Testing Competition in U.S. Offshore Oil and Gas Lease Bidding*

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Preliminary and Incomplete
Please do not quote

June 2012

Abstract

Since the 1980s, most of the oil and gas tracts auctioned by the federal government in the Gulf of Mexico are adjacent to tracts that are already under lease. Owners of neighboring leases enjoy incumbency advantages that act as a barrier to entry for other firms. We ask whether owners of neighboring leases take advantage of their situation and agree not to compete. To answer this question, we develop several tests of competitive bidding in pure common value, first-price auctions where rejection suggests collusion. We implement these tests using data on bids and ex post values. The results have important implications for rent capture and auction design.

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1 Introduction

The U.S. Mineral Management Service (MMS) uses a combination of auctions and royalties to recover "fair market value" from its oil and gas leases on federal lands on the Outer Continental Shelf (OCS). The leasing program for the Gulf of Mexico began in 1954 and has generated considerable revenue for the government. Figure 1 reports annual government revenues from the sale of leases and from royalty payments for the period 1954 to 2002. Revenues from the sale of leases rose dramatically in the 1970s and early 1980s, and the discoveries on these leases generated a substantial flow of royalty payments for many years thereafter. But revenues from lease sales plummeted after 1983.

In a previous paper [3], we provide evidence that not only bids but also rent capture fell after 1983, especially on deep water tracts\(^1\). We conjecture that one reason may be a lack of competition on tracts where adjacent tracts were already leased. The owners of these tracts, which we will refer to as neighbors, have previously invested in seismic surveys of the area and, in some cases, drilled wells. These investments may place non-neighbors at an informational disadvantage, and thereby deter them from bidding, which in turn would give neighbors an incentive not to compete against each other. The benefits from collusion are clear: lower prices and better information if neighbors share information. The costs are less obvious. Neighbors are required to coordinate their production plans in the event a field is discovered, and they have strong incentives to coordinate their drilling activity as well. Joint ventures among firms (except any involving two or more of the eight largest firms as of 1975) are not illegal, so an agreement by neighbors not to compete against each other would presumably not violate anti-trust laws. Figure 2 illustrates that the fraction of tracts sold with at least one previously sold adjacent tract grew over time, and these tracts came to dominate sales in the 1980s and 1990s.

In this paper, we provide tests of competitive bidding in first-price, common value auctions where rejection suggests collusion. We apply those tests to neighbor bids to determine whether they bid competitively. The answer to this question is important in its own right. If neighbors enjoy incumbency advantages, then rent capture depends critically upon the willingness of neighbors to bid competitively. The question is also an important specification test. Identifying model primitives and evaluating changes in technology and policies through the lens of a competitive model of bidding makes sense only if collusion is not a factor.

Our tests are based largely on the effect of the winner’s curse on participation. In com-

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\(^1\)We classify tracts as deep water if their water depth is greater than 200 meters. Shallow water tracts have water depths less than 200 meters.
mon value environments, the winner’s curse implies that bidders are less likely to participate as the number of bidders increases. Of course, collusion yields the same prediction. But, in the latter case, nonparticipation does not necessarily imply that bidders have low signals, breaking the statistical link between nonparticipation and realized tract value. The impact of the distortions under collusion can be detected because we observe the realized tract value and there is no such distortion on tracts with only one neighbor.

Our focus on neighborhood cartels is motivated by two considerations. We view tracts as located in a spatially differentiated market. The values associated with given locations are spatially correlated because of the way in which nature creates oil and gas deposits. Therefore, to the extent that the barrier to entry is informational, competition for unleased tracts may be limited primarily to the firms that lease tracts in the neighborhood. Thus, it is natural to ask if these firms can take advantage of the situation and agree not to compete against each other. Second, in previous work by two of the authors [7, 10], we documented that firms would frequently bid jointly on tracts in one area but against each other in other areas, both within and across sales. Thus, cooperation appears to be more location-based than sale or firm-based. Of course, cooperation at one location may spill over into other locations, including ones where firms are not neighbors. Our analysis does not preclude such spillovers but neither does it detect them.

Our paper makes several contributions. The tests provide a way of detecting collusive behavior in common value environments. The previous literature on collusion in auctions has focused on private value environments, where the participation decision of bidders are independent of the number of bidders. On the methodological front, we develop a strategy for identifying common value models when realized values are available only for a selected sample. In our case, we observe the value of a tract only if it is leased and drilled. On the policy front, our results inform auction design, which is currently a topic of discussion at the MMS.

Earlier work by Hendricks, Porter et al focused on the pre-1980 period. Hendricks and Porter [6] studied competition in auctions of drainage tracts, which are adjacent to tracts where oil and gas has been discovered. We showed that bidding for these tracts is consistent with a Bayesian Nash equilibrium of a pure common value auction in which neighbor firms are informed and collude, and non-neighbor firms are uninformed. This paper provides formal tests of the collusion hypothesis. Hendricks, Porter, and Pinkse [5] study competition in auctions of wildcat tracts. These tracts are typically in isolated areas that have not been explored. We could not reject the null hypothesis that bidding for these tracts are the Bayesian Nash equilibrium of a pure common value auctions with symmetric information. Rents were mostly competed away.
We begin in Section 2 with an overview of the offshore leasing program. In Section 3 we identify several implications of competitive bidding in first-price, common value auctions and outline methods for testing them. Section 4 describes implementation of the tests. The key problem is that tract value is observed only if the tract is leased and drilled. We develop a parametric approach to deal with this issue. Section 5 describes the data. Section 6 presents the results of the tests. Section 7 examines the assumptions that underlie the analysis. Section 8 concludes.

2 Background

In this section we describe the OCS auction mechanism employed by the MMS from 1954 to the present, and how the allocation process has changed over time. We then document how bidding and outcomes have varied by area and over the time. The facts motivate our modeling approach.

2.1 Mechanism

The primary objectives of the OCS leasing program are to expedite the development of oil and gas resources in the federal offshore lands, and to ensure a fair return to the public on these assets. Figure 3 presents a map of the federal lands in the Gulf of Mexico, the area that produces most of the offshore oil and gas in the United States. The area is divided into blocks or tracts. The tracts are typically 5,760 acres (9 square miles).

The leasing process begins when the MMS announces that tracts within a designated area will be available for sale on a given date. In recent years, sales in the Gulf of Mexico have been held twice a year. Before 1983, when the Area Wide Leasing (AWL) program was introduced, the government restricted the number and locations of tracts available in a sale. Firms were invited to nominate tracts in the designated area to be offered at the sale. Presumably firms nominated tracts that they believed most likely to have an oil and gas deposit. Under AWL, there is no such positive selection. The designated area is either the Western Gulf, Central Gulf or Eastern Gulf regions, and firms were invited to submit bids for any of the available tracts in the region. In the context of tracts with neighbor leases, the pre-AWL nomination procedure may have played an important informational role. By not nominating an adjacent tract, neighbors revealed that they were not interested in bidding for that tract.

Prior to the sale, companies need to learn about the designated area to determine which tracts to bid and how much to bid. The MMS restricts the kind of information that firms could acquire. They could conduct seismic surveys but were not permitted to drill
wells. Historically the interpretation of seismic data varied across companies, and typically companies focussed on different tracts and 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 several 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. The 3-D surveys are both more informative and more expensive. Furthermore, if firms own (or have owned) leases in the area and have drilled wells on those leases, they also have private drilling information. Production from wells is more or less public information.

The drilling and production rights for oil and gas on tracts are auctioned to oil and gas firms in the form of leases. The leases are offered simultaneously in a given sale. Each lease is sold by a 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 which was typically $15 per acre. 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 royalty rates under the pre-AWL system was 1/6; under the AWL system, it was 1/6 on shallow water tracts and 1/8 on deep water tracts. The government does not necessarily accept the highest bid, even one above the reserve price. It conducts a bid adequacy decision, based in part on its own independent assessment of tract value and the number of bids submitted. Rejection was not uncommon during pre-AWL period but infrequent during the AWL period. If a lease is sold, the winning bidder then has the right, but not the obligation, to conduct exploratory drilling of their tract. There is a fixed lease term during which time exploration must begin to avoid having the lease revert to the government. The lease term is 5 years for shallow water tracts and, after the AWL program was introduced, either 8 or 10 years for deep water tracts. 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.

In designing the allocation mechanism, the MMS’s primary concern was to ensure sufficient competition for the leases. By restricting the supply of tracts, the MMS forced firms to target their investments in information and compete for a relatively few tracts. Limiting the size of the lease to 5,760 acres may have led to less concentrated ownership of oil and gas fields and more efficient development. With larger tracts, there may have been less competition because only big oil firms would have the capital to bid for large areas. Lower royalty rates imply that marginal tracts are more likely to be drilled and developed because the firm earns a larger share of the returns. But firms would have to pay more money up-front, deterring risk averse, small firms from bidding. The MMS also allowed firms to enter
legally binding joint bidding agreements on the grounds that they help mitigate financial
costs and encourage more firms to participate.\footnote{All firms were allowed to bid jointly prior to 1975. After 1975, the (then) eight largest oil and gas companies were banned from bidding jointly with each other, although these firms could participate in joint bids with other firms.}

The main modifications of the mechanism have been the AWL program and the 1995 Deepwater Royalty Relief Act. The Act exempted deep water tracts from royalty payments on production up to a cap contingent on water depth and on prices being below $35 (except for sales in 1998 and 1999, when there was no cap on prices). The modifications were largely a response to high oil prices. The goal was to reduce dependence on foreign oil by expediting development of oil and gas fields on federal lands. Longer lease terms increased the option value of leases and incentivized firms to bid for more tracts; lower royalty rates encouraged them to bid for and drill more tracts; and unrestricted supply encouraged them to accelerate the discovery and production of oil and gas fields.

\subsection*{2.2 Overview}

We now provide an overview of bidding and exploration patterns since the inception of the MMS leasing program. We restrict our attention to sales of tracts in the Gulf of Mexico, which comprise the vast majority of OCS leases, MMS revenues and production.

Table 1 provides an overview of the impact of the oil crisis in 1973 and of the AWL program that began in 1983. We distinguish two pre-AWL periods, 1954-73 and 1974-82, and two areas in the 1983-2002 AWL period, shallow water and deep water, where the boundary is water depths of 200 meters. There were very few deep water tracts sold before 1983. The Table reports the number of tracts that received bids and the winning bid was accepted, the fraction of sold tracts that were drilled (i.e., at least one well was drilled), and the fraction of drilled tracts that yielded some production (and are designated as hits). We report the average number of bids and the mean and standard deviation of the winning bid. All dollar figures are denominated in millions of 1982 dollars. We also report average discounted revenues on productive tracts, average discounted drilling costs on tracts that are drilled, and average net profits on all tracts sold. The discounted revenue of a productive tract is computed by converting production flows of oil and gas into revenues using the real wellhead prices at the date of the sale, and discounting them to the auction date at a 5 percent per annum rate. The use of wellhead prices at the auction date implicitly assumes that firms have identical and constant expectations about the future prices of oil when they submit their bids. Costs are based upon the American Petroleum Institute annual survey of drilling costs of wildcat and production wells. We used the estimates for offshore Louisiana.
and Texas, conditional on the number and depth of wells, to compute drilling costs for each tract drilled, classifying wells as productive if the tract produced hydrocarbons and exploratory if it did not. These costs are also discounted to the auction date at a 5 percent per annum rate. The net profit of a tract is defined as discounted revenues less discounted drilling costs, winning bid, and royalty payments, with the latter computed as a fraction of discounted revenues according to the prevailing royalty rate.

We first compare the two pre-AWL periods. The higher oil and gas prices during 1974-82 led to an increase in the average number of bids from 2.82 to 4.16 and an increase in the average winning bid from $12.19 million to $16.92 million. The number of tracts sold and drill rates are essentially the same in the two period, although the later period is half as long. Thus the average number of wells drilled per year rose from 60 per year to 165. This increase in activity led to higher rig rental rates, and average drilling costs rose from $10.2 million per tract to $16.87 million. Average revenues on productive tracts are similar in the two periods. Actual revenues were higher for tracts sold in 1954-72, as many tracts were still productive after the increases in real oil prices in 1973 and 1980. In the case of 1974-82, returns may be understated for the early part of the period, but overstated for the later years, as prices fell dramatically in 1985. The run-up in prices through 1980 undoubtedly affected bids, and together with the subsequent fall in prices in 1985 explains in part why net profits for the 1974-82 are much lower. Circa 1980, firms may have expected prices to continue to rise. Bids were at an all time high.

We next compare the shallow and deep water areas during the AWL period. The average number of bids and average winning bid are similar in the two areas, with slightly higher numbers in shallow water areas. Drilling costs on deep water tracts are twice as high as drilling costs on shallow tracts. Drill rates on deep water tracts are much lower than on shallow water tracts, 13% versus 38%. Hit rates are also lower on deep water tracts. But average revenue on productive tracts are much higher on deep waters, $167 million versus $29 million. This latter difference explains why average net profits on deep water tracts are almost $4 million dollar per tract (or $29.1 billion dollars in total) more than net profits on shallow water tracts.

The differences between the pre-AWL period and the AWL period are striking. Many more tracts are sold during the AWL period, but the average number of bids and bid levels fell dramatically. Compared to the 1974-82 period, the number of bids per tract fell from 4.2 to roughly 1.4 and average winning bid fell from $12 million to $1 million. In addition, the standard deviation in winning bids fell, from approximately $23 million to $2.67 million. Drill rates are much lower in the AWL period, and hit rates are lower for AWL deep water tracts. Revenues from auctions during the AWL period are much lower relative to the
pre-AWL period.

We now consider sold tracts that are adjacent to previously sold tracts. The previously sold tracts are referred to as neighbor tracts, and their owners as neighbor firms. In Table 2, we divide tracts sold in the two pre-AWL periods into two categories, those which receive bids by neighbors (NB) and those tracts bid by non-neighbors only (NN). The striking result is that drill rates, hit rates, and average revenue per productive tract are significantly higher on NB tracts than on NN tracts. The average number of bids and average winning bids are also higher on NB tracts. A similar pattern would be obtained if we compare tracts that received only neighbor bids to NN tracts. These numbers suggest that neighbors are better informed than non-neighbors about which adjacent tracts are more likely to have an oil and gas deposit. Net profit per NB tract is similar to net profit per NN tract during the 1974-82 period, but net profits on NB tracts are significantly higher than on NN tracts during the 1954-73 period. Neighbors may have exploited their information advantage in the earlier period but not in the later period.

Table 3 provides comparable information on NB and NN tracts for shallow and deep water areas during the AWL period. The story is similar. Drill rates, hit rates, and average revenue are significantly higher on NB tracts than on NN tracts. The average number of bids and winning bids are also higher on NB tracts. Net profit per NB tract is significantly higher than net profit per NN tract on deep water tracts, but not on shallow water tracts. Neighbors may have been able to exploit their information advantage on deep water tracts but not on shallow water tracts.

3 Tests

We begin with a model of firms’ bidding decisions on an individual tract. The auction is first-price sealed bid with a public reserve price $r$. There are two sets of potential bidders for tract $t$: neighbors and non-neighbors. The set of neighbors is denoted by $N_t$, and the number of neighbors is given by $|N_t| = N_t$. The set of non-neighbors is denoted by $M_t$, and the number of non-neighbors is given by $|M_t| = M$. The number of non-neighbors is sufficiently large that we treat it as constant across tracts. The characteristics of tract $t$ are represented by $Z_t$. They mostly describe the tract’s neighborhood. The variables $N_t, Z_t, M$ are publicly observable.

Let $V_t$ denote the unknown, common value of the oil and gas deposit on tract $t$ net of extraction costs. By virtue of their past investments in the neighborhood, neighbors have private, real-valued signals $X_{it}, i = 1, ..., N_t$ about tract $t$ that are drawn independently from a strictly increasing marginal distribution $F_X$. In what follows, we condition on $M_t, Z_t$ and
suppose the notation. Given $N_t = n$, the joint distribution of $(V, X_{1t}, ..., X_{nt})$ is given by $F_{V,X}(V_t, X_{1t}, ..., X_{nt}; n)$.

**Assumption 1:** $(V, X_1, .., X_n | N_t = n)$ are affiliated and exchangeable with respect to the bidder indices.

Affiliation is a standard assumption in common value auctions. It assumes that the signals are informative of $V$ and implies that $E[V | X_{1t}, ..., X_{nt}]$ is strictly increasing in $X_{it}$. Symmetry is more questionable in our setting. Some of the tracts have neighborhoods that have been drilled. Drilling outcomes are publicly observable, but neighbors who have drilled wells may have better information based on drill cores. More importantly, even when firms only have access to seismic surveys, a neighbor may own more than one tract. The issue is whether seismic information on multiple tracts is best modeled as "one firm, one signal" or "one tract, one signal". If the former, then firms may have quite different estimates about the likelihood of finding oil and gas deposits depending upon the content and analyses of their surveys, but the precision of these estimates is unlikely to vary across neighbors. If the latter, then neighbors with more tracts are better informed. Our analysis can accommodate information asymmetries but at some cost in terms of notation and analysis. Our approach will be to impose symmetry initially and then relax this assumption later when we consider extensions.

**Assumption 2:** Non-neighbors have access to public information but have no private information.

Assumption 2 is a strong assumption. The intent is to approximate a situation in which non-neighbors are relatively uninformed. In practice, they are likely to make some investment in information and evaluation prior to bidding for tracts. However, modeling this decision and its impact on equilibrium bidding is somewhat tangential to the purposes of this paper. The assumption is testable, and we will provide evidence to support it.

Given our assumptions, a type symmetric Bayesian Nash equilibrium exists in which neighbors use monotone increasing bid functions. Let $\beta(X_{it}; n)$ denote the common bid function of neighbors conditional on $N_t = n$. Participation by neighbor $i$ on tract $t$ is determined by a threshold value of $x^*(n)$ defined by

$$E[V_t | X_{it} = x^*, \max_{j \in N_t, j \neq i} X_{jt} \leq x^*, N_t = n] = r.$$  

In choosing to participate at the reserve price, neighbor $i$ anticipates that if she wins, then her signal is higher than the signals of her neighbor rivals. This event lowers her expectation of the value of the tract and is known as the "winner’s curse" correction. The correction is
a distinguishing feature of common value environments. In private value environments, the number of rivals has no impact on the probability of participation.

3.1 Collusion

The main goal of any collusive agreement is to avoid competing away rents. To the extent that informational asymmetries are a barrier to entry, neighbors can earn rents if they agree not to bid against each other. They can also benefit from pooling their data and assessments to obtain a more precise estimate of tract value. Joint ventures among most bidders are not illegal in federal offshore auctions. And finally, neighbors typically cooperate in producing from a common pool if one is discovered. Therefore, neighbors have an incentive to cooperate in bidding for adjacent leases and the opportunity to do so.

Many forms of collusion are possible and we are reluctant to specify a particular model of collusion as the alternative to competition. But, in order to think about the power of a testable restriction of competitive bidding, we briefly consider two simple models that suggest what one might expect under the alternative hypothesis of collusion.

Suppose the cartel includes all neighbors and they select one firm as the designated bidder. This firm conducts an evaluation of the tract and competes against non-neighbors. Non-neighbors know this and therefore act as if there is only one neighbor. Given their behavior, the threshold and bidding equations for the neighbors are as if \( N_t = 1 \). There is no winner’s curse correction for neighbor firms so the bid distributions do not vary with \( N \). We call this model the designated bidder model.

Another simple model is one in which the cartel includes all neighbor firms and they pool their information prior to bidding. Non-neighbors are aware of the cartel and how it operates. The cartel submits one bid when

\[
E[V_t|X_1, \ldots, X_n, N_t = n] \geq r.
\]

The best response of the cartel is similar to that for the Bayesian Nash equilibrium with \( N = 1 \), but now beliefs about \( V_t \) are conditioned on all signals. With additional structure on how the signals can affect expectations about \( V \), we can say a little more. Suppose, for each \( n \), there exists (monotone increasing) function \( T_n : \mathbb{R}^n \rightarrow \mathbb{R} \) such that \( F(V|X_1, \ldots, X_n) = F(V|T_n(X_1, \ldots, X_n)) \). Here \( T_n \) is a sufficient statistic for the signals of the neighbors. The monotonicity of \( T_n \) implies that \((V, T_n)\) are affiliated. The cartel bidder’s type space is one-dimensional and we can specify its behavior in terms of the sufficient statistic \( T_n \). We can show that the participation probability of non-neighbors decreases with \( n \) and, in response, larger cartels bid less aggressively.
The models above involve only one neighbor bid. However, it is trivial to modify these models to allow for some phantom bids. The phantom bids do not change the behavior of non-neighbors or of the one serious cartel bidder. However, they can foil some testing approaches.

Although neighborhood bidding agreements are not illegal, neighbors have an incentive to engage in phantom bidding. The government reserved the right to reject the high bid on a tract if it perceived a lack of competition. The rejection rule is in part based on the number of submitted bids. During the period 1954-1982, the government rejected the high bid on approximately 13% of the tracts receiving bids. The rejection rate fell to 4% during the AWL period.

### 3.2 Affiliation Test

One approach to testing the competitive model is to look for violations of affiliation. Let \( B_{it} \) denote the bid by neighbor \( i \) on tract \( t \). Under competition, for \( i, j \in N_t \), monotonicity of \( \beta \) implies that

\[
\Pr\{B_{it} \geq r | B_{jt}, N = n\} = \Pr\{X_{it} \geq x^*(n) | X_{jt}, N_t = n\}
\]

By standard arguments, we obtain the following result.

**Proposition 1** With competitive neighbor participation, for any \( n > 1 \), any \( i, j \in N_t \), and any \( b \geq r, b' \geq r \),

\[
\Pr\{B_{it} \geq b | B_{jt} \geq b', N_t = n\} \geq \Pr\{B_{it} \geq b | N_t = n\} \\
\geq \Pr\{B_{it} \geq b | B_{jt} \leq b', N_t = n\}.
\]

Setting \( b = b' = r \), the proposition states that participation of neighbors should exhibit positive dependence. By contrast, if the cartel submits only one bid, there will be negative dependence (both inequalities strictly reverse). Note that this test could be foiled by phantom bidding. For example, if neighbors bid proportional to the serious cartel bid, then neighbor participation exhibit positive dependence.

To test affiliation in neighbor participation, we use the parametric test proposed by Li and Zhang [12]. (In future work, we plan to implement a non-parametric test.) Taking a linear approximation of the participation threshold, neighbor \( t \)'s participation decision on tract \( t \) is determined by the binary choice model

\[
P_{it} = 1\{Z_{it} \alpha_n + \eta_t + \varepsilon_{it}\}, i = 1, ..., n
\]
Here \( \eta_t \) denotes auction heterogeneity not observed by the econometrician and \( \varepsilon_{it} \) represents the idiosyncratic error induced by the private information of neighbor \( i \). The thresholds can vary across \( n \) but, given \( N_t = n \), symmetry implies that they are the same for each neighbor firm. We assume that \((\eta_t, \varepsilon_{1t}, ..., \varepsilon_{nt})\) is distributed joint normal. In this setting, the correlation between the idiosyncratic errors represents affiliation. Estimation is by maximum simulated likelihood (MSL) using the GHK simulator.

### 3.3 Winner’s Curse Test

A second approach is to look for the absence of the winner’s curse. Under competition, neighbors have to worry about outbidding other neighbors. Furthermore, ceteris paribus the magnitude of the winner’s curse correction increases with the number of bidders. Our test exploits this comparative static prediction.

**Assumption 3**: Conditional on \( Z_r \), for all \( n' \) and all \( n < n' \), \( F_{V,X}(\cdot; n) \) is identical to the marginal distribution of \((V,X_1,..,X_{nt})\) obtained from \( F_{V,X}(\cdot; n') \).

This is a standard notion of exogenous variation in the number of potential bidders conditional on observed lease characteristics. The characteristics can include the number of neighbor tracts. In that case, the assumption states that the ownership structure of the neighborhood is exogenous. Given Assumption 3, it is straightforward to show that \( x^*(n) \) increases with \( n \). This property is a distinguishing feature of common value environments. In private value environments, the probability of participation does not depend upon the number of bidders. However, it presents a challenge in trying to distinguish between competition and collusion. If we observe that neighbor firms are less likely to participate when they face more neighbors, is it because of the "winners curse" or because they have agreed not to bid against each other?

Our test looks at the impact of neighbor participation on outcomes. Using standard arguments, we obtain the following result.

**Proposition 2** *With competitive neighbor participation, \( E[V_t \mid B_{it} > r; N_t = n] \) is increasing in \( n \).*

We use data on bids and ex post tract values to estimate the conditional expectation.

Under collusion, we would not expect to observe a positive correlation between \( V \) and \( N \) since the bidder does not have to be concerned with the winner’s curse. For example, in the designated bidder model, \( x^*(n) \) is invariant to \( n \) and, in the information pooling model, \( x^*(n) \) is likely to be decreasing in \( n \).
3.4 Structural Tests

A third approach is to estimate the joint distribution $F_{V,X}(\cdot; n)$ from data on bids and ex post tract values and see how the information structure varies with $n$. For example, under Assumption 3, the joint distribution is invariant to $n$.

The structural approach is based on the following insight. According to the model, when $b_{it} > 0$, the underlying signal $x_{it}$ satisfies

$$F_X(x_{it}) = G_B(b_{it}; n)$$

where $G_B$ is the bid distribution of a neighbor. That is, the quantiles of the bid and signal distributions match. Recall that we are free to choose $F_X$, so, without loss of generality, we assume that $F_X$ is standard normal. In the first step, the neighbor bid distribution is estimated either nonparametrically or using a Tobit model for each $n$. Given an estimate $\hat{G}_B(b_{it}; n)$, the signals associated with positive neighbor bids are defined as

$$\hat{x}_{it} = \Phi^{-1}(\hat{G}_B(b_{it}; n)).$$

Signals of neighbors who do not bid are censored at $x^*(n)$. Threshold estimates $\hat{x}^*(n)$ are obtained by evaluating the empirical bid distributions at the reserve price. In the second step, the joint distribution $F_{V,X}$ is estimated by MSL using data on $V_t$ and treating the signal estimates $\{\hat{x}_{it}\}$ and thresholds $\{\hat{x}(n)\}$ as data.

What can we expect to observe if neighbors are not competing? Collusive nonparticipation when $n > 1$ will distort the mapping between quantiles of bids and quantiles of signals because, when a neighbor does not bid, we incorrectly assume that it received a signal below the threshold. The event $\{B_{it} < r, X_{it} > x^*(n)\}$ can happen under collusion, and the misclassification is likely to increase with $n$. The distortion is largest near the screening level but its effect on signal estimates is ambiguous. The reason is that, under the alternative of collusion, the threshold estimate $\hat{x}^*(n)$ can be larger or less than the competitive threshold, $x^*(n)$. For example, in the designated bidder model, the probability that a neighbor does not participate is

$$\Phi(\hat{x}^*(n)) = \frac{n-1}{n} + \frac{1}{n} \Phi(x^*(1)).$$

Typically, it exceeds $\Phi(x^*(n))$, the probability of not bidding under competition, due to excessive nonparticipation. In that case, the estimates of the signals obtained from $\hat{G}_B$ are biased upward. However, if $n$ is small, say, $n = 2$, and the winner’s curse is severe, then $\hat{x}^*(2)$ can be less than $x^*(2)$, in which case, the signal estimates are biased downward. The impact of the bias on $V_t$ can be detected because there is no such distortion when $n = 1$. 
Implementation of the Tests

In this section, we discuss the selection issues involved in estimating the primitives of the model and how we deal with them. The main challenge is that $V_t$ is observed only when tract $t$ is leased, drilled, and above a threshold for production to be profitable.

We begin by exploiting Assumption 2. If non-neighbors are uninformed, then there is no selection problem in using the sample of tracts bid by non-neighbors to analyze neighbor bidding. This sample offers several advantages over the alternative of using the sample of offered tracts. First, it allows us to study the pre-AWL period. The set of offered tracts with neighborhoods is not observed for lease sales held during this period. In each sale, the government restricted the area available for leasing and invited firms to nominate tracts in that area. Their nominations determined the set of tracts offered for sale. The number of tracts offered is reported, and was typically twice the number of tracts bid. But the locations of the offered tracts is not reported. Second, for sales held during the AWL period, roughly 10% of the tracts offered in any sale were bid. Therefore, tracts with no bids would tend to dominate the analysis. Third, it allows us to control for unobserved tract heterogeneity. We use the maximum non-neighbor bid and number of non-neighbor bids as a proxy for covariates that are observable to the firms but not to the econometrician.

Our approach to dealing with selection on drilling is to adopt a parametric model. The value of tract $t$ is

$$V_t^* = Z_t \beta + \gamma N_t + \varepsilon_t$$

Drilling is determined by

$$D_t = 1 \{W_t \gamma + U_t > 0\}$$

where $W_t \supset Z_t$. Our measure of $V_t^*$ is

$$V_t = \begin{cases} 
V_t^* & \text{if } D_t = 1 \text{ and } V_t^* > k \\
0 & \text{if } D_t = 1 \text{ and } V_t^* < k \\
\text{not observed} & \text{if } D_t = 0
\end{cases}$$

where $k$ is lowest reported value.

**Assumption 4:** (i) $(\varepsilon_t, U_t, X_{1t}, \ldots, X_{Nt}) \sim MN(\mu(N_t), \Sigma(N_t))$ and are independent

---

3 The assumption here is that the maximum non-neighbor bid, $B_t^N = \psi(\omega_t, Z_t)$ where $\omega_t$ is unobserved heterogeneity and $\psi$ is unknown function, strictly increasing in $\omega_t$. However, to be consistent with equilibrium, we require $B_t^N = \psi(\omega_t, Z_t) + \eta_t$ where $\eta_t$ is measurement error (see Huang and Hu (2011)).
of $W_t$; (ii) for all $n$, $\mu(n) = 0_n$ and (ii) $\Sigma(n)$ is the $(n + 3) \times (n + 3)$ matrix
\[
\begin{bmatrix}
\sigma^2 \epsilon & \sigma_{x\epsilon} & \cdots & \cdots & \sigma_{x\epsilon} & \sigma_{u\epsilon} \\
\sigma_{x\epsilon} & 1 & \sigma_{xx} & \cdots & \sigma_{xx} & \sigma_{xx} \\
\vdots & \sigma_{xx} & \ddots & \ddots & \vdots & \vdots \\
\vdots & \vdots & \ddots & \ddots & \sigma_{xx} & \vdots \\
\sigma_{x\epsilon} & \sigma_{xx} & \cdots & \sigma_{xx} & 1 & \sigma_{xx} \\
\sigma_{u\epsilon} & \sigma_{xx} & \cdots & \sigma_{xx} & \sigma_{xx} & 1
\end{bmatrix}.
\]

Here $\sigma_u = \sigma_x = 1$ are normalizations. Condition (i) imposes joint normality and condition (ii) imposes exogeneity of $N_t$, that is, means and covariances do not change with $N_t$. If (ii) holds, then $\gamma = 0$. The model described above is known as a Type II Tobit model (see Amemiya [1]).

Given the joint normality assumption, the structural parameters of the model can be obtained in one of two ways. One is to estimate the joint distribution directly by MSL as described in the previous section. The other approach is to focus on the conditional expectation $E[V_t|Z_t, X_{it} = x_{it}, N_t]$. The model conditional on any $X_{it}$ is
\[
V^* = \beta Z_t + \sigma_{xe} X_{it} + \gamma N_t + \nu_{it} \\
D_t = 1\{W_t \gamma + \sigma_{xx} X_{it} + \varsigma_{it}\}
\]

where $(\nu_{it}, \varsigma_{it}) \sim BVN(0, \Xi)$. The conditional model is easier to estimate, but the cost is that it fails to exploit all of the variation in the data, in particular, the variation in outcomes between tracts bid by neighbors and tracts not bid by neighbors.

In what follows, we report parameter estimates based on the second approach. In the first step, we estimate the bid distributions for each $n$ using a Tobit model. Under this assumption,
\[
\tilde{x}_{it} = \Phi^{-1}(\hat{G}(b_{it}; N_t)) = \frac{b_{it} - Z_t \alpha_n}{\sigma_{nb}}
\]
and $\tilde{x}^*(z_{t}, n_t)$ is defined by setting $b_{it} = r$. Treating the signals as data, we estimate a multi-variate Tobit model to obtain an estimate of $\sigma_{xx}$. In the second step, we estimate the conditional model on the sample of positive neighbor bids to obtain estimates of the other structural parameters: $\beta, \sigma_{xe}, \sigma_{xx}, \sigma_{ue}, \sigma_{e}$. We add $N_t$ to the revenue equation as a test of the invariance. Currently, we ignore first-stage estimation error and possible inconsistency of normal model of bids and signals. We are working on estimating the joint distribution, and preliminary results indicate that the results of the two approaches are quite similar.
5 Data

Our sample consists of all tracts with neighborhoods bid by non-neighbors and sold in sales held during the period 1954 to 2002. Let \( t = 1, \ldots, T \) index tracts in the sample. Here we adopt the convention that a tract is given a separate index each time it is sold. A tract is called a neighbor tract of tract \( t \) if it shares a boundary point or edge with tract \( t \). A neighbor tract of tract \( t \) in sale \( s \) is active if it was sold in a prior sale and its lease has not expired or terminated. A neighborhood for tract \( t \) consists of active neighbor tracts.

We classify the owners of tracts in the neighborhood of tract \( t \) into groups. If firm A is the sole owner of neighbor tracts, then it is a singleton and forms its own group. If firms A and B jointly own a neighbor tract, then they belong to the same ownership group. The assumption here is that they will agree not bid against each other on tract \( t \) and either submit a joint bid or a solo bid by one of the firms. Similarly, if firms A and B jointly own a neighbor tract and firms B and C jointly own another neighbor tract, then firms A, B, and C belong to the same ownership group. If A and B agree not to compete and B and C agree not to compete, then it is natural to assume that A and C also agree not to compete. More formally, the joint ownership relation determines an ownership graph in which each point represents a neighbor firm. Firms that are not connected (i.e., isolated points) are sole owners of tracts. Firms that are connected to each other through the joint venture relation belong to the same component. The number of ownership groups is equal to the sum of the number of isolated points and number of components. We will refer to the ownership groups as neighbors. The number of ownership groups for tract \( t \) is our measure of the number of neighbors, \( N_t \).

We measure the value of drilled tracts, \( V_t \), as the log of discounted revenues (if positive) and zero otherwise. The covariates \( Z_t \) represent characteristics of the neighborhood of tract \( t \). We use mainly the following list of variables: number of neighbor tracts (No_Tract); highest bid in the neighborhood (NB_Bid_Max); highest tract revenue in the neighborhood (NB_Rev_Max); an indicator that is equal to one if at least one neighbor tract has an expired lease (NB_Expired); an indicator that is equal to one if at least one neighbor tract has an expired lease and was drilled (NB_Expired_Drilled); water depth (Depth). The instruments included in \( W_t \) are year-of-sale real oil price, an indicator that is equal to one for royalty relief period (1996-2002), and year-of-sale dummies. The latter capture common price and cost shocks that are likely to influence the drilling decisions of leases sold in the same year.

In our analysis, we focus on tracts with \( 1 \leq N_t \leq 4 \). Tables 4 through 7 present summary statistics by number of neighbors for each of the four area-periods. The NB Bid Rate is
the fraction of tracts receiving at least one neighbor bid and Multiple NB Bid Rate is the fraction of tracts receiving at least two bids. NB Win Rate is the fraction of tracts won by neighbor firms conditional on bidding. NN Bid is the average number of non-neighbor bids and NN Bid Max is the average value of the maximum non-neighbor bid.

Within each sample, neighbor bid and win rates tend to increase with \( N \), but the number of non-neighbor bids and the value of their bids do not exhibit any trend. The variation in outcomes within each sample appears, for the most part, uncorrelated with \( N \), which provides some support for the exogeneity assumption. Drill and hit rates are roughly constant across \( N \); average revenue on productive tracts also does not vary much across \( N \), with the exception of \( N = 1 \). It appears that fields discovered on tracts with one neighbor tend to be larger than on tracts with multiple neighbors, particularly during the AWL period.

The AWL program had a large impact on participation rates and outcomes. Prior to 1983, the average neighbor bid rate was approximately 65%, the multiple neighbor bid rate ranged between 18% and 32% for \( N > 1 \), and drill rates were roughly 90%. It is worth noting that the latter result implies that selection on drilling is not a significant issue for the pre-AWL sample. After 1983, the neighbor bid rate dropped to roughly 18%, the multiple neighbor bid rate ranged between 1% to 7% for \( N > 1 \), and the drill rate dropped to 40% for shallow tracts and 18% for deep water tracts. The number of non-neighbor bids averaged a little more than 2 per tract during the pre-AWL period but dropped to a little more than 1 per tract in the AWL period. Finally, as we saw earlier in regards to the sample of all tracts sold, the average field size on shallow tracts bid by non-neighbors prior to 1983 was substantially higher than it was on shallow tracts after 1983, and much smaller than average field size on deep water tracts.

6 Results

In this section, we report and interpret the test results. Since behavior appears to differ across geographical areas and time periods, we present test results separately for tracts sold during the 1954-1973 period, tracts sold during the 1974-1982 period, shallow water tracts sold during the AWL period (AWL Shallow), and deep water tracts sold during the AWL period (AWL Deep).

6.1 Affiliation Test

Table 8 presents the results of the affiliation test. The number in each cell is an estimate of the correlation in the neighbor participation decisions for \( N = 2 \) and \( N = 4 \); standard errors
are in parentheses. We do not report the estimates for \( N = 3 \) since, in this case, Monte Carlo experiments indicate that our test is biased whenever the participation threshold is high. The number of observations in the 1954-1973 sample with \( N = 4 \) was too small to obtain reliable estimates. The covariates are neighborhood characteristics, non-neighbor bidding variables, and year dummies.

The correlation coefficient is significantly negative for the 1954-1973 period and significantly positive for AWL Shallow \( N = 4 \). The coefficients for 1974-1982 are negative but not significantly different from zero. The coefficients for AWL Deep are essentially zero. We interpret these results as indicating that neighbors may have colluded during the pre-OPEC period. The evidence is more mixed for the other two samples.

### 6.2 Winner’s Curse Test

Table 9 presents the results of the winner’s curse test. The number in each cell is an estimate of the coefficient on \( N \) in the (linear) Tobit regression of \( V_t \) on neighborhood characteristics, non-neighbor bidding variables, and \( N_t \); standard errors are in parentheses. Year and royalty relief dummies are included in the drilling equations for the AWL samples as instruments. The second column reports the coefficient estimates for the sample of tracts bid by non-neighbors (NN); the third column reports coefficient estimates for the sample of tracts bid by both neighbors (NB) and nonneighbors.

The results in the second column represents a test of the exogeneity assumption. If \( N \) is exogenous, then \( E[V|Z, N] = E[V|Z] \) and the coefficient on \( N \) should not be significantly different from zero. The assumption is not rejected for 1954-1973 and AWL Deep subsamples but is rejected for the 1974-1982 and AWL Shallow subsamples. In the latter two samples, tract values are on average higher when ownership is more concentrated. (Recall that we include number of neighbor tracts as a neighborhood characteristic.) A possible explanation for the negative coefficient is that it reflects the acquisition strategy of firms. The ownership structure of the neighborhoods are determined in prior auctions. If a firm gets a very promising signal on an area, it will bid aggressively and try to win several tracts to ensure coverage of the potential field. If it only gets a mediocre signal, then it may bid on a tract or two but not very aggressively. As a result, given the dispersion in signals, ownership of neighborhoods in promising areas may be more concentrated than in less promising areas. This argument suggests that the acquisition times of neighbors leases is more concentrated in neighborhoods with more concentrated ownership, in which case, we can use an age concentration measure as a control.

We can use the results of the second column to perform a difference test. Affiliation
implies that $E[V | Z, X_{it}] > x^*(z, n), N] - E[V | Z, N] > 0$. Under the null of competitive bidding, this difference will tend to increase with $n$. A sufficient condition is that $N$ does not affect the information structure (i.e., the covariances). The results of Table 9 indicate that the selection effect is indeed strongly increasing in $N$ for shallow tracts sold during the '74-82 and AWL periods. We interpret this result as evidence in support of the null hypothesis. By contrast, the winner’s curse effect does not appear to be present for deep water tracts and tracts sold during the pre-OPEC period, which is not consistent with competitive bidding.

6.3 Structural Tests

We turn next to tests based on the structural model. The strategy is to look for evidence that "no bids" are misclassified as signals below the threshold and, as a result, signal estimates are distorted away from their true values. The distortions should affect estimates of the structural parameters.

Table 10 presents the results for the pre-AWL samples. The covariates in this case are neighborhood characteristics, prices, and non-neighbor bid variables. Drilling rates are sufficiently high in these samples that we drop the drilling equation and estimate the joint distribution on the sample of drilled tracts. Here $\rho_{xe}$ is the correlation between $X_{it}$ and $E_t$ and $\rho_{xx}$ is the correlation between signals for tracts with $N > 1$.

Consider first the 1954-1974 period. The absence of a winner’s curse in this sample implies that conditioning on neighbor signals should have no effect on the coefficient on $N$. The results confirm this prediction. The correlation between neighbor signals and the tract value unobservable is significantly positive. It establishes that neighbor signals are informative but noisy. The correlation coefficient between signals is implausibly large. For example, under conditional independence, $\rho_{xx} = \rho_{xe}^2 = 0.049$. It is also inconsistent with the negative correlation reported in Table 8 for this period. That correlation is driven by the fact that the frequency of tracts with only one bid (57%) is high relative to the frequency of tracts with no neighbor bids (25%) and with two bids (17%). The high positive correlation between signals is due to the fact that the fraction of tracts with two bids is relatively high (17%) and the correlation between signals on these tracts is extremely high, about 0.95. By comparison, the fraction of tracts with zero bids in period 1974-1982 is higher (38%) and the correlation between signals on tracts with two bids is much lower, approximately 0.35. One interpretation of these results is that neighbors in the 1954-1973 period were engaged in "phantom" bidding to ensure that the government did not reject their high bid.

In the 1974-1982 period, conditioning on neighbor signals should eliminate the winner's
curse effect and we find that this is indeed the case. The estimate of -0.41 is quite similar to the coefficient value reported for \( N \) in the second column of Table 9. The correlation coefficient between signals and tract value is similar to the value of the correlation coefficient in the earlier period. However, the correlation between signals is much lower and more consistent with the correlation between signals and tract value.

Table 11 presents the results for the AWL samples. The estimates of the structural parameters for AWL Shallow are very similar to the estimates for the 1973-1982 period. However, the same cannot be said for the AWL Deep. Signals in this sample are uncorrelated and uninformative about tract value. To understand why, we estimated the correlations separately for each \( N \). This decomposition isolates the effects of the variation in \( X_{it} \) due to the variation in bids for each \( N \) and the variation due to shifts in the bid distribution across \( N \). We find that the correlations between signals are negative for \( N = 2 \) and \( N = 4 \) and, in the latter case, large and statistically significant. Regarding the correlation between signals and value, \( \rho_{xv} = 0.172 \) for \( N = 1 \) which is essentially the same as the correlation in AWL Shallow; but for \( N > 1 \), \( \rho_{xv} = -0.04 \) and is clearly not significantly different from zero. In the latter case, the main problem is that the correlation cannot be identified because of a lack of significant variation in bids - most of the neighbor bids are close to the reserve price.

We interpret the results as further evidence that neighbor bidding for shallow tracts in the period 1974 to 2002 appears to have been competitive. However, bidding in the 1954-1973 period and AWL Deep exhibit an absence of competition among neighbors.

7 Robustness (incomplete)

In this section, we examine several of the assumptions that underlie the analysis.

1. Are neighbors symmetrically informed? Neighbors who own more tracts may better informed. We can address this issue by estimating the conditional model for \( N = 1 \) and letting the correlation coefficient between \( X_{it} \) and \( V_t \) to vary depending upon the number of tracts owned by the neighbor. For \( N > 1 \), we would need to take into account strategic effects of multi-tract ownership among neighbors.

2. Are neighbors who own more tracts more likely to participate? Under competition, the neighbor with more tracts is more likely to bid if more tracts means more information. Under collusion, tract ownership may be used to determine who should bid even in symmetric environments.

3. Who are the neighbors of a tract? We have defined the neighborhood of a tract in
terms of shared boundaries or boundary points. Would the results change if we add another ring to the neighborhood?

4. Are non-neighbors informed? We can address this issue in a symmetric environment by adding a non-neighbor signal $Y$ and estimating the joint distribution $(V, X, Y)$.

5. Who are the non-neighbors?

8 Conclusion

In this paper we have developed several tests of competitive bidding in pure common value, first-price auctions using data on bids and expost values. We have also provided an econometric strategy for estimating the joint distribution of signals and value determining bids when these kind of data are available. We have applied our approach to offshore oil and gas auctions of tracts where adjacent tracts were already under lease. Specifically, we test whether the owners of the adjacent tracts bid competitively. Our tentative conclusion is that they bid competitively for shallow tracts after the oil crisis of 1973, but did not compete against each other for deep water tracts and for tracts sold during the period 1954 to 1973. However, much more work is needed to solidify these conclusions.
References


Table 1: Summary Statistics

<table>
<thead>
<tr>
<th></th>
<th>1983-2002</th>
<th>Pre-AWL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shallow</td>
<td>Deep</td>
</tr>
<tr>
<td>No. of Tracts</td>
<td>8555</td>
<td>7271</td>
</tr>
<tr>
<td>Drill Rate</td>
<td>0.38</td>
<td>0.13</td>
</tr>
<tr>
<td>Hit Rate</td>
<td>0.49</td>
<td>0.36</td>
</tr>
<tr>
<td>No. of Bids</td>
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<td>1.38</td>
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<tr>
<td>Win Bid</td>
<td>1.11</td>
<td>0.92</td>
</tr>
<tr>
<td>SD of Win Bid</td>
<td>2.67</td>
<td>2.63</td>
</tr>
<tr>
<td>Rev</td>
<td>Hit</td>
<td>28.78</td>
</tr>
<tr>
<td>Cost</td>
<td>Drilled</td>
<td>11.64</td>
</tr>
<tr>
<td>Net Profits</td>
<td>-1.04</td>
<td>2.88</td>
</tr>
</tbody>
</table>

*Dollar figures are in millions of 1982 dollars.

Net Profit = Revenue - Cost - Bid - Royalty.
### Table 2: Statistics by Bidder Types - 1954-82

<table>
<thead>
<tr>
<th></th>
<th>1954-73</th>
<th>1974-82</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NB</td>
<td>NN</td>
</tr>
<tr>
<td>No. of Tracts</td>
<td>305</td>
<td>117</td>
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<tr>
<td>Drill Rate</td>
<td>0.84</td>
<td>0.77</td>
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<tr>
<td>Hit Rate</td>
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<td>0.32</td>
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<td>No. of Bids</td>
<td>3.40</td>
<td>2.06</td>
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<tr>
<td>Win Bid</td>
<td>14.92</td>
<td>5.70</td>
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<tr>
<td>Rev</td>
<td>Hit</td>
<td>72.33</td>
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<tr>
<td>Cost</td>
<td>Drilled</td>
<td>12.75</td>
</tr>
<tr>
<td>Net Profits</td>
<td>6.85</td>
<td>-2.81</td>
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</table>

*Dollar figures are in millions of 1982 dollars.

NB = Tracts Bid by Neighbor Firms

NN = Tracts Bid by Non-neighbor Firms Only

### Table 3: Statistics by Bidder Types - AWL

<table>
<thead>
<tr>
<th></th>
<th>Shallow</th>
<th>Deep</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NB</td>
<td>NN</td>
</tr>
<tr>
<td>No. of Tracts</td>
<td>1930</td>
<td>4068</td>
</tr>
<tr>
<td>Drill Rate</td>
<td>0.41</td>
<td>0.36</td>
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<tr>
<td>Hit Rate</td>
<td>0.54</td>
<td>0.45</td>
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<tr>
<td>No. of Bids</td>
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<td>Win Bid</td>
<td>1.59</td>
<td>0.86</td>
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<tr>
<td>Rev</td>
<td>Hit</td>
<td>34.56</td>
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<tr>
<td>Cost</td>
<td>Drilled</td>
<td>13.22</td>
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<tr>
<td>Net Profits</td>
<td>-0.61</td>
<td>-1.05</td>
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</table>

*Dollar figures are in millions of 1982 dollars.

NB = Tracts Bid by Neighbor Firms

NN = Tracts Bid by Non-neighbor Firms Only
Table 4: 1954-1973 - Tracts Bid by NN

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<tbody>
<tr>
<td>No. of Tracts</td>
<td>156</td>
<td>116</td>
</tr>
<tr>
<td>NB Bid Rate</td>
<td>0.56</td>
<td>0.74</td>
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<tr>
<td>Multiple NB Bid Rate</td>
<td>0.00</td>
<td>0.17</td>
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<tr>
<td>NB Win Rate</td>
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<tr>
<td>Drill Rate</td>
<td>0.86</td>
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<tr>
<td>Hit Rate</td>
<td>0.51</td>
<td>0.60</td>
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<tr>
<td>NN Bid</td>
<td>3.49</td>
<td>2.59</td>
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<td>NN Bid Max</td>
<td>13.42</td>
<td>12.39</td>
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<tr>
<td>Rev</td>
<td>Hit</td>
<td>61.93</td>
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</table>

*Dollar figures are in millions of 1982 dollars.

Table 5: 1974-1982 - Tracts Bid by NN

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<tr>
<td>No. of Tracts</td>
<td>281</td>
<td>281</td>
<td>165</td>
<td>71</td>
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<tr>
<td>NB Bid Rate</td>
<td>0.52</td>
<td>0.62</td>
<td>0.68</td>
<td>0.77</td>
</tr>
<tr>
<td>Multiple NB Bid Rate</td>
<td>0.00</td>
<td>0.19</td>
<td>0.27</td>
<td>0.32</td>
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<tr>
<td>NB Win Rate</td>
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<td>0.45</td>
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<tr>
<td>Drill Rate</td>
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<td>Hit Rate</td>
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<td>NN Bid</td>
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<td>NN Bid Max</td>
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<td>Rev</td>
<td>Hit</td>
<td>86.00</td>
<td>54.06</td>
<td>46.15</td>
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*Dollar figures are in millions of 1982 dollars.
Table 6: AWL Shallow - Tracts Bid by NN

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<tr>
<td>No. of Tracts</td>
<td>874</td>
<td>1254</td>
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<td>NB Bid Rate</td>
<td>0.08</td>
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<tr>
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<td>0.01</td>
<td>0.03</td>
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<tr>
<td>NB Win Rate</td>
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<tr>
<td>Hit Rate</td>
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<td>0.49</td>
<td>0.50</td>
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<tr>
<td>NN Bid</td>
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<td>1.44</td>
<td>1.47</td>
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<tr>
<td>NN Bid Max</td>
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<td>1.14</td>
<td>0.92</td>
<td>0.69</td>
</tr>
<tr>
<td>Rev</td>
<td>Hit</td>
<td>48.01</td>
<td>29.00</td>
<td>28.95</td>
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</tbody>
</table>

*Dollar figures are in millions of 1982 dollars.

Table 7: AWL Deep - Tracts Bid by NN

<table>
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<th>N=3</th>
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<td>0.19</td>
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<td>0.40</td>
<td>0.37</td>
<td>0.53</td>
<td>0.43</td>
</tr>
<tr>
<td>Drill Rate</td>
<td>0.13</td>
<td>0.16</td>
<td>0.20</td>
<td>0.22</td>
</tr>
<tr>
<td>Hit Rate</td>
<td>0.32</td>
<td>0.30</td>
<td>0.29</td>
<td>0.45</td>
</tr>
<tr>
<td>NN Bid</td>
<td>1.32</td>
<td>1.36</td>
<td>1.38</td>
<td>1.46</td>
</tr>
<tr>
<td>NN Bid Max</td>
<td>0.99</td>
<td>0.88</td>
<td>1.15</td>
<td>1.19</td>
</tr>
<tr>
<td>Rev</td>
<td>Hit</td>
<td>173.32</td>
<td>102.35</td>
<td>132.97</td>
</tr>
</tbody>
</table>

*Dollar figures are in millions of 1982 dollars.
### Table 8: Affiliation Test

<table>
<thead>
<tr>
<th></th>
<th>N=2</th>
<th>N=4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1954-1973</td>
<td>-0.331*</td>
<td>n.a.</td>
</tr>
<tr>
<td></td>
<td>(0.144)</td>
<td></td>
</tr>
<tr>
<td>1974-1982</td>
<td>-0.073</td>
<td>-0.106</td>
</tr>
<tr>
<td></td>
<td>(0.099)</td>
<td>(0.080)</td>
</tr>
<tr>
<td>AWL Shallow</td>
<td>-0.010</td>
<td>0.107*</td>
</tr>
<tr>
<td></td>
<td>(0.103)</td>
<td>(0.047)</td>
</tr>
<tr>
<td>AWL Deep</td>
<td>0.009</td>
<td>0.031</td>
</tr>
<tr>
<td></td>
<td>(0.090)</td>
<td>(0.119)</td>
</tr>
</tbody>
</table>

Significance levels: †: 10%  *: 5%  **: 1%

Covariates: NB Bid Max, NB Rev Max, NB Expired,
            NB Expired Drilled, NN Bid, NN Bid Max, Oil Price

### Table 9: Test for Winner’s Curse

<table>
<thead>
<tr>
<th></th>
<th>NN and NB</th>
<th>NN</th>
</tr>
</thead>
<tbody>
<tr>
<td>AWL Shallow</td>
<td>-0.4233*</td>
<td>-0.7354**</td>
</tr>
<tr>
<td></td>
<td>(0.2027)</td>
<td>(0.1367)</td>
</tr>
<tr>
<td>AWL Deep</td>
<td>1.8361</td>
<td>0.9360</td>
</tr>
<tr>
<td></td>
<td>(1.5035)</td>
<td>(0.7563)</td>
</tr>
<tr>
<td>1954-1973</td>
<td>1.1002</td>
<td>0.9833</td>
</tr>
<tr>
<td></td>
<td>(0.6769)</td>
<td>(0.6251)</td>
</tr>
<tr>
<td>1974-1983</td>
<td>-0.1641</td>
<td>-0.4572*</td>
</tr>
<tr>
<td></td>
<td>(0.2118)</td>
<td>(0.2196)</td>
</tr>
</tbody>
</table>

Significance levels: †: 10%  *: 5%  **: 1%

Covariates: NB Bid Max, NB Rev Max, NB Expired,
            NB Expired Drilled, NN Bids, NN Bid Max, No.Tract
            Sales Year Dummies for AWL Samples
Table 10: Structural Test - Pre-AWL

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>1.361†</td>
<td>-0.468</td>
</tr>
<tr>
<td></td>
<td>(0.702)</td>
<td>(0.304)</td>
</tr>
<tr>
<td>$\rho_{x\epsilon}$</td>
<td>0.205**</td>
<td>0.154**</td>
</tr>
<tr>
<td></td>
<td>(0.064)</td>
<td>(0.032)</td>
</tr>
<tr>
<td>$\rho_{xx}$</td>
<td>0.376**</td>
<td>0.053</td>
</tr>
<tr>
<td></td>
<td>(0.102)</td>
<td>(0.037)</td>
</tr>
<tr>
<td>$\sigma_\epsilon$</td>
<td>4.452**</td>
<td>5.318**</td>
</tr>
<tr>
<td></td>
<td>(0.305)</td>
<td>(0.219)</td>
</tr>
</tbody>
</table>

|                | 242       | 707       |

Significance levels: †: 10% *: 5% **: 1%
Covariates: NB Bid Max, NB Rev Max, NB Expired, NB Expired Drilled, NN Bids, NN Bid Max, No.Tract

Table 11: Structural Test - AWL

<table>
<thead>
<tr>
<th></th>
<th>AWL Shallow</th>
<th>AWL Deep</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>-0.528*</td>
<td>1.530</td>
</tr>
<tr>
<td></td>
<td>(0.205)</td>
<td>(1.514)</td>
</tr>
<tr>
<td>$\rho_{x\epsilon}$</td>
<td>0.284**</td>
<td>0.275**</td>
</tr>
<tr>
<td></td>
<td>(0.012)</td>
<td>(0.009)</td>
</tr>
<tr>
<td>$\rho_{xx}$</td>
<td>0.171**</td>
<td>0.097</td>
</tr>
<tr>
<td></td>
<td>(0.063)</td>
<td>(0.083)</td>
</tr>
<tr>
<td>$\rho_{uu}$</td>
<td>0.063**</td>
<td>0.026</td>
</tr>
<tr>
<td></td>
<td>(0.023)</td>
<td>(0.041)</td>
</tr>
<tr>
<td>$\rho_{ue}$</td>
<td>0.551**</td>
<td>-0.145</td>
</tr>
<tr>
<td></td>
<td>(0.140)</td>
<td>(0.315)</td>
</tr>
<tr>
<td>$\sigma_\epsilon$</td>
<td>3.077**</td>
<td>12.534**</td>
</tr>
<tr>
<td></td>
<td>(0.186)</td>
<td>(1.355)</td>
</tr>
</tbody>
</table>

|                | 477       | 189       |

Significance levels: †: 10% *: 5% **: 1%
Covariates: NB Bid Max, NB Rev Max, NB Expired, NB Expired Drilled, NN Bids, NN Bid Max, No.Tract
Figure 1: Sources of Government Revenues

Payments are in millions

Bonus Payment
Royalty Payment
Figure 2: Fractions of Tracts with Neighbors

The bar chart shows the fractions of tracts with neighbors from 1954 to 1997. The y-axis represents the fraction, and the x-axis represents the year. The fractions increase significantly from 1977 onwards.
Appendix

Testing Procedures

Affiliation Test

For a sample of tracts with \( n \) neighbors, we write the reduced-form participation equation as

\[ E_{it} = 1 \{ Z_i' \alpha + X_{it} > 0 \} \]

The covariance matrix of \((X_{1t}, \ldots, X_{nt})\) is given by

\[
\Sigma = \begin{bmatrix}
1 & \sigma_{xx|n} & \cdots & \sigma_{xx|n} \\
\sigma_{xx|n} & 1 & \cdots & \sigma_{xx|n} \\
\vdots & \vdots & \ddots & \vdots \\
\sigma_{xx|n} & \sigma_{xx|n} & \cdots & 1
\end{bmatrix}
\]

We estimate \((\alpha_n, \sigma_{xx|n})\) by the multivariate probit. The likelihood for tract \( t \) which received \( a_t \) bids will be written as

\[ \mathcal{L}_t (\alpha_n, \sigma_{xx|n}) = \left( \frac{n_t}{a_t} \right) \int_{E_{it} = 0}^{x_{nt}} \cdots \int_{E_{it} = 0}^{x_{1t}} \prod f (x_1, \ldots, x_{nt}) \, dx_1 \cdots dx_{nt} \]

where

\[
\bar{x}_{it} = \begin{cases} 
-Z_t \alpha_n & \text{if } E_{it} = 0 \\
\infty & \text{if } E_{it} = 1
\end{cases}
\]

\[
\tilde{x}_{it} = \begin{cases} 
-Z_t \alpha_n & \text{if } E_{it} = 0 \\
-Z_t \alpha_n & \text{if } E_{it} = 1
\end{cases}
\]

Winner’s Curse Test

The drilling equation is given by

\[ D_t = 1 \{ W_t \gamma + U_t > 0 \} \]

and the value of the tract is given by

\[
V_t = \begin{cases} 
V_t^* & \text{if } D_t = 1 \text{ and } V_t^* > k \\
0 & \text{if } D_t = 1 \text{ and } V_t^* \leq k \\
\text{not observed} & \text{if } D_t = 0
\end{cases}
\]

where \( V_t^* = Z_t \beta + \xi_t \). The variance-covariance matrix between \((U_t, \xi_t)\) is given by

\[
\Sigma_{u, \epsilon} = \begin{bmatrix}
1 & \sigma_{u \epsilon} \\
\sigma_{u \epsilon} & \sigma^2_{\epsilon}
\end{bmatrix}
\]

Estimation Algorithm:
1. Estimate on drilling and log-revenue:

   (a) Joint: the likelihood is defined jointly for the drilling and the log-revenue.

   \[ \mathcal{L}_{it} (\gamma, \beta, \Sigma_{u,\epsilon}) = \begin{cases} 
   \int_{-\infty}^{-W_t^\gamma} f_u(u) \, du & \text{for } D_t = 0 \\
   \int_{-W_t^\gamma}^{\infty} f_{u,e}(u, v_t - z_t \beta) \, du & \text{for } D_t = 1, V_t > V \\
   \int_{-W_t^\gamma}^{\infty} \int_{-\infty}^{V - Z_t^\beta} f_{u,e}(u, \epsilon) \, d\epsilon \, du & \text{for } D_t = 1, V_t \leq V 
   \end{cases} \]

   where \( f_u(\cdot) \) denotes the marginal density of \( U_t \), and \( f(\cdot, \cdot) \) denotes the density of \( (U_t, \mathcal{E}_t) \).

   (b) Concentrated: estimate the drilling equation first by the probit:

   \[ \mathcal{L}_{D_{it}} (\gamma) = \begin{cases} 
   \int_{-\infty}^{-W_t^\gamma} f_u(u) \, du & \text{for } D_t = 0 \\
   \int_{-W_t^\gamma}^{\infty} f_u(u) \, du & \text{for } D_t = 1 
   \end{cases} \]

   Estimate the log-revenue equation conditional on \( \hat{\gamma} \) by the MSL

   \[ \mathcal{L}_{it} (\gamma, \beta, \Sigma) = \begin{cases} 
   f_{\epsilon}^{\mid u}(v_t - z_t \beta | U_t > -W_t^\gamma) & \text{for } V_t > V \\
   \int_{-W_t^\gamma}^{\infty} f_{\epsilon}^{\mid u}(\epsilon | U_t > -W_t^\gamma) \, d\epsilon & \text{for } V_t \leq V 
   \end{cases} \]

   where \( f_{\epsilon}^{\mid u}(\cdot) \) denotes the density of \( \mathcal{E}_t \) conditional on \( U_t \).

Structural Test

- Bid equation:

  \[ B_{it} = (Z_t' \alpha_n + \omega_{it}) 1 \{ Z_t' \alpha_n + \omega_{it} > 0 \} \]

  where \( X_{it} = \frac{\omega_{it}}{\sigma_{\omega | u}} \).

- Drilling equation:

  \[ D_t = 1 \{ W_t^\gamma + U_t > 0 \} \]

- Value equation:

  \[ V_t = \begin{cases} 
   V_t^* & \text{if } D_t = 1 \text{ and } V_t^* > k \\
   0 & \text{if } D_t = 1 \text{ and } V_t^* \leq k \\
   \text{not observed} & \text{if } D_t = 0 
   \end{cases} \]

  where \( V_t^* = Z_t \beta + \mathcal{E}_t \).
Two-step Tobit  An observation is (bid, tract) pair with a positive bid. The variance-covariance structure of \((X_{it}, U_t, \mathcal{E}_t)\) is assumed to be

\[
\Sigma = \begin{bmatrix}
1 & \sigma_{xu} & \sigma_{xe} \\
\sigma_{xu} & 1 & \sigma_{ue} \\
\sigma_{xe} & \sigma_{ue} & \sigma_e^2
\end{bmatrix}
\]

for any \(i \in \{1, \ldots, n\}\).

Estimation Algorithm:

1. Tobit on bid equation:

2. Recover signals by \(\hat{x}_{it} = \frac{\hat{\omega}_t}{\sigma_u}\).

3. Estimate on drilling and log-revenue:

   (a) Drilling and log-revenue jointly: the likelihood is given by

   \[
   L_{it}(\gamma, \beta, \Sigma) = \begin{cases}
   \int_{-\infty}^{W_t} f^{|x|}_u(u|X_{it} = \frac{B_{it}-Z_t\hat{\alpha}}{\sigma_u}) \, du & \text{for } D_t = 0 \\
   \int_{-\infty}^{W_t} f^{|x|}_u(u, v_t - z_t\beta|X_{it} = \frac{B_{it}-Z_t\hat{\alpha}}{\sigma_u}) \, du & \text{for } D_t = 1, V_t > k \\
   \int_{-\infty}^{W_t} f^{k-Z_t\beta}_u f^{|x|}_u(u, \epsilon|X_{it} = \frac{B_{it}-Z_t\hat{\alpha}}{\sigma_u}) \, d\epsilon \, du & \text{for } D_t = 1, V_t \leq k
   \end{cases}
   \]

   where \(f^{|x|}_u(\cdot)\) denotes the marginal density of \(U_t\) conditional on \(X_{it}\), and \(f^{k-Z_t\beta}_u(\cdot, \cdot)\) denotes the density of \((U_t, \mathcal{E}_t)\) conditional on \(X_{it}\).

   (b) Concentrated likelihood: estimate the drilling equation first

   \[
   L^D_{it}(\gamma, \sigma_{xu}) = \begin{cases}
   \int_{-\infty}^{W_t} f^{|x|}_u(u|X_{it} = \frac{B_{it}-Z_t\hat{\alpha}}{\sigma_u}) \, du & \text{for } D_t = 0 \\
   \int_{-\infty}^{W_t} f^{|x|}_u(u|X_{it} = \frac{B_{it}-Z_t\hat{\alpha}}{\sigma_u}) \, du & \text{for } D_t = 1
   \end{cases}
   \]

Estimate the log-revenue equation conditional on \((\hat{\gamma}, \sigma_{xu})\)

\[
L_{it}(\gamma, \beta, \Sigma) = \begin{cases}
\int f^{k-Z_t\beta}_e f^{|x,u|}(v_t - z_t\beta|X_{it} = \frac{B_{it}-Z_t\hat{\alpha}}{\sigma_u}, U_t > -W_t\hat{\gamma}) \, dv & \text{for } V_t > k \\
\int f^{k-Z_t\beta}_e f^{|x,u|}(\epsilon|X_{it} = \frac{B_{it}-Z_t\hat{\alpha}}{\sigma_u}, U_t > -W_t\hat{\gamma}) \, d\epsilon & \text{for } V_t \leq k
\end{cases}
\]

where \(f^{|x,u|}(\cdot)\) denotes the density of \(\mathcal{E}_t\) conditional on \((X_{it}, U_t)\).
**Joint Signal Model** An observation is a tract. The variance-covariance structure of \((X_{1t}, X_{2t}, \ldots, X_{nt}, U_t, \varepsilon_t)\) is

\[
\Sigma = \begin{bmatrix}
1 & \sigma_{xx} & \cdots & \sigma_{xx} & \sigma_{xu} & \sigma_{xe} \\
\sigma_{xx} & 1 & \cdots & \sigma_{xx} & \sigma_{xu} & \sigma_{xe} \\
\vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\
\sigma_{xx} & \sigma_{xx} & \cdots & 1 & \sigma_{xu} & \sigma_{xe} \\
\sigma_{xu} & \sigma_{xu} & \cdots & \sigma_{xu} & 1 & \sigma_{ue} \\
\sigma_{xe} & \sigma_{xe} & \cdots & \sigma_{xe} & \sigma_{ue} & \sigma^2_e
\end{bmatrix}
\]

Estimation Algorithm:

1. Tobit on bid equation. Recover \((\hat{\alpha}, \hat{x}_{it})\).

2. Estimate on drilling and log-revenue. The likelihood for a tract with the size \(n_t\) and the number of bids \(a_t\) is given by

\[
L_t (\gamma, \beta, \Sigma) = \begin{cases}
\int_{-\infty}^{-Z_t} \cdots \int_{-\infty}^{-Z_t} \int_{-\infty}^{-W_t} f_{x,u}(\hat{x}_1, \ldots, \hat{x}_{a_t}, x_{n_t-a_t}, \ldots, x_{n_t}, u) \, du \, dx_{n_t-a_t} \cdots dx_{n_t} & \text{for } D_t = 0 \\
\int_{-\infty}^{-Z_t} \cdots \int_{-\infty}^{-Z_t} \int_{-\infty}^{\infty} f_{x,u}(\hat{x}_1, \ldots, \hat{x}_{a_t}, x_{n_t-a_t}, \ldots, x_{n_t}, u, \nu_t - z_t \beta) \, du \, dx_{n_t-a_t} \cdots dx_{n_t} & \text{for } D_t = 1, V^*_t > k \\
\int_{-\infty}^{-Z_t} \cdots \int_{-\infty}^{-Z_t} \int_{-\infty}^{\infty} f_{x,u} f^{k-Z_t \beta}(\hat{x}_1, \ldots, \hat{x}_{a_t}, x_{n_t-a_t}, \ldots, x_{n_t}, u, \epsilon) \, du \, dx_{n_t-a_t} \cdots dx_{n_t} & \text{for } D_t = 1, V^*_t \leq k
\end{cases}
\]

where \(f_{x,u}\) is the density function of \((X_{1t}, X_{2t}, \ldots, X_{nt}, U_t)\) and \(f\) is the density function of \((X_{1t}, X_{2t}, \ldots, X_{nt}, U_t, \varepsilon_t)\).