Buying Anonymity: An Investigation of Petroleum and Natural Gas Lease Auctions

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Abstract

This paper examines how concealing the existence of private information affects winning bids in a large, well-functioning auction environment. Standard auction theory suggests firms should wish to advertise the existence of private information in order to reduce the bids of their competitors (Milgrom and Weber, 1982). There are a limited number of empirical studies on how *concealing* the existence of private information affects bids. Instead, most articles test for the *presence* of private information, rather than the effect of revealing or concealing its existence.

An institutional feature of the auctions for petroleum and natural gas leases in Alberta is that firms can hire a broker to bid on their behalf, thereby hiding their identity. Anecdotal evidence suggests firms use brokers to conceal information from their competitors. In order to test the predictions of standard theory, I develop a model of bidding behaviour incorporating the choice to use a broker. The model provides an explicit relationship between broker usage, firms' private information, and equilibrium bids. Using a newly constructed dataset, I estimate this relationship. I find results consistent with standard theory: bids are higher when brokers are used to hide the existence of some private information.

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Bidding is much like a poker game, with oil companies using Scott [Land and Lease] to front their bids, in order to keep rivals from seeing which land they're interested in and escalating prices.

CBC News, March 10, 2010

1 Introduction

How does public and private information affect the bidding decisions of firms involved in auctions for petroleum and natural gas leases? The ability to conceal private information (or it's existence) has important implications for bidding behaviour and the development of leases. The objective of this paper is to study the relationship between the ability to conceal the existence of private information and winning bids in auctions for petroleum and natural gas leases in Alberta. I utilize a unique industry feature, where exploration and development firms hire brokers and use the broker's name for their bid. Anecdotal evidence suggests firms use brokers to conceal information from their competitors, and to behave strategically in acquiring leases. The information concealed is a firm's interest in a lease or area, which is associated with the potential quality of leases. A secondary objective is to identify the determinants of a firm choosing to hire a broker.

As information can directly affect bidding behaviour, this has implications for both the allocation of leases and the revenue raised from the auctions. Over the past ten years, natural resource revenues have accounted for 30-40% of government revenues in Alberta. Natural resource revenues consist mainly of auction proceeds (20%) and taxes on *ex post* production (70%). The remaining ten percent comes from other minerals. The outcomes of the auctions are important for the efficient allocation of resources, to firms that can develop a lease at the least cost, or are able to extract the most resources from the ground.

The provincial government of Alberta auctions mineral rights for petroleum and natural gas leases in first price, sealed bid auctions. The cost of hiring a broker is approximately $100 per lease, which is 0.002% of the average winning bid. The use of brokers sends a noisy signal about which firms are interested in a given area, the value of a lease (which is not necessarily reflected in the winning bid), as well as the activity of firms in Alberta. As the leases are sold in a first price auction, equilibrium strategy even in the presence of symmetric information is to "shade" the bid below the true valuation.

The activity of firms in Alberta is uncertain, as it is not clear how often firms are bidding, and whether or not they choose to use a broker. Firms can choose to bid themselves, and be revealed as the winner, or to hire a broker and use that name instead of their own. In the absence of brokers, a firm would reveal their interest in a given area through the acquisition of leases. By revealing interest and/or private information in a given lease, firms also reveal information regarding the value of a lease and the surrounding leases. This has the potential to increase bids in subsequent periods, and increase the probability the firm *revealing* the private information loses in subsequent auctions. The implication is that brokers are used to reduce competition over leases, and hence bids. This paper examines the use of brokers in the auctions, and the relationship between the use of brokers and winning bids.

There is a large theoretical literature evaluating the effect of private information on equilibrium bids in sealed bid auctions. Engelbrecht-Wiggans et al. (1983) model the sale of an item where one bidder has private information and the other bidders only have access to public information. They find the expected profit of the informed bidder is positive, while the uninformed bidders have zero expected profits. Milgrom and Weber (1982) examine bidders' incentives to gather information in auctions, when there is one bidder with private information and another bidder with public information. The informed bidder's profits rise when it gathers extra information, and the increase is greater when information is collected overtly compared to covert collection. The uninformed bidder prefers to gather information covertly instead of overtly. In both articles, the uninformed bidder will only win when the informed bidder has a low estimate of the object's value, lowering the equilibrium bids of both the uninformed and informed bidders. In the Alberta auctions, firms appear to gather information covertly. Moreover, they use brokers to conceal the existence of private information. This is consistent with the predictions for the behaviour of an uninformed bidder, but not for the behaviour of a better informed bidder.[1]

Auctions for petroleum and natural gas leases have been studied frequently over the past few

[1] A caveat to these results is that the theoretical models are static one-shot auctions, and the introduction of dynamics could alter the incentives of both informed and uniformed bidders. However, this type of expansion is beyond the scope of this paper.

decades, most often analyzing leases in the US Outer Continental Shelf (OCS). Few articles have studied auctions in Alberta; Watkins (1975) and Watkins and Kirkby (1981) have studied the efficiency of rent collection in Alberta in the 1960s. In studying US offshore auctions, Mead et al. (1984), Hendricks and Porter (1988), Hendricks et al. (1989) and Hendricks et al. (1994) have examined whether firms owning adjacent leases (neighbour firms) have an informational advantage. Hendricks, Porter and coauthors find a firm owning an adjacent lease has better information regarding the value of a lease (Hendricks and Porter, 1988; Hendricks et al., 1987), earns higher rents (Hendricks and Porter, 1993; Hendricks et al., 1989, 1993) and is more likely to submit lower bids (Hendricks et al., 1994). These articles test for the existence of private information, and find results consistent with Milgrom and Weber (1982).

The relationships between information and winning bids is not so clear in Alberta. The unconditional average of price per hectare is $252, and conditioning on a broker winning the auction yields an average price per hectare of $375. This suggests firms with higher signals and/or valuations are more likely to bid higher even when using a broker. Indeed, even the use of brokers is inconsistent with standard auction theory, as firms should wish to advertise the existence of private information in order to reduce the bids of their competitors.[2] In the context of a one-shot game, concealing information or the presence of private information has no use. However, the standard theory fails to take into account the possibility of dynamic spillovers. In repeating auctions where the value of leases are correlated through locational proximity, winning bids and the identity of the winning bidder reveals information to all potential bidders. When this is the case, failing to conceal private information could have a detrimental effect on the probability of the winning firm acquiring nearby leases in subsequent auctions. Consequently, firms should wish to engage in activities that hide their interest in a lease, such as the use of brokers.

Gupta (2009) develops a dynamic auction model where a seller sells multiple goods via a series of first price auctions. Bidders are *ex ante* symmetric, but the first period winner has an informational advantage in the second period auction. The endogenous asymmetry leads to excessive entry and overbidding in the first period relative to a one-shot auction. He applies the model to US

[2] See Milgrom and Weber (1982).

Outer Continental Shelf oil tract auctions. Gupta finds the government only recovers 23% of the willingness to pay of previous winners in the second period. The value of information to bidders is at most 12% of the first period information rent. However, Gupta does not address the issue of firms actively hiding information.

I develop a static, two-stage model that incorporates the choice to hire a broker in the bidding strategies of firms. This approach adds to the existing theoretic understanding of strategic interaction in auctions. To my knowledge, no other research has modeled the use of brokers in auctions. Bids and broker usage depends on private signals received by each firm. Equilibrium bids are derived under the assumption of symmetric conditionally independent private values. Equilibrium bids are used to derive an estimating equation which is additively separable in the private signals received by firms.[3] The additive separability allows identification of the specific effects of private information and the choice to use a broker on equilibrium bids.

The contribution of this paper is to analyse a unique institutional feature, the use of brokers, with a previously unused dataset linking auction outcomes to drilling activity. The combination of lease and well data allows identification of the firm hiring a broker, conditional on a well being drilled. A limitation of the data is that private information held by firms regarding the value of a lease and overall interest in an area is unobserved. Under the assumptions of the model, the choice to use a broker is positively correlated with the unobserved private information, which also affects equilibrium bids. This omitted variable problem creates a positive bias on the coefficient associated with a broker winning. I correct for this issue by creating proxies for the private signals using constructed measures of information. Furthermore, as only the identity of the winning bidder is revealed, the number of potential bidders and the number of actual bidders is unknown. Omitted variable bias will result if the number of bidders is excluded from the equation of interest. Proxies for the number of bidders are constructed using a weighted average of the number of leases sold at each auction date. The model proposed has the number of bidders enter additively separably in the winning bid equation.

Several proxies of private information were examined in an attempt to reduce omitted variable

[3] The assumptions on the structure of the model are driven by data limitations, and ensure identification of the estimating equation.

bias. These include previous behaviour of the winner in acquiring adjacent leases, previous behaviour of all firms acquiring adjacent leases and variables describing adjacent wells, in total and those operated by the winner. Surprisingly, previous behaviour explains very little of the variance in bids per hectare, and the same problem arose with adjacent well characteristics. The variable with the most explanatory power is the average price per hectare for a lease's geographic area in the year the lease was sold. This indicates winning bids provide the best measure of private information, and that previous behaviour regarding the choice to use a broker does not affect the contemporaneous decision on the amount to bid. Conditioning on the average price per hectare reduces the broker coefficient by $28 per hectare relative to the basic OLS results. For a lease of average size, this amounts to a $7,100 reduction in the equilibrium bid.

Examining the determinants of broker usage revealed that previous behaviour by winners and all firms acquiring adjacent leases are reasonable predictors of whether a broker will be used on a given lease. The marginal effect of the winner previously using a broker to acquire an adjacent lease is a 15% increase in the probability a broker will be used. The marginal effect of the winner bidding under their own name previously is a 5% decrease in the probability a broker will be used. Similarly, the marginal effect of an adjacent lease won using a broker is positive (10%) and the marginal effect of a firm bidding under their own name is negative (2%). Not surprisingly, the previous behaviour of the winner has a larger effect than the previous behaviour of all other firms.

The remainder of the paper is organized as follows. Section 2 describes the auction environment in Alberta. A brief model of bidder behaviour and the empirical specification is presented in Section 3. Section 4 describes the data and its limitations. Section 5 describes the construction of the measures of private information. Econometric analysis of bidder behaviour and the use of brokers is presented in Section 6. Section 7 concludes.

2 Auction Environment

In Alberta, 81% of the subsurface mineral rights are owned by the province. The remaining 19% is owned as freehold by individuals, companies or held by the federal government. The government of Alberta holds an average of 24 auctions per year to offer firms petroleum and natural gas leases and licenses. Approximately 9000 leases and licenses are issued each year.[4]

The maximum size of a given parcel is 15, 32 or 36 square miles, depending on the area of Alberta. The minimum size is a spacing unit.[5] In the sample of auctions from 1996 to 1999, the average parcel size was 234 hectares, or slightly less than a square mile. The relatively small parcels of land implies there is potential for information externalities and competition over a given lease. The smaller the average lease size, the more likely it is that multiple leases cover an oil pool, and that multiple firms are active in the same pool.

Firms bid on petroleum and natural gas leases and licenses offered by the Crown in a first price, sealed bid auction. The minimum bid on each parcel is currently set at $2.50 per hectare. Following the auction, a firm that holds a lease or license must pay annual rent of $3.50 per hectare as well as royalties on production. Once a firm has acquired a lease, it has five years to license and drill a well. It must be the true owner of the lease that licenses and drills the well on the lease. Title to the lease must be transferred before a well can be licensed and drilled.

If the lease is shown to have fluid in paying quantities, it is continued indefinitely.[6] The tenure ends when the lease holder can no longer show the lease is capable of producing in paying quantities, or through royalty default. If, at the end of the original five year term the lease has not been proven productive, it reverts to the province.

2.1 Selection of Leases

The entire selection and auction process occurs through the province's Electronic Transfer System (ETS). Firms can search for mineral rights at any time, and can request leases they are interested in be posted for an auction, up to nine weeks before the auction date. The identity of firms requesting leases is private information known only by the government and requesting firms. Only requested leases are posted for sale in a given auction. The Department of Energy limits the number of leases requested by a given firm to 20% of the total leases in a sale (Alberta Department of Energy, 2011).

[4]Licenses differ from leases in time horizon, and minimum and maximum sizes but in general, the process is the same.

[5]A section is a square mile. A spacing unit is one quarter section for an oil well and one section for a gas well.

[6]A lease is proven productive by drilling, producing, mapping, being part of a unit agreement or by paying offset compensation.

A sale is closed to requests a week before the available parcels are revealed. The parcels available on a given auction date are posted eight weeks before the auction date. At any point in time, firms observe leases available at three or four subsequent auction dates. Prior to a sale, firms have information on the surface location and size of each parcel, any surface access restrictions, the type of mineral rights included in the lease[7], and the formation[8] to which the mineral rights pertain.

Results are posted the day of the auction. The total bid includes the bonus offer, the annual rent and a processing fee. A firm which requests a lease and fails to bid is fined and does not win the lease, unless another firm bids. The fine is equivalent to the minimum revenue the government would have received had a bid been made. Failing to request parcels does not exclude a firm from participating in an auction. Sale results include the winning bid, and the identity of the winning bidder. No other information is revealed. The parcels available for a sale and the auction results are posted on the Alberta Department of Energy website.

2.2 Use of Brokers

A unique feature of the auctions for petroleum and natural gas leases in Western Canada is the ability of firms to hire brokers, and use the broker's name instead of their own for the bid. Brokers provide many services involving the acquisition of surface access and mineral rights for freehold[9] and Crown lands. They are also a way for exploration and production firms to outsource the administration of their land and mineral rights holdings. Brokers can also represent smaller firms that do not have access to the ETS database, and hence are unable to submit their own bid; however, it is not necessarily the case that the firm uses the broker's name. The service of interest for our purposes is the use of the name in the auctions.

The exploration and development firms choose which parcels to bid on, and the amount of the bid. Firms choose whether to bid under their own name, or hire the broker. In Alberta, all bids are submitted electronically, and payment is made through a pre-authorized debit system.[10] Firms

[7] Petroleum, natural gas or both.

[8] The formation and producing zones indicate depth and the relative layer of the Western Canadian Sedimentary Basin.

[9] Privately owned lands and mineral rights.

[10] In British Columbia and Saskatchewan, paper bids are accepted and so another service provided by a broker is carrying the bid for firms, though this service is separate from the use of the name.

must have access to ETS to bid (Alberta Department of Energy, 2011). A broker "name" must be hired separately for each lease. The cost per lease is approximately $100, and the fee includes the transfer of title from the broker to the hiring firm.

A concern may be that brokers are also bidding under their own authority, in competition with the exploration and development firms. If this were the case, then bids made by brokers may not accurately measure the willingness to pay of exploration and development firms, as it would not be their bidding decision. It would also be impossible to identify who is making the bidding decision, brokers or the firm that hires the broker. Both brokers and the exploration and development firms are required to use licensed land agents to negotiate for and acquire surface and subsurface rights (Alberta Department of Employment and Immigration, 2009). The licensing of land agents is regulated by the Land Agents Licensing Act and the Land Agents Licensing Regulation in Alberta. A land agent is defined as "a person who negotiates for or acquires an interest in land (i) on behalf of the person's employer, (ii) as an agent on behalf of another person, or (iii) on the person's own behalf" (Alberta, 2010).

Standards of conduct enforced by the government of Alberta and Registrar of Land Agents include a requirement to act in the client's best interest, keep confidential information acquired in the course of a professional relationship, and not enter into a situation with a conflict of interest (Alberta Department of Employment and Immigration, 2007). The professional conduct of land agents in Alberta is also regulated by the Canadian Association of Petroleum Landmen (CAPL). The ethical standards are in the same vein as those enforced by the government of Alberta. Members of CAPL are prohibited from undertaking activities creating a conflict of interest with their employer or client, or from disclosing confidential information (Canadian Association of Petroleum Landmen, 2009).

The regulations on land agents – and their employers, the brokers – prevents the brokers from using information gained in the provision of services to acquire leases on their own. Anyone found in violation of the ethical standards risks losing their license. These standards ensure brokers are not competing with the firms hiring them, and means the only strategic effect of brokers is through the use of the name.

3 A Model of Bidder Behaviour

3.1 Assumptions

We start with the simplest assumptions possible. Though leases for mineral rights are more commonly studied in the context of a common value auction, Athey and Haile (2002) show a common values model can only be identified when the full joint distribution of signals and values is observed. However, symmetric independent private value (IPV) models are nonparametrically identified even when only the winning bid is observed. The model can be tested against an alternative model only if more than one bid is observed, or if there is exogenous variation in the number of bidders. Identification in an asymmetric private value framework requires knowledge of the identity of the winning bidder. Thus, we restrict ourselves to a symmetric independent private values model due to the limitations enforced by the data.[11] The goal of the empirical model developed here is to derive an equation allowing for identification the parameters of the distribution of lease valuations. In particular, we are interested in the coefficient on broker, which is assumed to affect the mean of the distribution of valuations.

Within a symmetric IPV framework, assume a single lease for sale in a first price sealed bid auction. There are N potential buyers of the lease; each has common knowledge of the value of a lease, denoted by μ. Each potential bidder i receives a private signal $X_i + Y_i$ of the value of the lease; conditional on μ, each signal is independently and identically distributed over the interval $[\underline{\omega}, \bar{\omega}]$ according to the increasing distribution function F.[12] We assume F admits a continuous density function $f \equiv F'$ and has full support. The expected value of the signal, $\mathbb{E}[X_i + Y_i]$, is assumed to be bounded at a value less than infinity. Each bidder i knows the realizations x_i of X_i and y_i of Y_i, and only that the other bidders' values are iid according to F. Let equilibrium bids be denoted by $\beta(\cdot)$. We also assume an equilibrium bid at a valuation of zero is $\beta(0) = 0$, and bidders will never bid higher than the maximum valuation, $\bar{\omega}$.

One can think of the signals as arriving in two stages. The component Y_i is a firm's interest in

[11] A common values model would be preferred as it intuitively fits with auctions for mineral rights. However, developing a model that cannot be identified is rather pointless.

[12] Independence of signals is consistent with a common value setting, though a more restrictive assumption than IPV.

a given area, or a random profitability shock that determines whether or not the firm will invest in hiring a broker. The signal Y_i is observed in stage one, and reflects the firm's dynamic interest. The greater a firm's interest in a given area, the greater the value of each individual lease to the firm. Firms obtain a benefit of $\mathfrak{B}(y_i)$ when they hire a broker, which charges a fee c. We assume a broker will only be used when the benefit is greater than the fee. Let $\mathbf{1}(\mathfrak{B}(y_i) > c)$ be the indicator function for when a broker is used by firm i, i.e., when the benefit is greater than the fee. Let $B(y_i) = [\mathfrak{B}(y_i) - c]$ define the net benefit of employing in a broker. The signal X_i is received in stage two, and is the value of the lease to the firm from engaging in private information gathering, such as seismic analysis or drilling a well nearby. We assume an additively separable form in valuations. The valuation of a lease for broker i is given by

$$V_i = \mu + x_i + y_i + B(y_i) \tag{1}$$

where μ is the average lease value and common knowledge to all bidders, and $B(y_i)$ is a function that captures investment in a broker. Conditional on μ, the valuation of each bidder i is independent and private. Each firm submits a bid b_i, and payoffs (π) are of the form

$$\Pi_i = \begin{cases} \mu + x_i + y_i + B(y_i) - b_i & \text{if } b_i > \max b_{-i} \\ 0 & \text{if } b_i < \max b_{-i} \end{cases} \tag{2}$$

3.2 Equilibrium Strategies

Bidder i wins whenever they submit the highest bid, whenever $\max_{j\neq i} \beta(X_j + Y_j + B(Y_j)) < b_i$, conditional on μ. Let us fix a bidder, say bidder 1, and examine their equilibrium strategy. Let the random variable $Z_1 \equiv Z_1^{(N-1)}$ denote the highest value among the remaining $N-1$ bidders. Z_1 is the highest order statistic of $X_2 + Y_2 + B(Y_2), X_3 + Y_3 + B(Y_3), \ldots, X_N + Y_N + B(Y_N)$. Let G denote the distribution function of Z_1, so that for all z, $G(z) = F(z)^{N-1}$.

As the equilibrium bid function $\beta(\cdot)$ is increasing,

$$\max_{i\neq 1} \beta(X_i + Y_i + B(Y_i)) = \beta(\max_{i\neq 1} X_i + Y_i + B(Y_i)) = \beta(Z_1)$$

Bidder 1 will win whenever $\beta(Z_1) < b_1$, or equivalently, whenever $Z_1 < \beta^{-1}(b_1)$. The expected payoff to bidder 1 is $G(\beta^{-1}(b_1))(\mu + x_1 + y_1 + B(y_1) - b_1)$.

Generalizing from bidder 1, and maximizing the expected payoff with respect to the bid b yields the first order condition,

$$-G(\beta^{-1}(b)) + [\mu + x + y + B(y) - b]\frac{g(\beta^{-1}(b))}{\beta'(\beta^{-1}(b))} = 0 \tag{3}$$

In the above, $g \equiv G'$, is the density of Z_1, conditional on μ. In a symmetric equilibrium, $b = \beta(\mu + x + y + B(y))$. Substituting this into the first order condition yields

$$-G(\mu + x + y + B(y)) + [\mu + x + y + B(y) - \beta(\mu + x + y + B(y))]\frac{g(\mu + x + y + B(y))}{\beta'(\mu + x + y + B(y))} = 0 \tag{4}$$

The above can be rewritten as a differential equation

$$\frac{\mathrm{d}}{\mathrm{d}u}[G(u)\beta(u)] = ug(u)$$

where $u = \mu + x + y + B(y)$. Given the assumption $\beta(0) = 0$, this provides a boundary for the above differential equation, allowing us to solve for the equilibrium bid.

$$\begin{aligned}\beta(u) &= \frac{1}{G(u)}\int_0^u zg(z)\mathrm{d}z \\ &= \mathrm{E}[Z_1 | Z_1 < u]\end{aligned}$$

The equilibrium bid given above is the conditional expectation on the highest order statistic (Z_1) of the other $N-1$ bidders, given that Z_1 is less than the signal received by bidder 1, $\mu+x+y+B(y)$. If the other $N-1$ bidders follow $\beta(\cdot)$, then it is optimal for any bidder with value u to bid $\beta(u)$.[13] The equilibrium bid function given above can be rewritten, using that $\int_0^v tg(t)\mathrm{d}t = vG(v) - \int_0^v tG(t)\mathrm{d}t$:

$$\beta^*(\mu + x + y + B(y)) = \mu + x + y + B(y) - \int_0^{\mu+x+y+B(y)} \frac{G(u)}{G(\mu + x + y + B(y))}\mathrm{d}u \tag{5}$$

[13]Proof of the symmetric equilibrium is trivial, and available upon request.

Equation (5) shows that the equilibrium bid is less than the lease value, $\mu + x + y + B(y)$. The second term on the right hand side of (5) is the degree of shading associated with the first price sealed bid auction, which depends on the number of bidders. Recall that $G(z) = F(z)^{N-1}$, which implies

$$\frac{G(u)}{G(\mu + x + y + B(y))} = \left[\frac{G(u)}{G(\mu + x + y + B(y))}\right]^{N-1}$$

The bid shading component in equation (5) depends on the distribution of valuations. The degree of shading depends on the number of competing bidders, and as N increases, the equilibrium bid $\beta^*(\mu + x + y + B(y))$ approaches the true valuation $\mu + x + y + B(y)$.

3.3 Estimating Equation

The assumptions of the model and the structure chosen allow an estimating equation that is additively separable in the parameters of interest. Following Paarsch and Hong (2006), in the case when only winning bids are observed, the valuation for the highest bidder in an auction t can be recovered from the relation

$$\hat{V}_{(1:N)t} = W_t + \frac{N}{N-1}\frac{\hat{F}_W(W_t)}{\hat{f}_W(W_t)}$$

where W_t is the winning bid in auction t, F_W is the cumulative distribution function of the winning bids, and f_W its density. Given the above derivation of the equilibrium bid, and the definition of the value of a given lease for the (winning) bidder given in (1), we have an estimating equation of the form

$$W_{it} = \mu_t + x_{it} + y_{it} + B(y_{it}) - h(N_{it}) \tag{6}$$

The parameter μ is average lease value, and can be defined by lease-specific characteristics. The signal realizations x_{it} and y_{it} are firm-specific and are absorbed in the error term. The function $B(y_{it})$ determines investment in the use of a broker. The function $h(N_{it}) = \frac{N}{N-1}\frac{\hat{F}_W(W_t)}{\hat{f}_W(W_t)}$ describes the effect of the number of bidders on the winning bid. We begin with a simple linear specification, and rewrite (6) in terms of observed variables:

$$W_{it} = Z_{it}\beta + X_{it}\theta + Y_{it}\phi + \gamma \cdot Broker_{it} + \eta \cdot N_{it} + \xi_{it} \tag{7}$$

In (7), Z_{it} is a vector of auction and lease specific characteristics for lease i in auction date t, and ξ_{it} is the error term. *Broker* is a dummy variable that equals unity if a broker is used, and zero otherwise. Estimation and identification of (7) requires the inclusion of proxies for the signals x_i and y_i. Variables we consider are those that approximate the *ex ante* information held by firms, such as adjacent wells. Potential proxies for y_i are previous behaviour of the winner and other firms active in the area surrounding a lease.

In (7), we allow the number of bidders to enter linearly, and abstract from any effects on the distribution of bids. The benefit of (7) is that it is much less computationally challenging as it includes the number of bidders without requiring the calculation of the distribution function of the winning bids.

3.4 Econometric Issues

There are five econometric issues with the estimation of (7). These are

(i) Only the winning bid (W_{it}) is observed.

(ii) The number of bidders participating in each auction is unknown.

(iii) Private signals ($X_{it} + Y_{it}$) are known only to the firms and are unobserved by the econometrician.

(iv) The choice of hiring a broker and a broker winning is correlated with the unobserved private signal Y_{it}.

(v) Only leases requested by firms are offered in the auctions, resulting in sample selection.

Only the Winning Bid is Observed

As only the winning bid is revealed, the distribution of valuations of other bidders is unobserved by the econometrician. Paarsch and Hong (2006) show the valuation for the winning bidder can be uncovered from the distribution of winning bids, conditional on knowing the number of bidders. However, not only is the number of potential bidders unknown, the number of participants in a given lease auction are unknown as well. The solution to this problem is to construct a proxy for the number of bidders, discussed in more detail below. However, any proxy for N will be measured with error relative to the true number of bidders, and will bias the results. Therefore, we face a trade-off between omitted variable bias and bias from error in the proxy for N. Unfortunately, accounting for this limitation is beyond the scope of this paper as it stands.

Unknown Number of Bidders

The omitted variable problem of unknown N can be partially accounted for by construction of proxies for the number of bidders. Similar to Choo and Eid (2008), we construct a proxy for N using a weighted sum of the number of transactions at each auction date and a weighted proportion of sales transactions for each auction date. The estimate for the number of bidders for all auctions at date t in year j is given by

$$N_{tj} = \frac{1}{14}\left(\frac{n_{tj}}{\sum_{t=1}^{T} n_{tj}} m_{tj} + leases_{tj}\right) \tag{8}$$

In the above, $leases_{tj}$ is the number of leases sold at date t in year j. Both n_{tj} and m_{tj} are different measures of transactions to provide variation in the construction of N. One permutation has n as the number of leases sold at date t in year j, and m as the number of licenses sold. Another permutation creates weights by geographic area, so that n is the number of leases sold in a given region on each auction date, and m is the number of leases sold on that date. A third measure uses n as the number of leases sold, while m is the number of leases sold by area. The fourth estimate is a slight modification of the first, with m as the number of firms operating adjacent wells. As auctions occur approximately every two weeks, a relative weight of $\frac{1}{14}$, the frequency of auctions, is used. Given no prior on the distribution of auctions over time, this seems reasonable. Figure 1 shows the distribution of lease sales by month for the four years of the sample. The figure shows no clear pattern in the distribution of sales, confirming a relative weight based on sales fluctuations is appropriate.

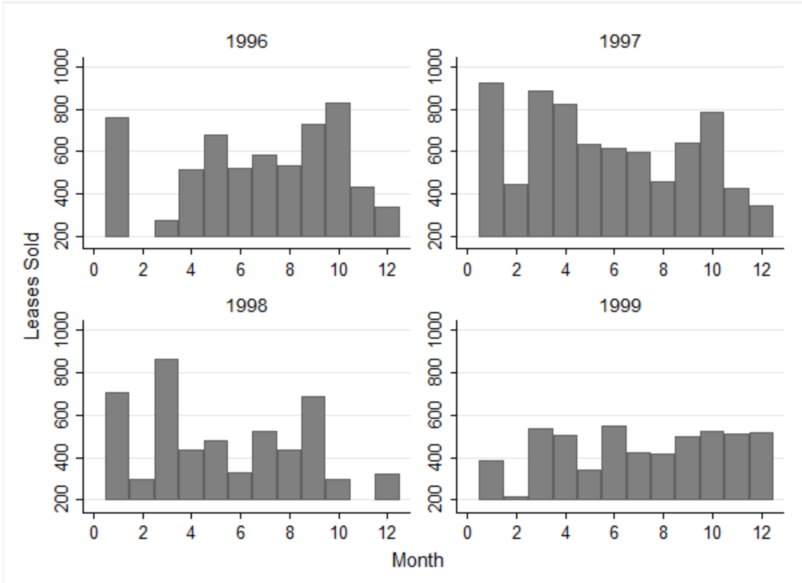

Figure 1: Distribution of Leases Sold by Month and Year

Unobserved Private Signals

The third and fourth issues are closely related. Under the assumption that the choice to use a broker is positively correlated with the value of a lease, omission of the private signals will bias the coefficient on broker upwards. One method of correcting for the omitted variable bias is the use of instrumental variables methods. A valid instrument in this case is one that is correlated with the decision to hire a broker but does not affect the bid itself. However, any variable that is correlated with the signal y_i would affect the bid, and hence is not a valid instrument. A supply side variable, such as one that affects the fee paid to a broker, would be a valid instrument. Unfortunately, such information is not available.

An alternative way to correct for the omitted variable bias is by including variables that are correlated with the private information held by firms. Constructed measures of firm behaviour, and potentially private information that influences the decision to hire a broker can be used as proxies for the unobserved signals. Proxies considered are adjacent lease acquired by the winner, total adjacent leases sold, the number of adjacent wells, the number of adjacent wells operated by the winner, the total number of firms operating adjacent wells, firm-specific characteristics, and average price in the area surrounding the lease from previous auctions.

Sample Selection

The fifth issue of sample selection is difficult to address. Though the Heckman (1979) correction method would account for the sample selection, it requires knowledge of firm characteristics that drive selection of each lease. Moreover, the identity of the firm requesting each lease is unknown, making it difficult to uncover these firm characteristics. The inability to control for sample selection means the results are not generalizable out of the sample.

A final issue related to the limitations of the data is when a broker wins a lease, the "true" winner is only observed when a well is drilled. This necessarily restricts the analysis of firm behaviour and the determinants of lease payments to auctions where the winner can be identified. This issue is further expanded upon in the discussion of the results in Section 6.

4 Data Description

The dataset used in this analysis is new to the literature and was constructed by acquiring lease characteristics and auction results from the government of Alberta's website. A weakness of the data is only the identity of the winning bidder is revealed, necessitating a secondary source to determine the hiring firm in the case of a broker winning. A dataset of well information acquired from a private exploration and development firm allows identification of the true winner. As with the bidders, a unique code was assigned to each firm observed to be operating a well. In order to do this accurately, the chain of title for each firm was tracked so there was accurate contemporaneous ownership in each year an auction occurred.[14] Wells drilled after the auction date were matched to each lease by specific geographic location. These matches provide a basis for computing the *ex post* value of a lease. Wells drilled prior to the auction date were matched to lands adjacent to each lease. These wells provide an indication of *ex ante* information held by firms. Finally, leases sold in each month were matched to subsequent leases sold to uncover the dynamics of firm behaviour.

[14] Chain of title includes mergers, name changes, and amalgamations, etc.

4.1 Lease Data

Data for leases sold in auctions from January 1996 to December 1999 have been collected from the Government of Alberta's auction results website. Information provided to firms by the government includes the surface location of the lease, the size of the lease, the pertinent mineral rights, and any surface access restrictions. A lease can include multiple tracts, which can differ by physical location or by mineral rights. Mineral rights can be natural gas, petroleum or both. The description of mineral rights also includes the depth of any relevant formations, or restrictions on drilling depth and formations attached to the lease. An unrestricted lease would be petroleum and natural gas from the surface to basement (bedrock). A restricted lease could be restricted to a certain type of fluid, include only fluid above or below a certain formation/depth, or exclude a certain formation or interval.

The total number of leases in the data set is 25,133. There were a total of 97 auction dates, with an average of 259 leases sold at each date. Of these, 32 were withdrawn after posting, 290 received no offers, and 42 had the highest bid rejected. An additional nine had unreported winners. The average size of a lease is 234 hectares, with a minimum of 0.02 hectares and a maximum of 6400 hectares.

Once an auction date has passed, the government of Alberta reveals the name of the winning bidder, the total bid paid, and the bid per hectare. No other information is revealed. If a broker wins, the title must be transferred to the producing firm prior to licensing and drilling a well, pursuant to government regulations. This regulation is how the true winner of a lease is identified when a broker wins. Wells drilled on the lease after the auction date were matched to each lease. The operator of the first drilled well is assumed to be the true winner.

Lease Characteristics

Removing leases that were withdrawn, had no offers or where all offers were rejected leaves 24,761 observations. Of these, 49.6% of the leases were allowed to lapse. No well was drilled on these leases between the auction date and July 2007. The unconditional average price per hectare is \$251.81, is \$301.97 for non lapsed leases, and \$200.85 for lapsed leases. When a broker wins, the average price per hectare is \$374.96, and when a broker is not used the average price per hectare is \$197.38. The simple conditional averages suggest there is a difference in willingness to pay associated with hiring a broker. The average lease size is 234.73 hectares. Summary statistics are presented in Table 1.

Table 1: Lease Summary Statistics

	mean	standard deviation	min	max
Lease Size (hectares)	234.731	194.107	0.02	6400
Auction Bid (dollars)	52,135.43	93,010.20	2.2	3,248,654.00
Bid per Hectare	251.81	704.03	2.5	75,280.50
Broker Wins (0,1)	0.294	0.456	0	1
Lease Lapses (0,1)	0.496	0.500	0	1
Number of Adjacent Wells (pre-auction)	20.032	24.983	0	261
Number of Wells Drilled on Lease (post-auction)	1.523	3.100	0	143
Number of Firms Operating Adjacent Wells	6.882	4.829	0	46
Number of Adjacent Leases Sold	2.861	2.874	0	44
Number of Adjacent Lapsed Leases	1.457	1.991	0	18
Revenues (millions)	1.603	6.508	0.00	283.00
Drilling Costs (millions)	0.776	1.603	0.00	43.80
Operating Costs (millions)	0.178	0.483	0.00	15.80

N: 24,761

4.2 Well Data

The well data set includes every well drilled in Alberta from the start of drilling activity (1892) to July 2007, a total of 466,640 wells. Pertinent information includes license date, initial drilling date, on production date, off production date, cumulative production, total and daily average production in the first 12 months; total and daily average production in the last (final) 12 months, and total production hours. Production includes natural gas, oil, condensate and water produced from each well. This information allows a rough calculation of the value of each well.

Additional information in the dataset includes the original well operator; the current well operator; current production status; well status history; producing pool name; producing field name;

producing or injection formation; well depth; on injection date; off injection date; and cumulative volume injected.

The original well operator is used to identify the owner of a given well. The true owner of the well must license the well, and in most cases the true owner is also the operator.[15] The chain of title was traced for each well operator, ensuring consistent concurrent identification of well owners for each year of the data.

Revenues

Revenues by well are approximated using cumulative production over the well lifetime and the average yearly price for each fluid over the well's lifetime. Each well has cumulative lifetime production in oil, natural gas, condensate and water. For the well lifetime, an average price is calculated based on the number of years the well is producing. An average price is calculated for oil and natural gas. As the Alberta government includes condensate with oil in royalty calculations, the price of oil was used for calculating the value of condensate. Revenues for each fluid are the cumulative production multiplied by the average price. Total revenues are the sum of revenues from each fluid.

Costs

Costs are based on the cost of drilling the well, as well as the cost of operating the well. Cost data is acquired from the Canadian Association of Petroleum Producers (CAPP) Statistical Handbook. From 1947 to 2008, CAPP reports total expenditure on drilling; and from 1955 to 2009 reports the number of wells drilled by province as well as the total metres drilled. With this information, the average cost per metre in a given year was calculated. Based on the year the well was drilled and the total depth of the well, the cost of drilling each well was calculated.

From the period 1956 to 2009, CAPP reports the number of operational wells at year end, and expenditures on well operation by year from 1947 to 2008. With this information, the average cost of operating a well in Alberta is calculated. Total production hours are calculated based on the

[15] This was corroborated using a separate data set of wells in Alberta available from the University's Library. The licensee and operator were the same firm 95% of the time.

month and year a well goes on production, and the month and year the well goes off production. The total cost of operating each well in the data set is created by summing the average operating costs for the number of years a well is in operation, prorated by months operation for partial years.

4.3 Data Limitations

An unavoidable limitation of the data is that because the government only reveals the winning bidder, the number of bidders and number of potential bidders is unknown. Furthermore, in the case where a broker wins, the wells drilled on the lease subsequent to the auction is the only method of uncovering the firm that hired the broker, and the true winner of the lease. Another issue is that use of a broker is only observed when a broker wins a lease. It is possible in the case of a non broker win that at least one firm hired a broker and failed to win. When a broker wins, whether other firms also used a broker, or did not use a broker is unobserved. As well, the decision by a firm to use a broker is based on private information held by the firm that is unobserved by the firm's competitors as well as the competition.

The set of potential bidders can be proxied by the number of firms observed to be active in bidding over the sample period. An additional measure is the number of firms operating adjacent wells, as these can be expected to be the firms with the most interest in a given area. Without knowledge of the number of bidders or the number of potential bidders, analysis of bidder strategy in the traditional sense is impossible. The private information influencing a firm's decision to bid and hire a broker can be proxied by measures of private information, discussed in more detail in Section 5. The general idea is that adjacent wells and leases owned by the winning firm prior to the auction date provides additional information about the expected value of the lease, and affects the decision to hire a broker as well as the bid.

Another limitation of the data is missing information prior to 1996. Though leases were auctioned prior to the start of the data set, the results were not reported online by the Alberta government. Thus for 1996 no information about adjacent leases is available. The best that can be done is determine activity through matching wells on lands adjacent to each lease. A third issue is that the dynamics of the data set are unbalanced. Moving forward in time yields more information about adjacent wells and leases sold in previous auctions. However, the earlier the lease is sold, the more post-auction data there is in terms of the productivity of wells drilled on each lease.

5 Measures of Information

The *ex post* value of a lease is determined by drilling a well, whether the well is dry or produces, and how much it is able to produce. Presumably, a firm may observe wells drilled by it's competitors, but it's own wells provide more information. In order to proxy the information available to firms prior to each auction, wells are matched to each lease. For a given lease, the number and type of adjacent wells provides information about the potential profitability of each lease. Wells are matched from each square mile of lease surrounding a lease, creating a nine mile square for the average lease size.

5.1 *Ex Ante* Information

Wells where drilling is completed before the auction date are matched to each lease. Wells are differentiated by type: dry, abandoned, injection, producing, and suspended. The number of adjacent wells owned by the winner of the lease is matched to each lease that does not lapse. The number of firms operating adjacent wells is matched to each lease, as well as the total number of adjacent wells.

For leases auctioned in 1997, 1998 and 1999, adjacent leases auctioned in previous years are matched to each lease. This set of matches includes whether the lease was won using a broker or won by a firm bidding on its own; whether the winning bidder of the current lease won any adjacent lease, and whether the adjacent leases lapsed. For each year of data, leases auctioned in the same year are matched by month to reflect the sequential nature of the auction process.[16]

The number of adjacent leases sold in a given year and subsequent years indicates the activity and interest surrounding each lease. The number of adjacent leases acquired by the winning firm indicates that firm's interest and activity in the area. As the stated reason for using a broker is to hide interest from a firm's competitors, one would expect using a broker previously to acquire

[16] A lease auctioned in January of 1996 will have fewer adjacent leases matched than one auctioned in July of 1996.

an adjacent lease is positively correlated with the choice to use a broker currently, and acquiring a lease without using a broker is negatively correlated with the decision to use a broker currently. The number of adjacent wells provides an indication of the activity surrounding a lease prior to the auction year. The type of well drilled, dry, producing, etc., indicates the potential profitability of a lease, as it provides a signal about whether a lease contains petroleum.

Winning bids provide an indication of the value attributed to the lease by the winning firm. Winning bids from previous auctions can affect bids submitted today or in future auctions. Computing the average price per hectare in a given geographic location for leases sold previously and over the year a given lease was auctioned in provides a proxy for the value of an area.

5.2 *Ex Post* Information

With the acquisition of a lease, a firm has won the option to drill. What happens on adjacent lands after the auction affects the firm's decision to drill or to let the lease lapse. To uncover this information, wells where drilling begins after the auction date are matched to each lease. Revenues and costs for each well are aggregated to determine the profits associated with each lease. Revenues and costs provide an independent measure of the value of a lease. As well, adjacent leases that lapse are matched to each lease. The choice to let a lease lapse is likely related to *ex post* updating regarding the potential revenue or costs associated with the lease.

6 Data Analysis

Discussion with industry experts has indicated firms are strategic in their bidding decisions. The decision to bid on a specific lease and the decision to use a broker in acquiring the lease are related. We begin with a simple regression of the winning bid on lease characteristics. The dependent variable is the price per hectare paid by the winning bidder. The explanatory variables are lease size, whether a broker wins, whether the lease subsequently lapses, revenue, drilling costs, the number of firms operating adjacent wells, as well as the number of adjacent wells. Other variables of interest are the number of adjacent leases sold in the same year, and the number of adjacent leases sold in a previous year. These variables provide an indication of the overall activity in the area surrounding each lease. The number of firms operating adjacent wells is a simple proxy for the number of bidders. Other lease characteristics included are dummies for location and mineral rights, whether a joint venture won the lease, and the number of firms in the joint venture. Auction specific characteristics controlled for are the month and year, and the number of other leases available at the auction date, as well as the total area of leases available at the auction. Results are reported in Table 2.

Table 2: Regression of Winning Bid on Lease Characteristics

Dependent Variable: Bid per Hectare

	(1)	(2)
Constant	403.396**	417.494**
	(42.122)	(43.157)
Size (Hectares)	-0.257**	-0.245**
	(0.034)	(0.034)
Broker Wins (0,1)	148.012**	147.037**
	(9.630)	(9.520)
Number of firms operating adjacent wells	9.766**	4.900**
	(1.345)	(1.406)
Lease Subsequently Lapses (0,1)	-72.658**	-72.512**
	(9.214)	(9.120)
Revenue (million $)	5.63**	5.64**
	(1.050)	(1.040)
Drilling Costs (million $)	11.60**	11.60**
	(0.376)	(0.374)
Operating Costs (million $)	-2.08	-11.90
	(11.700)	(114.000)
Number of Adjacent Leases Sold in the Same Year		-3.697*
		(1.508)
Number of Adjacent Leases Sold in a Previous Year		6.557*
		(2.781)
Number of Adjacent Wells Drilled (pre-auction)		1.292**
		(0.205)

Notes: $N = 24,761$. Robust standard errors in parentheses. Other controls: auction month and year; lease location by area (plains and northern); dummies for mineral rights; number of leases sold on the auction date; total area of leases sold on the auction date; joint venture wins; number of firms in winning joint venture. Statistical significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

The average bid per hectare is well over the reservation price of $2.50 per hectare, indicating firms place high value on the leases, or there is substantial competition for each lease. The number of firms operating adjacent wells is an initial proxy for both the number of potential bidders and activity in an area; the positive sign indicates as the number of firms increases, competition increases, driving the bids up. The number of adjacent lease sold in the same year has a negative effect on the winning bid, whereas the number sold in a previous year has a positive effect on price. Both are measures of interest in an area, though the negative coefficient on the same year variable is somewhat puzzling. The number of adjacent wells drilled has a positive effect on price, as expected. Drilling a well is correlated with positive expectations of finding oil or natural gas, which would in turn influence willingness to pay.

Table 2 suggests that a firm winning a lease while using a broker has a substantial effect on the winning bid relative to the average. As a rough calculation, ignoring all other marginal effects, a broker winning increases the winning bid by $148 or 27%. However, there is likely endogeneity in a broker being used and winning, and the price per hectare. Presumably, a lease that has a higher value to a firm is associated with a willingness to hide interest from competitors, suggesting a broker is more likely to be used when a firm is willing to bid high, or when the firm has some private information regarding the value of the lease. Unfortunately, the firm that hires a broker can only be determined when a lease does not lapse, and so identifying the determinants of a broker winning necessitates restricting the data to non-lapsed leases. Section 6.1 describes how this restriction is unlikely to bias the results.

6.1 Option Value

On average, profits on a lease are positive, as are profits net of the bid paid for the lease, at roughly $650,000 and $597,000 respectively. The maximum profits obtained on a lease was $277 million, and a minimum profit of negative $38 million. Unconditionally, 17% of leases earn positive profit. Conditional on drilling a well, net profits are on average $1.2 million and 71% of leases have at least one well which produces oil, natural gas or condensate. Conditional on a lease containing at least one producing well, average net profits are $2.1 million. The distribution of the logarithm of net profits is shown in Figure 2, below.

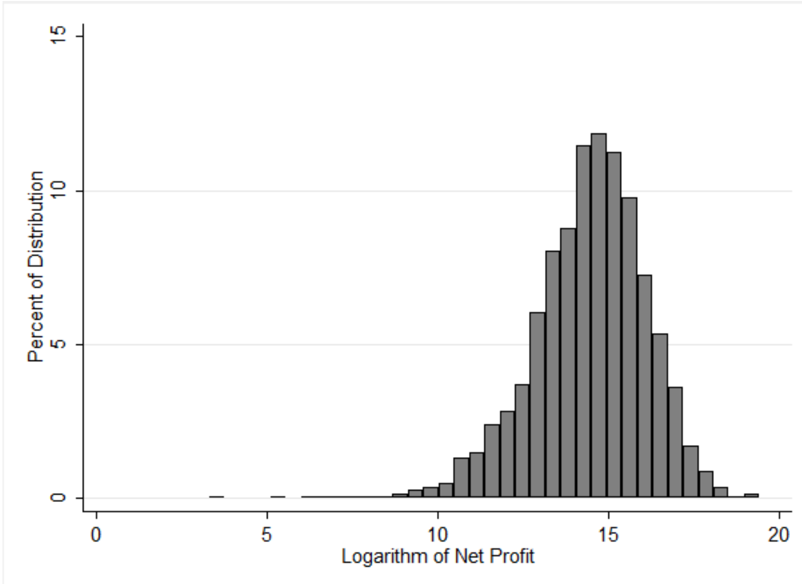

Figure 2: Distribution of Log Net Profits

In contrast, the average amount paid for a lease is $52,135. This is 9% of average net profit for a lease. Average drilling costs, conditional on drilling, are $1.56 million. The amount paid to acquire a lease is 3% of total costs, conditional on drilling occurring. Total costs are defined as the lease payment, drilling cost and operating costs. A scatter plot of the lease payment as a share of total costs is displayed in Figure 3. The distribution of the lease payment as a share of total costs is displayed in Figure 4. The majority of leases have the lease payment as a very low share of costs, between just above zero to 20%. Forty-three percent of leases have the lease payment as less than ten percent of total costs, and 50% have the lease payment as less than 25% of total costs. Conditional on a well being drilled, for 87% of leases the lease payment is less than 10% of the total cost associated with the lease. These statistics indicate that the value of a lease to each firm is the option to drill, or the lease's option value.

We also must consider the determinants of a lease lapsing in our analysis. If the hypothesis that brokers are used to hide information is true, one would expect these leases have higher value and are thus less likely to lapse. In the full dataset, a lease lapses 49% of the time. If a broker wins the lease, the occurrence of lapsing is 47%; if a firm wins under its own name, a lease lapses 51% of the time. However, broker usage and the probability of a lease lapsing are not independent, demonstrated

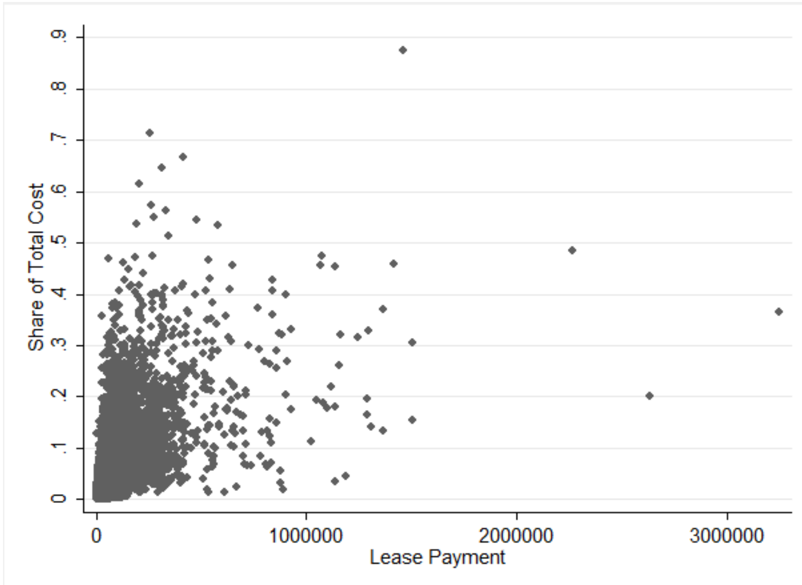

Figure 3: Lease Payment as a Share of Total Costs

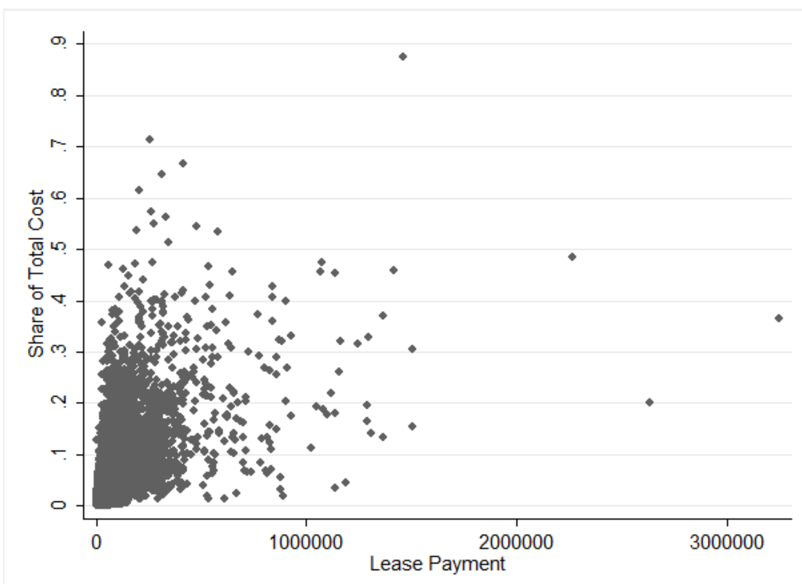

Figure 4: Distribution of Lease Payments as a Share of Total Costs for Non-Lapsed Leases

in Table 3. We are not truly interested in predicting a lease lapsing, but are interested in the correlations between relevant explanatory variables, especially the usage of a broker. To that end, we regress the indicator variable for a lease lapsing on broker winning, and firm characteristics, controlling for lease and auction characteristics. Lease characteristics included are dummies for location and mineral rights, whether a joint venture won the lease, and the number of firms in the joint venture. Auction specific characteristics controlled for are the month and year, and the number of other leases available at the auction date, as well as the total area of leases available at the auction.

From Table 3 we see that a broker winning and a lease lapsing are negatively and significantly correlated. If a lease lapsing was independent of lease value, and hence uncorrelated with private information held by firms, the coefficient on *Broker* would be insignificant. This indicates a lease is less likely to lapse when firms hold private information about the value and use a broker. In general, the other explanatory variables are statistically significant but the coefficients are so small as to render them economically insignificant. A few conclusions can be made, however. A lease is less likely to lapse the higher the average bid per hectare, and the higher the average bid per hectare in its geographic area. A lease lapsing is positively correlated with adjacent leases lapsing, and negatively correlated with the number of adjacent leases sold. This indicates a lease is less likely to lapse if there is a lot of activity and/or interest in the area through the auctions, and is more likely to lapse if there is little subsequent activity. The results reported in specification (3) are most likely misspecified and subject to error, as it is impossible to identify firm characteristics associated when a broker is used and a lease lapses. With that caveat, an interesting result is that the total amount spent by a firm is positively correlated with a lease lapsing. A possible explanation is that firms fail to endogenize exploration and development costs when bidding on leases. As the average drilling cost per well is close to \$0.6 million dollars, this seems likely, given the relatively low cost of acquiring a lease.

Table 3: Regression of Lease Lapsing on Lease and Firm Characteristics

Dependent Variable: Lease Lapses (0,1)

	(1)	(2)	(3)
Constant	0.848***	0.731***	0.611***
	(0.055)	(0.051)	(0.045)
Broker Wins (0,1)	-0.025***	-0.021***	-0.295***
	(0.007)	(0.006)	(0.008)
Bid per Hectare	-2.56e-05*	-2.16e-05	-1.64e-05
	(1.55e-05)	(1.32e-05)	(1.09e-05)
Average price per hectare by geographic	-3.65e-05***	-2.55e-05***	-2.88e-05***
area	(1.04e-05)	(8.81e-06)	(6.95e-06)
Size (Hectares)	1.189e-04***	1.563e-04***	1.16e-04***
	(4.71e-05)	(4.49e-05)	(3.78e-05)
Number of firms operating adjacent wells	-0.004***	-0.005***	-0.002***
	(0.001)	(0.001)	(0.001)
Number of adjacent wells	0.001***	0.001***	4.913e-04***
	(0.0002)	(0.0002)	(0.0001)
Number of adjacent leases sold in the		0.068***	0.053***
same year that lapsed		(0.003)	(0.003)
Number of adjacent leases sold in		0.052***	0.043***
previous years that lapsed		(0.005)	(0.004)
Number of adjacent leases sold in		-0.023***	-0.016***
the same year		(0.003)	(0.003)
Number of adjacent leases sold in		-0.021***	-0.016***
previous years		(0.003)	(0.003)
Total spent by firm			3.39e-09***
			(1.82e-10)
Total hectares acquired by firm			-3.88e-07**
			(1.86e-07)
Number of leases acquired by firm			6.98e-05
			(4.72e-05)
R^2	0.3159	0.3482	0.4543
F-stat	67.52***	125.41***	-

Notes: $N = 24,761$. Robust standard errors in parentheses. Other controls: auction month and year; lease location by area (plains and northern); dummies for mineral rights; number of leases sold on the auction date; total area of leases sold on the auction date; joint venture wins; number of firms in winning joint venture. Statistical significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

6.2 Bidder Strategies

An issue with the dataset is that the true winner of a lease is unobserved when a broker wins and a lease lapses. Accordingly, to accurately study firm behaviour, the data must be restricted to leases where a well is drilled. Restricting the data to when a lease does not lapse and the true winner is always observed reduces the number of observations to 12,478. The summary statistics for this data are described in Table 4.

Table 4: Summary Statistics for Non-Lapsed Leases

	mean	standard deviation	min	max
Lease Size (hectares)	253.684	227.061	1.6	6224
Auction Bid (dollars)	66,236.21	112,024.90	4	3,248,654.00
Bid per Hectare	298.31	490.72	2.5	12,690.05
Broker Wins (0,1)	0.307	0.461	0	1
Number of Adjacent Wells (pre-auction)	22.942	26.451	0	255
Number of Wells Drilled on Lease (post-auction)	3.023	3.810	1	143
Number of Firms Operating Adjacent Wells	7.484	4.756	0	46
Number of Adjacent Leases Sold in the Same Year	1.937	2.160	0	41
Total Number of Adjacent Leases Sold	2.812	2.717	0	44
Number of Adjacent Lapsed Leases Sold in the Same Year	0.692	1.256	0	15
Total Number of Adjacent Lapsed Leases	0.969	1.538	0	17
Revenues (millions)	3.180	8.891	0.00	283.000
Drilling Costs (millions)	1.540	1.981	0.00	43.800
Operating Costs (millions)	0.353	0.633	0.00	15.800

N: 12,478

Compared to the full sample, all variables listed in Table 4 have higher means. The bid per hectare alone is 16% higher. It is not surprising that the average number of adjacent wells or the number of firms operating adjacent wells is higher, as presumably a lease that does not lapse is in an area with more activity and more interest. The change in the average number of adjacent leases that lapse supports this. What is somewhat surprising is that the number of adjacent leases sold is not substantially different from that in Table 1. As well, a broker winning occurs only marginally more frequently. Conditional on a well being drilled, 71% of leases have positive production and

34% of leases have positive profits. It should be noted, however, that the calculation of profits is skewed towards older leases, as the production data for newer wells does not necessarily reflect the full potential of the well.

We can examine the variation in broker usage through graphical analysis. Figure 5 shows the distribution of the ratio of number of brokers used to the number of wins using a broker, by firm. The figure displays the distribution conditional on a firm winning using a broker more than once, as the ratio would always be unity in that case. The ratio is low when a firm wins using a broker and only uses a few brokers. The ratio increases towards unity as the number of brokers used approaches the number of wins using a broker. The distribution indicates considerable variability in the number of brokers used by individual firms, consistent with the hypothesis of strategic behaviour.

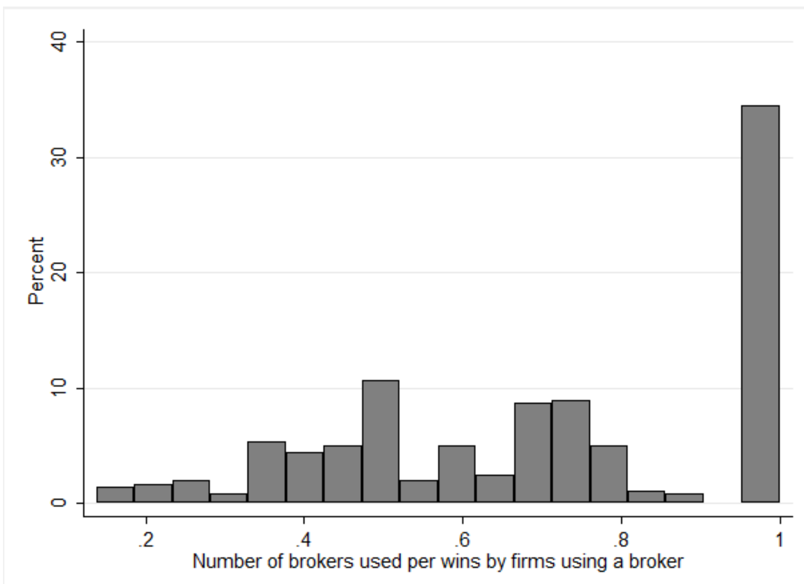

Figure 5: Broker Usage: Distribution of $\frac{\text{Number of Brokers Used}}{\text{Wins Using a Broker}}$

With the exclusion of lapsed leases, there is more flexibility in the choice of proxies for the private information held by firms. Past behaviour of the firm winning a lease can be taken into account, as the true winner is always known, under the assumptions outlined above. The most natural choice for variables which proxy private information held by firms are those measuring *ex ante* value, such as the number of adjacent wells drilled, and average price in the lease's geographic area. Additional variables to consider are those that influence the decision to invest in a broker, such as the winner's previous behaviour. Table 5 describes the summary statistics for the constructed measures of information held by winning bidders.

Table 5: Summary Statistics for Measures of Private Information

	mean	standard deviation	min	max
Number of Adjacent Leases Won by Broker in Same Year	0.580	1.075	0	14
Number of Adjacent Leases Won without a Broker in Same Year	1.357	1.898	0	41
Number of Adjacent Leases Won by Current Winner using Broker in the Same Year	0.127	0.479	0	7
Number of Adjacent Leases Won by Current Winner without a Broker in the Same Year	0.873	1.738	0	41
Number of Adjacent Wells	22.942	26.451	0	255
Number of Adjacent Wells Operated by Current Winner	3.072	9.101	0	168
Number of Firms Operating Adjacent Wells	7.484	4.756	0	46
Average price in the area by year and geographic location	248.667	372.355	0	12,690.05
Number of wells drilled on a lease	3.023	3.810	1	143
Number of producing wells drilled on a lease	1.828	3.117	0	138
Cumulative production on a lease (m^3)	53,725	157,962	0	4,728,809

N: 12,478

Conditional on a lease having at least one adjacent lease sold in the same year, 31% of adjacent leases are won by a broker on average. When a given lease is itself won by a broker, the share of adjacent leases won by a broker jumps to 66%. If one does not expect a broker to be associated with private information, then we should not expect there to be a positive relationship between the number of adjacent leases won through a broker and a given lease being won through a broker. On the other hand, if a given lease is valuable enough to warrant investment in a broker, then it stands to reason that subsequent adjacent leases are also valuable and the winner is likely to use a broker again. If this is the case, though previous use of a broker does not*reveal* the private information itself, it can indicate the presence of private information and hence be used as a proxy. Choosing to not invest in a broker previously provides a different type of variation that can be used to explain whether a broker is used.

Other instruments that should be considered are based on the information provided by adjacent wells. Whether an adjacent well is dry or producing provides a signal about the potential profitability of a lease. Presumably, wells owned by the winner provide more information than wells operated by other firms. Finally, the number of firms operating adjacent wells provides a measure of competition within the area surrounding a lease, which could also potentially influence the decision to hire a broker. In an area with several leases already acquired and wells drilled, the benefit to a broker would be quite low, compared to an area that is largely undeveloped.

In order to determine the marginal effects of private information on the bids, we add the proxies for private information to the basic OLS results in an incremental fashion. The results as reported in Table 6. Column (1) displays the results conditioning solely on observed lease characteristics and whether a broker won. Column (2) adds the average bid per hectare by a lease's geographic location (defined by blocks of 36 square miles) in the year the auction occurred. A potential pitfall with this variable is that prices may trend upward over time; however, its use allows a different type of variation compared to using the average price per hectare for adjacent leases. Notice that the R^2 almost doubles with inclusion of the average price. This indicates winning bids have substantial explanatory power, and bids on nearby leases are a relatively good proxy for the signal received by firms. Column (3) reports the results for a regression of price per hectare on broker and firm-specific fixed effects. Little additional variance in winning bids is explained using firm fixed effects, and the model is not identified with robust standard errors.[17]

Next we consider previous behaviour by the winner and other firms that acquired adjacent leases as proxies for the private information held by firms. The results reported in column (4) are very similar to those in column (2). There are marginal and not statistically significant changes in the constant and the broker coefficient. Very little additional variance in the bid per hectare is explained by the inclusion of previous bidder behaviour. This is puzzling, as one would expect previous behaviour by the winner to reflect private information regarding the value of a lease.

[17] Other firm characteristics are considered, such as the total number of leases acquired by firm, the total amount spent by firm, and the total hectares acquired by firm. However, these characteristics provided little explanatory power and increased the broker coefficient.

However, the benefit of this unexpected result is that the measures of private information used in column (4) may be acceptable instruments, if they are correlated with the decision to hire a broker and uncorrelated with the bid. This is an alternative method for correcting for omitted variable bias, and has the additional benefit of correcting for any potential endogeneity in the decision to hire a broker.

Finally we consider proxies for private information based on *ex ante* information provided by adjacent wells. These include total adjacent wells, total producing adjacent wells, total adjacent wells operated by the winner, and the number of firms operating adjacent wells. The number of producing wells drilled on a lease is also included. Again, there is little value added with the addition of these proxies. There are two possible explanations for the curious results explored in Table 6. The first is that average prices in a lease's geographic area is the best proxy of the private information held by firms. However, winning bids are observed by all potential bidders, suggesting that updating of beliefs occurs quickly. The second explanation is that the regression is misspecified, in that the private information or interest in an area that induces firms to hire a broker is uncorrelated with the actual bid, and hence the value of individual leases. This suggests a different model of equilibrium behaviour may be justified.

It was suggested above that the inability of the proposed proxies to explain variation in winning bids makes them potential instruments for explaining the decision to hire a broker, and correcting for the omitted variable bias in that fashion. Though many combinations of instruments are possible, we restrict ourselves to reporting the combinations with the most explanatory power.[18] As a prior, own behaviour is likely to influence a firm more than a competitor's behaviour, or aggregate activity in an area. This is borne out in the data, as the coefficients for the instruments using the winner's behaviour as a predictor are larger in magnitude than those for instruments involving overall behaviour surrounding a lease. In the interest of brevity, we restrict ourselves to reporting previous bidder behaviour. Table 7 displays the results. The top panel of the table displays the second stage results, with bid per hectare as the dependent variable. The bottom

[18]The number of adjacent wells and adjacent wells operated by the winner failed the weak instrument test. Using a broker or not using a broker in previous years was not highly correlated with using a broker, and failed the validity test.

Table 6: Regression Results Conditional on Drilling a Well

Dependent Variable: Bid per Hectare

	(1)	(2)	(3)	(4)	(5)
Constant	729.665***	531.307***	24.452	532.829***	518.291***
	(153.591)	(152.099)	(439.061)	(151.267)	(151.779)
Broker Wins	153.412***	126.695***	190.417***	130.790***	127.057***
	(10.117)	(10.296)	(11.849)	(11.423)	(10.310)
Average price in the auction year by geographical location		0.407***	0.397***	0.409***	0.391***
		(0.049)	(0.011)	(0.049)	(0.048)
Number of Adjacent Leases Won by Current Winner using Broker in Same Year				-6.402	
				(10.688)	
Number of Adjacent Leases Won by Current Winner without using Broker in Same Year				9.345**	
				(3.939)	
Number of Adjacent Leases Won by Broker in the Same Year				-2.112	
				(5.154)	
Number of Adjacent Leases Won without Broker in the Same Year				-9.036***	
				(2.779)	
Number of firms operating adjacent wells					4.634***
					(1.383)
Total adjacent wells					1.008*
					(0.524)
Total adjacent wells operated by winner					1.902***
					(0.725)
Total adjacent producing wells					-0.582
					(0.779)
Number of producing wells drilled on lease					-13.152***
					(3.900)
Adjusted R^2	0.1040	0.1909	0.2009	0.1916	0.2000
F-stat	29.64***	35.78***	4.80***	31.10***	33.21***

Notes: $N = 12,478$. Robust standard errors in parentheses. Other controls (except (3)): auction month and year; lease location by area (plains and northern); dummies for mineral rights; number of leases sold on the auction date; total area of leases sold on the auction date; joint venture wins; number of firms in winning joint venture.

Statistical significance: $^{***}\ p < 0.01$, $^{**}\ p < 0.05$, $^{*}\ p < 0.10$.

panel of the table reports the first stage results, with broker as the dependent variable and the four measure of previous bidder behaviour as the excluded instruments. Column (1) reports the OLS results from column (2) of Table 6 for ease in comparing the relative value of IV estimation.

We see from the second stage results in Table 7 that using instrumental variables buys us very little in terms of eliminating remaining omitted variable bias. Column (2) uses the combination of all four instruments. Adjacent leases being acquired by a broker increases the probability a broker will be used by 10.5%, and when the winner uses a broker to win an adjacent lease, this increases the probability a broker will be used by 15%. An adjacent lease won without using a broker decreases the probability a broker will be used by 2%, and the winner choosing to not use a broker to acquire adjacent leases decreases the probability of a broker winning by 4.6%. The instruments are jointly significant, and reject null hypotheses of weak identification and under-identification. Hansen's J statistic is an overidentification test of all instruments. The joint null hypothesis is that the instruments are valid instruments, i.e., uncorrelated with the error term, and that the excluded instruments are correctly excluded from the estimated equation. We reject the null hypothesis, which casts some doubt on the validity of the instruments used. Testing the validity of each instrument against the other three reveals that the second instrument fails the test of exogeneity. That is, the number of adjacent leases won by the winner without using a broker is not conclusively exogenous. Column (3) reports the results when this instrument is excluded. The coefficients on the instruments are not substantially changed by the exclusion, and the second stage results remain unaffected as well.

The effect of the instruments on a broker winning are quite interesting. If the current winner has used a broker in the past to acquire an adjacent lease, a broker is more likely to win. As the number of adjacent leases acquired by the current winner without using a broker increases, they are less likely to use a broker. A broker winning an adjacent lease has a positive effect on the probability of a broker winning, though the own win effect is substantially larger. These results indicate firms engage in dynamic strategies for acquiring leases. From the third instrumental variables regression, we see a broker winning is associated with a 24% premium on the price per hectare, suggesting private information has a substantial effect on the bids made by firms.

Table 7: Instrumental Variables Regression Results

(Second Stage) Dependent Variable: Bid per Hectare

	(1)	(2)	(3)
Constant	531.307*	491.101*	446.249*
	(152.099)	(139.627)	(140.670)
Broker Wins	126.695*	112.850*	122.533*
	(10.296)	(23.052)	(23.316)
Average price in the auction year by geographical location	0.407*	0.377*	0.389*
	(0.049)	(0.045)	(0.048)
R^2 (centered)	0.1909	0.1901	0.1906
R^2 (uncentered)		0.4086	0.4090
F-stat	29.64*	29.39*	29.56*

(First Stage) Dependent Variable: Broker Wins (0,1)

	(1)	(2)	(3)
Constant		0.160*	0.195*
		(0.073)	(0.069)
Instruments:			
Number of Adjacent Leases Won by Current Winner using Broker in Same Year		0.151*	0.148*
		(0.013)	(0.013)
Number of Adjacent Leases Won by Current Winner without using Broker in Same Year		-0.046*	
		(0.004)	
Number of Adjacent Leases Won by Broker in the Same Year		0.103*	0.110*
		(0.005)	(0.005)
Number of Adjacent Leases Won without Broker in the Same Year		-0.021*	-0.048*
		(0.003)	(0.002)
R^2 (centered)		0.2747	0.2636
R^2 (uncentered)		0.4974	0.4897
F-stat		125.36*	147.25*

Statistical Tests

	(1)	(2)	(3)
F Test of Excluded Instruments		458.63*	699.07*
Kleibergen-Paap Multivariate Wald F-statistic (Weak ID)		467.16*	716.41*
Kleibergen-Paap Rank LM Statistic (Under ID)		1617.95*	1486.87*
Hansen's J statistic (Over ID)		12.39*	3.93

Notes: $N = 12,478$. Robust standard errors in parentheses. Controls in both stages: auction month and year; lease location by area (plains and northern); dummies for mineral rights; number of leases sold on the auction date; total area of leases sold on the auction date; joint venture wins; number of firms in winning joint venture.
Statistical significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

6.3 Number of Bidders

We must also consider the role the number of bidders in the regression results reported in Table 6, as the number of bidders participating in the auction is unknown. Recall from equation (8) the constructed proxy for the number of bidders is

$$N_{tj} = \frac{1}{14}\left(\frac{n_{tj}}{\sum_{t=1}^{T} n_{tj}} m_{tj} + leases_{tj}\right)$$

The first column regression uses a weighted average of the number of leases sold at each auction date and the number of licenses sold. The weight on the number of licenses sold is the proportion of leases sold on that auction date out of the whole year. The second column creates weights by geographic area. The number of leases sold at a given date is weighted by the proportion of total leases sold on that date by geographic area. The third column replaces the number of licenses sold in (1) with the number of leases sold in each of the three geographic areas of Alberta. The fourth column uses the number of firms operating adjacent wells as the source of variation in the weighted average.

One can notice from Table 8 that even though the coefficients for the number of bidders change substantially depending on the proxy used, the coefficient on broker does not. This suggests that the decision to use a broker and a broker winning is not affected by the number of bidders. An alternative explanation is that a broker winning is unaffected by the omitted variable bias from unknown N. The theoretical model predicts that equilibrium bids are increasing in the number of bidders. However, given the choice to invest in a broker can be separately identified from the equilibrium bid equation, it is not surprising that the premium associated with a broker is invariant to the number of competitors.

7 Conclusions

This paper examines the behaviour of firms in petroleum and natural gas lease auctions in Alberta from 1996 to 1999. A unique feature of these auctions is the ability of firms to use brokers as proxy bidders; discussion with industry insiders indicates the use of brokers is associated with hiding

Table 8: Regressions Comparing Proxies for N

Dependent Variable: Bid per Hectare					
	No Proxy	Proxy 1	Proxy 2	Proxy 3	Proxy 4
Constant	530.305*	515.187*	424.574*	537.537*	538.979*
	(120.641)	(151.376)	(108.682)	(127.784)	(113.269)
Broker Wins	129.041*	129.017*	128.989*	129.044*	128.960*
	(10.309)	(10.303)	(10.316)	(10.307)	(10.303)
Number of Bidders		-43.206	-82.944	-1.493	290.203
		(157.735)	(61.242)	(23.032)	(847.495)
Adjusted R^2	0.1956	0.1956	0.1960	0.1956	0.1952
F-stat	37.01*	36.01*	36.24*	36.12*	35.85*

Notes: $N = 12,478$. Robust standard errors in parentheses. Other controls (except (3)): auction month and year; lease location by area (plains and northern); dummies for mineral rights; number of leases sold on the auction date; total area of leases sold on the auction date; joint venture wins; number of firms in winning joint venture.
Statistical significance: * $p < 0.01$.

private information and attempts to acquire market power within a resource play. The objective of the paper was to examine the determinants of winning bids, and to determine whether broker usage is indeed associated with private information held by firms.

The results can be summarized as follows. First, regressing winning bids on lease and auction specific characteristics indicate that a broker winning is positively correlated with a lease of higher value. Winning bids per hectare are 19% higher when a broker is hired and wins the auction. Second, in examining the determinants of a broker (being hired and) winning, we find the probability of a broker winning is positively correlated with a broker previously winning and the winning firm previously using a broker to win adjacent leases. Both are consistent with the theory a broker is used to hide private information.

The contribution of this paper is developing a model of bidder behaviour that incorporates the choice to use a broker in equilibrium strategies, and explore the relationship between the use of brokers and winning bids using a previously unused dataset. The results indicate the repeated nature of these auctions has an important role in firm strategies. The use of brokers deserves further study, and highlights the importance of developing models that allow for dynamic firm strategies.

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