profits plus payments to the government). In the 1980-1982 period, bids were very high, and firms losses were severe. Recall that profits are calculated using sale date prices, and therefore actual returns were even lower, as prices fell, especially in 1985. Firms earned very high profits in the 1983-1987 period, and they captured more than half of the value. Since then, average values have fallen. In 1988-1992 aggregate returns were high, both in an absolute sense and relative to overall value. The 1993-1997 numbers are included for comparison purposes, but the truncation of production, and the fact that some of these leases have not yet attained peak production in 2007, means that the returns numbers for this period are less reliable, and probably too low.

At first glance, the findings reported in the above tables are somewhat puzzling, particularly when one compares firm participation and win rates in the pre-OPEC period to those in the post-1983 period. In the earlier period, the biggest players in the auctions were the large oil companies, including Shell, ARCO, Getty, Chevron, Gulf Oil, Amoco, Exxon, Texaco and Mobil. The participation rates of the twelve largest bidders ranged from a low of 12% to a high of 47%. They accounted for roughly 75% of the bids and a slightly higher fraction of the wins. By contrast, the participation rates of these firms in the AWL period range from 3% to 16%. For example, the consortium of ARCO and Getty bid on 47% of the tracts in the pre-OPEC period but on only 7% of the tracts in the AWL period. The corresponding percentages for Shell were 35% in the pre-OPEC period and 16% in the AWL period. For Chevron, they were 38% in the pre-OPEC period and 7.4% of the tracts in the

AWL period. Thus, many more bidders participated in sales held after 1983 than in the pre-OPEC period, and bidder concentration was much lower.

6 What Explains the Observed Changes?

The data point to several notable changes after 1982 in participation, bidding, exploration, and production. What explains these changes? How do they affect the conclusions reached previously regarding the success of the Federal offshore lease program? To begin answering these and other questions, we first point to several changes in the market environment, at least some of which may have played an important role in explaining the changes we have documented.

6.1 Area-Wide Leasing and the Expansion into Deep Water

As mentioned previously, one major change was the introduction of Area-Wide Leasing in 1983. Prior to AWL the tracts to be offered were chosen through a nomination process. Firms would suggest (nominate) tracts they were interested in, and the MMS would choose tracts based on these nominations, often selecting tracts nominated by multiple firms. AWL eliminated the nomination process in favor of making a large number of tracts available at every sale.

A goal of AWL was to encourage exploration and development. As noted already, one result was that the number of leases offered for sale increased by an order of magnitude beginning in 1983 (see Table 1). Since then the number of tracts offered in a given sale has ranged from 3,647 to 8,868 tracts, and there have been two or three sales a year in the Gulf of Mexico region. Sales were less frequent during the first twenty years of development.

The effect of AWL has been to offer much more of the offshore for sale at any given date, and some leases have been offered repeatedly. Essentially, most of the offshore lands are available in every sale: tracts sold in a sale exit the set of available tracts, and tracts whose leases have expired or terminated during the period between sales re-enter the set. Many of the tracts sold would be wildcat tracts re-offered after relinquishment or high bid rejection, while others would be tracts that did not receive bids in the original wildcat sale. These are typically near previously explored areas. The distinctions among wildcat, development, and drainage tracts became less relevant and MMS dropped the classification of sales into wildcat and drainage.

AWL may have directly affected participation and bid levels in several ways. The most obvious is that the large increase in supply of tracts reduced the scarcity of tracts available for exploration and development. If firms have different views about which tracts are most likely to be productive, this would naturally lead to less coordinated participation decisions, i.e., fewer bids for any one tract, but with more tracts receiving at least one bid. This is consistent with the patterns seen in Table 1.

An additional factor is selection. Under the pre-AWL system, a tract had to be nominated by one or more firms to be offered for sale, and presumably firms nominated tracts they believed most likely to be productive. Under AWL, there is no such positive selection mechanism. Indeed, in some cases tracts may be adversely selected: many are tracts that were re-offered after a previous lessee failed to explore. The favorable selection of tracts that existed prior to AWL may also have played an important informational role. Under the nomination process the mere fact that a tract was offered suggested that at least one other firm thought the tract was likely to be valuable (Moody and Kruvant [10]). Thus the nomination process might have provided both a way of coordinating competition and a way of reducing the severity of the winner's curse.

Both the increase in supply and the less favorable selection mechanisms suggest that tracts offered under AWL may be of lower value, at least on average. A fact that might seem consistent with this is that in the post-AWL period, tracts have tended to be in deeper water. Costs in deep water areas are much higher, most notably the costs of equipping and maintaining a platform. This implies higher extraction costs and, all else equal, lower net value.

However, the data suggest a more subtle story. To see this we first classified tracts into shallow (water depths less than 200 feet) and tracts with water depths exceeding 800 feet. For the purposes of this section we will refer to the latter as deep water tracts. There are striking differences in the participation rates of the large firms in shallow and deep water areas. For example, in the 1980-2002 period, Shell was the most frequent bidder. Shell bid solo or in a joint bid on 1,723 of the 6,608 tracts in deep water that were sold, or 26 percent. In contrast, they bid on only 544 of the 6,321 shallow depth tracts, or 9 percent. Other frequent bidders included BP, which bid on 850 deep water and 167 shallow water tracts (13 percent and 3 percent, respectively) and Chevron, which bid on 697 deep water and 390 shallow water tracts (11 percent and 6 percent, respectively). Most of the other large bidders were also much more likely to submit bids on deep water tracts. An exception is ARCO/Getty which bid on 633 deep water and 488 shallow water tracts (10 percent and 8 percent, respectively).

Table 5 reports returns on shallow and deep water tracts sold in the period 1980 to 2002. The numbers of shallow and deep water tracts sold are 6,717 and 6,660 respectively. Revenue per tract drilled in deep water was $68.3 million, which is more than four times higher than the revenue per tract drilled in shallow waters. Costs per tract drilled in deep water was \$23.5 million, which is only twice as high as the cost per tract drilled in shallow waters. Profits per tract sold in deep waters is \$3.76 million compared to losses of \$1.64 million on tracts sold in shallow waters. These numbers largely reflect returns in the AWL period since the numbers of shallow and deep water tracts sold in the period 1980-82 were only 326 and 52 respectively.

These data suggest that the opening of exploration into deep water areas under AWL caused large oil firms to shift their exploration efforts from shallow to deep water tracts where they earned substantially higher profits. The distribution of participation rates of firms that bid in auctions for deep water tracts was much more concentrated than the distribution of participation rates of firms that bid in auctions for shallow water tracts, but was similar to the distribution of participation rates of firms that bid in auctions of wildcat tracts during the pre-OPEC period. Therefore, one puzzle that remains is why firms earned substantial shares of the rents on deep water tracts but not on wildcat tracts.

Tables 6 and 7 provide a potential answer to this puzzle. In each table, we classified tracts sold in the period 1988-1992 into tracts with and without active adjacent ("neighbor") leases. We refer to owners of neighboring tracts as "neighbor firms" and decompose neighbor leases into three categories: leases on which neighbor firms did not bid; leases where at least one neighbor firm bid but the lease was won by a non-neighbor firm; and leases where at least one of the neighbor firms bid and won the lease. (The tables are similar to those reported in Hendricks and Porter [4] for drainage tracts.) The goal is to determine whether the neighbor tracts are more profitable than isolated tracts and, if so, whether the neighbor firms enjoy an advantage in bidding for these tracts.

Table 6 reveals that, in shallow waters, there were essentially no isolated tracts, which is consistent with the view that most of the tracts sold in the shallow waters are development leases. Neighbor firms were much more likely to win when they bid (73%) but the profits earned on these tracts did not differ significantly from the profits earned (by non-neighbors) on the tracts for which they did not bid. In both cases, the mean profit is slightly negative, which suggests that these tracts were marginal. Table 7 reveals a much different story. In deep water areas, isolated tracts and neighbor tracts not bid on by neighbor firms are marginally profitable, but neighbor tracts bid on by neighbor firms are very profitable. Furthermore, a neighbor firm won almost all of these tracts (93%). These results suggest that a substantial fraction of the auctions of deep water tracts were more similar to the drainage auctions in the pre-OPEC period than the wildcat auctions.

6.2 Technological Changes

Technological changes in exploration and extraction may have played important roles. One important change concerns the quality of information available to bidders prior to a sale. With advances in computing speed, costs of conducting 3-D seismic surveys fell dramatically. For example, the cost of analyzing a 50 square mile survey fell from $8 million in 1980 to $1 million in 1990, to less than $100,000 in 2000. The fall in costs lead to widespread adoption of 3-D technology in the 1990s. In 1989, less than 5% of the wells drilled in the Gulf of Mexico made use of 3-D seismic data; by 1996, the figure was 80% and the surveys were more sophisticated.

From the perspective of a single firm, 3-D imaging is likely to provide more precise information regarding the likelihood of finding extractable minerals (and location). This should result in better decisions regarding which tracts to bid on and where to drill, for example.[2] Likewise, it should reduce bidder uncertainty about the value of a lease. This reduction in unproductive exploration should make leases more valuable, all else equal.

A strategic perspective adds additional considerations. An increase in the precision of bidders' signals may reduce the severity of the winners curse, reduce the dispersion in bidders' assessments of tract values, and lead to bids that are less dispersed for any given tract. Of course, equilibrium bids cannot be too close to tract values or bidders will not earn sufficient rents to cover the fixed cost of participation (e.g., obtaining and analyzing the seismic data). On the other hand, if all potential bidders participate with probability one, equilibrium bidding must compete away much of the rent available at the auction. Thus, even with many potential bidders, equilibrium may involve substantial nonparticipation and bids that leave profits for winners. The low participation rates and significant profits (at least in deep water) may be consistent with this story. On the other hand, the dispersion in bids—at least as measured by money left on the table for tracts attracting at least two bids—has not changed much.

Other changes in drilling technology have also occurred over this time frame. Firms began using directional and horizontal drilling, whereby drilling can change directions while underway. In addition, new "measurement-while-drilling" technology enabled drill operators to monitor the location of the bit. Both of these advances complement the improvements in seismic analysis, leading to an improvement in recovery rates. The advances have also opened new areas of exploration, most notably in deep waters.

[2]The evidence in Table 2 does not appear to support this, although the truncation bias discussed previously works against the predicted finding. Further, Table 2 takes no account of the significant changes in the types of tracts sold.

6.3 Collusion

Collusion is another factor that might contribute to the observed decline in competition. Under collusion, firms would coordinate participation decisions, making bidders aware of when their potential rivals would refrain from bidding on some tracts, with the ultimate goal of suppressing prices.

Although prior work (e.g., Hendricks, Pinkse and Porter [3]) has found support for competitive bidding, this could have changed over time. Also, the advent of AWL could have made it easier for firms to coordinate geographically. One possible mode of collusion involves coordination among owners of neighboring leases. After AWL, many tracts were adjacent to previously sold tracts. The fraction of tracts where neighboring leases had been previously sold has increased steadily, from 0.66 in the period 1983-1987 (2,476 of 3,750 tracts), to 0.89 in 1988-1992 (3,299 of 3,698 tracts), to 0.91 in 1993-1997 (4,471 of 4,896 sold). In these cases, if the firms owning neighboring tracts have drilling experience, they will have an informational advantage relative to non-neighbors (see Hendricks and Porter [4]). Moreover, if information is nearly symmetric among neighbor firms, there will be a strong motivation to collude to avoid competing away information rents.

7 Conclusion: A Research Agenda

All of this points to few clear answers but many interesting questions. One potentially fruitful direction for future work is to use implications of equilibrium models to analyze the roles played by each of the factors discussed in the previous section. A large literature on estimation of auction models[3] provides tools that we hope to adapt to the post-1983 OCS environment.

Evaluating participation and bidding behavior through the lens of a competitive model makes sense only if collusion does not appear to be a factor. Thus a first step in our effort to understand the changes we observe after 1983 is to look for evidence of collusive behavior. Many forms of collusion are possible, but we are developing a battery of tests of competitive behavior based on some simple insights. One involves the information about the value of a tract contained in the decision of a potential bidder not to participate in a sale. Under competition, this decision reveals information about the bidder's signal of the tract's value. Under collusion, however, this statistical link between nonparticipation and the realized tract value will typically break down. A second approach is to look for failures of affiliation under collusion. For example, suppose that the firms colluding on a

[3] See, e.g., Athey and Haile [1] and Hendricks and Porter [7].

tract are those who already own adjacent leases ("neighbors"). In contrast to a competitive model, under collusion neither the second neighbor's participation decision nor its bid level need be correlated with ex post tract value. A third approach is to examine implications of the winner's curse in a competitive model. If neighbors are acting competitively, they will respond to variations in the severity of the winners' curse that arise from exogenous changes in the number of neighbor tract owners (see Haile, Hong and Shum [2]). If neighbors are colluding, there is no information contained in the behavior of other cartel members, and the force of the winner's curse vanishes.

If the evidence suggest that bidders are behaving competitively, it may then be possible to use models of bidder participation and bidding to evaluate the roles of changes in the industry structure, auction rules, royalty policies, supply of tracts, expectations about oil prices, technology, and bidder information. Each of these is potentially important for policy makers. For example, several of the policy changes, including area-wide leasing and the Deepwater Royalty Relief Act were designed at least in part with the objective of encouraging exploration and production. Assessing the success of the program in this dimension and the costs, if any, in terms of government revenues will be possible through a properly calibrated model.

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Table 1: Summary of Offshore Oil and Gas Lease Sales, Gulf of Mexico 1954-2006

Period	Tracts Offered	Tracts Bid	Bids per Tract	Tracts Sold	Total Winning Bids	Mean Winning Bid	Bids Rejected	Mean Rejected Bid
1954-82	7,715	3,974	3.24	3,525	53,104	15.07	449	2.30
1983-87	71,243	3,763	1.47	3,473	9,424	2.71	285	1.80
1988-92	60,228	3,811	1.16	3,701	1,956	0.53	107	0.44
1993-97	52,563	5,183	1.52	5,017	2,501	0.50	149	0.33
1998-06	57,946	6,175	1.37	5,951	3,667	0.62	236	0.46
1954-06	249,155	22,906	1.71	21,667	70,653	3.26	1,226	1.43

*Dollar figures are in millions of 1982 dollars.

Table 2: Bidding by Number of Bidders

	Number of Bidders					
	1	2	3-4	5-9	10-18	Total
1954-1979						
# of Tracts	902	463	467	498	180	2,510
cum. share	0.36	0.54	0.73	0.93	1.00	
B_1	2.85	5.92	10.49	23.97	48.33	12.29
$(B_1 - B_2)/B_1$	–	0.55	0.48	0.37	0.30	0.44
1980-1982						
# of Tracts	292	131	119	98	15	655
cum. share	0.45	0.65	0.83	0.98	1.00	
B_1	4.40	12.17	23.25	45.47	60.67	16.82
$(B_1 - B_2)/B_1$	–	0.56	0.40	0.35	0.28	0.44
1983-1987						
# of Tracts	2,693	690	286	81	1	3,751
cum. share	0.72	0.90	0.98	1.00	1.00	
B_1	1.61	3.59	5.79	10.04	13.65	2.48
$(B_1 - B_2)/B_1$	–	0.40	0.40	0.35	0.53	0.40
1988-1992						
# of Tracts	2,791	594	262	47	5	3,699
cum. share	0.75	0.92	0.99	1.00	1.00	
B_1	0.28	0.62	1.01	2.01	4.99	0.42
$(B_1 - B_2)/B_1$	–	0.48	0.42	0.42	0.17	0.46
1993-1997						
# of Tracts	3,472	854	455	112	3	4,896
cum. share	0.73	0.88	0.98	1.00	1.00	
B_1	0.19	0.42	0.70	1.78	2.11	0.32
$(B_1 - B_2)/B_1$	–	0.46	0.44	0.41	0.22	0.45
1998-2002						
# of Tracts	3,067	560	234	52	4	3,917
cum. share	0.78	0.93	0.99	1.00	1.00	
B_1	0.27	0.58	1.28	3.74	9.02	0.43
$(B_1 - B_2)/B_1$	–	0.48	0.49	0.40	0.33	0.48

*B_1 denotes the highest bid on a tract, and B_2 the second highest bid. Both measured in millions of 1982 dollars.

Table 3: Drilling and Production

	1954-82	1983-87	1988-92	1993-97	1998-02
# of Tracts Sold	3,525	3,480	3,610	4,754	3,763
# Drilled (by 2007)	2,256	1,478	966	1,014	754
(fraction of sold)	(0.64)	(0.42)	(0.27)	(0.21)	(0.20)
# Productive (by 2007)	1,121	592	406	490	401
(fraction of drilled)	(0.50)	(0.40)	(0.42)	(0.48)	(0.53)
(fraction of sold)	(0.32)	(0.17)	(0.11)	(0.10)	(0.11)
# Productive in 2006		294	185	313	373

Table 4: Profits and Government Receipts

	1954-72	1980-82	1983-87	1988-92	1993-97
Average Crude Price		28.97	23.86	18.54	17.11
# of Tracts Sold	1,527	578	3,480	3,610	4,754
# of Tracts Drilled		394	1,478	966	1,014
Revenue per Tract Drilled	28.89	39.15	42.42	18.62	16.46
Cost per Tract Drilled	9.98	25.73	15.34	11.97	13.75
Mean Bid per Tract Sold	9.54	16.93	2.73	0.53	0.48
Bid + Royalty per Tract Sold	13.35	21.47	5.25	1.24	0.98
Profit per Tract Sold	1.60	(12.32)	6.25	0.54	(0.37)
Value per Tract Sold	14.95	9.15	11.50	1.78	0.61

*Dollar figures are in millions of 1982 dollars. Revenues are evaluated at sale date prices. Profit = Revenue – Cost – Bid – Royalty.

Table 5: Deep vs. Shallow Water Tracts
1980-2002

	Shallow	Deep
# of Tracts Sold	6,717	6,660
# Tracts Drilled	2,754	871
Revenue per Tract Drilled	16.39	68.26
Cost per Tract Drilled	12.72	23.51
Mean Bid per Tract Sold	1.39	0.66
Bid + Royalty per Tract Sold	2.07	0.98
Profit per Tract Sold	(1.64)	3.76
Value per Tract Sold	0.43	4.74

*Dollar figures are in millions of 1982 dollars. Deep denotes water depth greater than 800 feet. Shallow denotes water depth less than 200 feet.

Table 6: Bidding and Neighbor Lease Status, 1988-1992
Shallow Water Tracts

	No Neighbor Lease	Active Neighbor Lease: No Neighbor Bid	Active Neighbor Lease: Neighbor Loses	Active Neighbor Lease: Neighbor Wins
# of Tracts Sold	8	1,228	69	182
Mean # of Bids	1.25	1.45	3.65	1.68
Fraction Neighbor Win	–	–	0.73	
Mean Bid	0.20	0.49	1.18	0.65
Fraction Drilled	0.25	0.36	0.61	0.40
Fraction Productive	0.00	0.41	0.50	0.53
Mean Profit	(0.56)	(1.11)	(2.63)	(1.36)

*Dollar figures are in millions of 1982 dollars. Profit = Revenue – Cost – Bid – Royalty. Tracts are classified as shallow if water depth is less than 200 feet.

Table 7: Bidding and Neighbor Lease Status, 1988-1992

Deep Water Tracts

	No Neighbor Lease	Active Neighbor Lease		
		No Neighbor Bid	Neighbor Loses	Neighbor Wins
# of Tracts Sold	386	482	22	282
Mean # of Bids	1.17	1.10	2.14	1.19
Fraction Neighbor Win	–	–	0.93	
Mean Bid	0.34	0.42	1.03	0.51
Fraction Drilled	0.06	0.12	0.23	0.15
Fraction Productive	0.36	0.37	0.60	0.44
Mean Profit	0.69	(0.12)	33.88	8.30

*Dollar figures are in millions of 1982 dollars. Profit = Revenue – Cost – Bid – Royalty. Tracts are classified as deep if water depth exceeds 800 feet.