Information Asymmetry, Trade, and Drilling: Evidence from an Oil Lease Lottery

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Abstract

We exploit a government oil lease lottery that randomly assigned leases to individuals and firms. We examine how initial misallocation affected trade, drilling, and production outcomes. When parcels are far from existing production, leases won by individuals have similar drilling and production outcomes as those won by firms. However, for parcels close to existing production, we find that leases are about 50% *less* likely to be drilled when they are won by firms. We find evidence that information asymmetries drive these results.

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1 Introduction

As Coase (1960) demonstrated, reallocation via secondary markets can correct for misallocation, but trade frictions like information asymmetry can reduce the efficacy of secondary markets. A fundamental question in economics is how effectively markets correct for misallocation. Our article explores this question in an oil setting with random assignment of oil leases, examining the effect of initial lease assignment on eventual drilling and production outcomes.

We exploit a 1970's oil lease lottery that randomly assigned the right to lease government parcels of land for oil (and gas) drilling. The low cost of entry allowed many individuals, as well as firms, to participate. Individuals who won leases typically lacked the necessary capital and expertise to develop their leases and often only entered in hopes of flipping their leases to firms to make a quick profit. In contrast, oil firms that won leases were more likely to be able to effectively exploit their leases. We test whether initial assignment to firms versus individuals led to differences in drilling and production. If secondary markets were efficient, initial assignment to an individual rather than to a firm would have no effect on drilling and production.

A challenge to identification using a lottery is endogenous entry. Even though the lottery provided randomized assignment conditional on entry, some leases had more entrants than others, potentially leading to correlation between the probability that a firm won and the expected productivity of the lease. To correct for this endogeneity, we exploit the fact that the lottery also drew names of second- and third-place winners who would serve as backups. By conditioning on the identity of all three winners, we construct a subsample for which the probability that a firm wins is fixed and exogenous. We also take an alternative approach using the full sample and controlling for observables. We find these approaches yield similar results.

For most leases, we find that leases won by individuals are quickly resold. We also find no statistical significance in the difference between drilling and production of leases won by individuals versus firms. These results are consistent with (though not indicative of) a Coasian setting where secondary markets efficiently reallocate leases. Our findings for this oil setting contrast with literature on reallocation in housing and land markets who find that correcting for misallocation can take 20 years or more (Bleakley and Ferrie, 2014; Akee, 2009).

However, some leases were close to existing oil production where the nearby producing firm likely had private information about geological productivity. For these leases, we find evidence of inefficient secondary markets: Leases won by individuals were nearly twice as likely to have drilling and production than leases won by firms.

We discuss why buyer-side private information about lease productivity can cause inefficiencies in trade and drilling. Private information held by the nearby producing firm leads to a buyer-side "lemons" problem. If the buyer is willing to buy, the seller's expected value of the lease shifts upward, increasing the seller's outside option of retaining the lease. This mechanism makes it difficult for the buyer to make an offer that the seller is willing to accept while still being profitable for the buyer. Because individuals have higher drilling costs and therefore worse outside options, trade is more likely and the buyer's offer is lower when the initial lease winner is an individual rather than a firm.

We write a simple model that shows why assigning a lease to a firm rather than an individual can lead to not only a lower probability of trade, but also a lower probability of drilling. The intuition is that if the initial lessee does not receive an offer, they will shift beliefs about lease productivity downward and potentially not drill. If neither firms nor individuals drills in the absence of an offer, leases won by firms will be less likely to be traded and therefore less likely to be drilled.

We discuss additional empirical evidence consistent with information asymmetry. For example, leases won by individuals are more likely to be traded to nearby producing firms, and leases traded to nearby producing firms have a higher probability of drilling and production. We also discuss why alternative explanations for our drilling findings, such as differences in trade timing, overly optimistic individuals, common pools, and heterogeneous types are less able to explain our findings.

Our work ties in with a large empirical literature on information asymmetry and secondary markets. Within the oil and gas setting, Hendricks and Porter (1988); Porter (1995); Hendricks and Porter (1996), Lin (2013), and Compiani, Haile, and Sant'Anna (2020) discuss how drilling within one lease gives a firm private information about production potential of nearby leases and how such information affects later market outcomes. Covert and Sweeney (2019) show that how markets allocate oil leases to lessees affects lease productivity outcomes. Our work also ties in with theoretical literature examining trade and bargaining under information asymmetry, especially when buyer and seller values are correlated, including Akerlof (1970), Myerson and Satterthwaite (1983), Samuelson (1984), Myerson (1985), Samuelson (1985), Ausubel, Cramton, and Deneckere (2002), Deneckere and Liang (2006), and Schweinzer (2010). Our article's major contribution is that it uses random assignment coupled with applied theory to explore and explain the effect of initial misallocation in an industry with significant information asymmetry.

2 Background: Oil Lottery and Reallocation

We examine leasing, trading, drilling, and production using data on United States Bureau of Land Management (BLM) land in Wyoming. We focus on BLM oil leases that were allocated via a lottery system. The lottery provided an orderly and fair allocation of leases (Bureau of Land Management, 1983), and the randomized assignment is key to our identification strategy. Lotteries were used in cases where the leased parcel was the site of a lapsed lease, the previous lease was not known to be productive, and the parcel was at least one mile from known oil or gas production

(Fairfax and Yale, 1987).[1]

To initiate the lottery, regional BLM offices would compile and publish a list of the parcels that would be offered in the lottery. Interested individuals and firms typically had about a week to submit an entry card by mail to the regional BLM office for each parcel they were interested in (Bureau of Land Management, 1983). For the period of our data (1975-1978), the entry fee was only $10, which attracted a large number of individuals. The regional BLM office would then draw three entry cards—one for the first-place winner, along with two runner-ups—which we refer to as the second- and third-place winners. The first-place winner had 30 days to submit their first rental payment, equal to $1 per acre per year, in order to secure a lease of the parcel.[2] If the first-place winner did not respond in time, the BLM then offered it to the second-place winner, and then on to the third-place winner (Bureau of Land Management, 1983).[3]

In order to retain leases after winning, lessees were required to comply with BLM leasing rules. Prior to production, lessees were required to pay a rental fee of $1/acre annually to continue the lease to the next year. After leases began production, lessees paid a royalty, typically 12.5%, on revenues from production. Leasing contracts were governed by holding-by-production clauses: If a lease had oil or gas production within ten years of the lease start date, the lease continued until production ended. If there was no production within ten years and if qualifying drilling operations were not in progress, leases expired and were returned to the BLM. A lease also ended if the lessee formally relinquished it or failed to pay rental fees (Fairfax and Yale, 1987).

Each regional BLM office facilitated reallocation by maintaining an open records center where anyone could easily look up the names and addresses of current lessees.

[1] This lottery system was first used in 1960 and lasted until 1987, when the BLM began using auctions to allocate these parcels.

[2] The typical lease was about 1 square mile, implying an average annual rental payment of $640, or about $2,835 in 2020 dollars.

[3] By matching winner records with transactions records, we estimate that approximately 98% of leases were claimed by the first-place winner.

Prospective buyers could identify possible misallocation (e.g., whether the lessee was an individual) and contact the lessee with a purchase proposal. BLM restrictions on transferring leases appeared to be minimal, with the BLM requiring such transfers to be recorded, but with little to no regulatory scrutiny.

In cases where there was existing nearby production, the firm producing oil nearby likely had the lowest costs to develop the lease. Nearby producing firms would have already built infrastructure, like roads and pipelines, and therefore may have had spatial economies of scale.[4] Nearby producing firms may also have superior information about optimal drilling depths and techniques to most effectively target and produce oil, yielding further cost advantages (McKie, 1960; Covert, 2015).

Because it has produced oil nearby, a nearby producing firm typically also had a more precise signal of the amount of oil that can be produced from the lease. Other literature has shown that the presence of a nearby producing firm with private information about lease productivity has significant effects on market outcomes for offshore oil lease auctions, with nearby producing firms typically purchasing those leases they believe to be productive while bidding less or not at all for other leases (Hendricks and Porter, 1988; Porter, 1995).

3 Theoretical Framework

We write a model of secondary trade and drilling, examining how initial assignment of a lease to a firm or an individual will affect trade and drilling outcomes when there is a nearby producing firm with private information about the lease's productivity. Our stylized model of trade and asset utilization is similar to those in Akerlof (1970), Samuelson (1984), Myerson (1985), and Samuelson (1985). As with this previous literature, we have a common value setting, where the value of the asset to the seller

[4] If a firm other than the nearby producing firm produced from the lease, it would either need to pay to access that nearby producing firm's pipeline, build its own pipeline, or ship by truck/rail. Vissing (2017) also discusses evidence that firms value contiguous leases.

is correlated with the value of the asset to buyer. Unlike many "lemon" settings where it is the seller who has private information, here it is the buyer who has private information.

A lease is randomly assigned to either a firm, F, or an individual, I. Costs of drilling are publicly known and satisfy $C_I > C_F > 0$. Higher costs for individuals may be driven by factors like less industry familiarity, larger search costs to find contractors, and larger costs to verify contractor suitability. The initial winner does not know the value of oil (θ) within the lease, but knows that it is drawn from a distribution with a cdf $F(\theta)$. There is a potential buyer B which has drilled and produced oil nearby, and therefore knows the true value of θ.

We focus on the case where the buyer has all the bargaining power and can make a take-it-or-leave-it offer. For trade to happen, it must be individually rational for both the buyer B and the initial winner $j \in \{I, F\}$. The buyer either makes a take-it-or-leave-it offer $O_j = O_j^*$ to the initial winner j or makes no offer ($O_j = \varnothing$). Buyer-side individual rationality implies the offer O_j^* cannot exceed the buyer's value of the lease, $\theta - C_B$, where C_B is the buyer's cost of drilling. Knowing this, the initial winner updates their beliefs upon receiving an offer O_j^*, inferring $E(\theta | O_j = O_j^*) = E(\theta | \theta \geq C_B + O_j^*)$. Because the buyer must satisfy the initial winner's individual rationality constraint and because the buyer has all the bargaining power, the offer, if made, will equal the initial winner's outside option of keeping the lease: $O_j^* = \max\{E(\theta | \theta \geq C_B + O_j^*) - C_j, 0\}$. The offer O^* is weakly decreasing in C_j, meaning that an offer made to an individual is lower than that made to a firm. In turn, this implies that the probability that an offer is made and therefore that trade happens is $1 - F(O_j^* + C_B)$, which is higher if the lease winner is an individual.

In this model, it is theoretically ambiguous whether leases won by individuals or firms have a higher probability of drilling: On one hand, all traded leases are drilled and leases won by individuals are more likely to be traded. On the other hand, untraded leases are more likely to be drilled if the initial lessee's cost of drilling is lower. If in spite of their lower costs, firms tend not to drill in the absence of an offer, then the lower probability of trade for leases won by firms will lead to a lower probability of drilling for leases won by firms. Proofs and a graphical example of the comparative statics are in Appendix A.[5,6]

4 Data Description & Summary Statistics

To examine how lease assignment affects trade, drilling, and production outcomes, we use data from Wyoming on lease lotteries, lease transfers, and well-level drilling and production:

Our BLM lease lottery data cover January 1975 through December 1978 and are from the BLM office in Cheyenne, Wyoming. Records include information on the leases offered and the winners of each lease. Lotteries were held monthly with an average of about 225 parcels offered each month. We drop a small number of leases (<1%) due to illegibility in the raw data or for having fewer than three winners. This leaves a total sample of 10,762 leases offered over 48 months. Information on lease parcel boundaries allows us to match leases to drilling and production activity. The data include the total number of entry cards submitted for each parcel to be leased, as well as the names of the first-, second-, and third-place winners. The names of other entrants were not recorded. Appendix B includes a more detailed discussion of the data.

The winners' names allow us to determine whether each winner was a firm

[5]Our results below are sensitive to bargaining power assumptions. If the seller has all the bargaining power instead, then, at least under a uniform distribution of θ, leases won by individuals will have a higher probability of trade and a weakly lower probability of drilling than leases won by firms. See Online Appendix A. Our empirical results in Section 6 – showing that leases won by individuals have a higher probability of drilling than those won by firms – suggest that buyers have at least some bargaining power.

[6]Online Appendix A includes discussion of real world nuances, including bargaining power, liquidity constraints, real options, and the timing of trade and drilling. These can substantially complicate the model, though the central findings remain possible.

or an individual. We first search the names for terms like "Inc.", "Production", and "Corporation." We then reviewed each lease's winners by hand to ensure that they were accurately categorized. Most firms appear to be oil and gas production companies. Of the individuals that entered, some appear only once or twice and do not seem to have connections to the oil industry, whereas others seem to be more sophisticated, appearing multiple times in the list of winners.[7]

Our second data source is the BLM's LR2000, an administrative database of federal leases. It includes detailed information on lessee names, lease transfers, and lease terminations. We use it to identify when the lease is transferred to a buyer and the identity of the buyer.[8] We find that approximately 95% of leases from our lottery data can be linked to the LR2000. The remaining 5% are likely leases that were abandoned before they were digitized and entered into the LR2000, and therefore cannot be matched.

Our third data source is from the Wyoming Oil and Gas Conservation Commission (WOGCC). These data have been lightly edited to improve quality by the United States Geological Survey (Biewick, 2011). We use WOGCC data on drilling and production to determine whether drilling and production eventually happened on a lease.[9] These data are also used to determine whether a lease was close to known oil-producing wells when it was offered via lottery. We define a lease as having nearby production if it is within 2.6 miles of an oil-producing well that was drilled at most five years before the lease was offered in the lottery.[10] In Online Appendix B, we consider

[7]In Online Appendix B, we discuss the possibility of individuals entering on behalf of firms. We show that leases won by individuals with similar addresses as firms have similar drilling outcomes as leases won by firms.

[8]It was very rare for a nearby producing firm to win a lease. We find that of the 2,399 leases within 2.6 miles of existing production, only 7 were won by a nearby producing firm.

[9]While our first lotteries are in 1975, our production data begins in 1978. This is unlikely to significantly understate whether production happened, as we find that less than 10% of wells drilled between 1979 and 1985 had production lifespans less than 3 years.

[10]We identify nearby well location based on the reported Public Land Survey System (PLSS) section. We use 2.6 miles to differentiate between cases where a nearby section was approximately $\sqrt{5} \approx 2.2$ miles away (e.g., two sections east and one section north) and approximately $\sqrt{8} \approx 2.8$ miles away (e.g., two sections east and two sections north). We do not consider leases that were

a variety of alternative definitions of nearby production and find that our results are broadly consistent. We use WOGCC data on operator identity to determine whether the lease buyer was a nearby producing firm.

Columns (1) and (2) of Table 1 show summary statistics for the full sample of leases in the lottery. A typical lease had about 600 entries submitted and an area just over one square mile (640 acres), although the variance was large. We find that firms made up a relatively small fraction of winners: Only 6% of leases had a firm as the first place winner. Similarly, 6% of all winners (first-, second-, or third-place) were firms. These leases typically had low expected productivity—only 3% produced oil within twelve years of the lease's start.[11]

[Table 1 approximately here]

5 Establishing Exogeneity

Identifying the causal effect of initial assignment on lease outcomes requires exogeneity conditions to be satisfied. One threat to exogeneity is endogenous entry: We find that the probability that an entry came from an individual was higher for leases that had greater acreage and for leases that had a larger number of total entries (see Appendix B). As a result, the probability that the winner was an individual was likely higher for leases with higher expected productivity.

In order to construct unbiased estimates, we exploit the random assignment of winners among first, second, and third place. We construct a subsample (the "restricted sample") limited to those leases where the first-, second-, and third-place winners consisted of exactly one firm and two individuals. Within the restricted sam-

close to gas-producing wells to have nearby production as natural gas wells were often unprofitable to develop both because of the extensive pipeline requirements as well as gas price ceilings imposed by the Federal Power Commission.

[11] We use twelve years because lease terms were ten years with a possible two-year extension in the event of "qualifying drilling operations"—serious progress toward drilling a well.

ple, the probability that the first-place winner is a firm is fixed at 1/3 and uncorrelated with omitted variables.[12] There are 1,800 leases within this restricted sample.

Table 2 provides a balance table that indicates exogeneity within the restricted sample. Leases won by individuals are very similar to those won by firms; those won by individuals have slightly more total entries and are slightly larger, but the differences are well within the type of statistical variation we would expect to see. Further evidence of exogeneity is in Section B.2 of the Online Appendix.

[Table 2 approximately here]

Columns (3) and (4) of Table 1 provide summary statistics for the restricted sample. Relative to the full sample, parcels in the restricted sample tend to have fewer entrants, smaller acreage, and lower likelihood of eventual drilling and production.

We also look for evidence of corruption. We do not find that firms placed first at disproportionately high rates: Of the 2047 appearances by firms in our data, 697 (34.0%) of these are in first place, 658 (32.1%) are in second, and 692 (33.8%) in third. Although 34.0% of firm observations being in first place is slightly above the 33.3% that we would expect, the binomial distribution predicts that there is a 24% chance of observing 697 or more firms in first place. Within the restricted sample of 1,800 parcels we have a similar distribution (619 in first place), with a 16% chance that at least 619 firms appear in first place. The Online Appendix includes additional checks for corruption.[13]

[12] Appendix B includes a proof of why this subsample approach ensures exogeneity. A sample limited to those leases with two firms and one individual would also ensure exogeneity. We focus on the one-firm and two-individuals sample because it is much larger.

[13] Later lotteries may have had corruption problems: There were a number of individuals in 1984 who won multiple leases at long odds. An Interior Department audit could not rule out corruption, but no charges were filed (Coates, 1985).

6 Analysis

This section presents our empirical analysis. We first discuss the heterogeneous treatment effect regression specification we use. We follow by discussing our empirical results, starting with trade outcomes and continuing with drilling and production outcomes. Additional robustness results are in Online Appendix B.

Empirical Strategy

Our analytical approach examines the treatment effect of assigning a lease to a firm. Outcome variables of interest, Y_i, include indicators for secondary market trade activity, drilling, and production.[14] The heterogeneous treatment effect regression allows the treatment effect to vary depending on whether the lease is close to existing production:

$$Y_i = \beta_0 + \beta_1 F_i + \beta_2 NearbyProd_i + \beta_3 NearbyProd_i * F_i + \Omega X_i + \varepsilon_i \tag{1}$$

F_i is an indicator for whether the first place winner was a firm, while $NearbyProd_i$ is an indicator for whether there was nearby oil production within 2.6 miles when the lease was offered in the lottery. Therefore, β_1 is the treatment effect of assigning a lease to a firm when it is far from existing production, while $\beta_1 + \beta_3$ is the treatment effect of assigning a lease to a firm when it is close to existing production. The coefficient β_2 reflects differences between leases that are close to existing production and those that are not, including expected productivity, proximity to pipelines, and other lease characteristics. Because proximity to nearby production may be correlated with other factors that affect outcome variables of interest, neither β_2 nor β_3 (unlike β_1

[14] We use a linear probability model, which is appropriate for calculating average treatment effects (Angrist and Pischke, 2008). The AIC and BIC suggest a linear probability model is a better fit for our data than a logit or probit.

and $\beta_1 + \beta_3$) has a causal interpretation.[15] We include a number of control variables (X_i), including a spline with six knots in the number of entries received, total acreage of the parcel, and month-of-lottery fixed effects.

Using this regression specification, we examine two data samples. The first is the restricted sample where exactly one of the three winners was a firm. The second is the full sample, where we rely on the control variables X_i to correct for endogenous entry. These two approaches are complementary: the restricted sample ensures exogeneity while the full sample is larger and has more precisely estimated coefficients. Our results are similar across approaches.

Throughout the analysis, we use Conley (1999) spatial standard errors unless otherwise indicated: We allow ε_i and ε_j to be correlated if parcel i and parcel j are within twenty miles of each other, consistent with Lewis (2019).

Secondary Market Trade

For the approximately 95% of leases with LR2000 data, we construct measures of lease transfer activity, identifying how many years until the lease was first transferred.[16] We also identify cases where a lease was never transferred and cases where the lease does not appear in the LR2000.

[Figure 1 approximately here]

Figure 1 shows raw histograms of the time until first lease transfer, comparing leases won by individuals to those won by firms. More than 30% of leases won by individuals were transferred within the first year of a lease, and approximately three-fourths of all leases won by individuals were transferred. The probability that leases

[15]See Appendix B for additional details on why β_1 and $\beta_1 + \beta_3$ identify treatment effects.

[16]We find similar results when we examine first date transferred to a firm. See Online Appendix Table B.13. One disadvantage of using transfer to a firm is that LR2000 data only identify receiving parties by shorthand, and in about 10% of cases does not identify the receiving party at all.

could not be matched to the LR2000 data is about 5% for both individuals and firms, suggesting little likelihood of bias from non-matching.

[Table 3 approximately here]

Columns (1) and (2) of Table 3 report results using the specification in Equation 1, setting the dependent variable to a binary variable representing whether the lease was traded within twelve years of the lease's start. We find that firms were about 22 percentage points less likely to transfer their leases than individuals. Individuals' greater propensity to trade is consistent with the idea that many individuals found it too costly to develop their leases in the absence of trade. Columns (3) and (4) show that when a lease was transferred, leases won by firms took more than twice as long to be initially reassigned as leases won by individuals. We do not find that trade patterns varied significantly depending on whether the lease was close to existing production (β_2 and β_3 are not statistically significant and are small in magnitude relative to β_1).

Reassignment to a Nearby Producing Firm

We next examine whether the lease is sold to nearby producing firms.[17] We limit this analysis to those leases that are within 5.2 miles of existing production such that for each lease, we can identify the name of the nearby producing firm. As above, our nearby production variable flags leases that are within 2.6 miles of existing production. Table 4 reports our regression results. Because there are so few observations that are both within 5.2 miles of existing production and within the restricted sample, we focus our discussion on full-sample results in Columns (2) and (4).

[Table 4 approximately here]

[17]There are a number of measurement challenges to construct this variable: Name changes frequently occurred and joint ventures were common. We discuss name matching details in more detail in Online Appendix B.

Column (2) finds that when production is within 2.6 miles of the lease, reassignment to the nearby producing firm is nearly three times more likely when the lease is won by an individual. In contrast, when production is between 2.6 and 5.2 miles away from the lease, individuals are only slightly more likely than firms to transfer the lease to the nearby producing firm, and the difference is not statistically significant. We also find that for individuals, proximity to nearby production is positively correlated with probability of trade to a nearby producing firm ($\beta_2 > 0$), whereas for firms, the correlation is negative ($\beta_2 + \beta_3 < 0$, although not statistically significant).[18] We find similar results in Column (4) where the sample is restricted to cases where lease reassignment is observed, showing that our findings are not being driven by the fact that leases won by individuals have an overall higher probability of reassignment.

Drilling and Production

We next turn to drilling and production outcomes. Table 5 presents regression results where the dependent variables are whether there was drilling within twelve years of the start of the lease (Columns 1 and 2) and whether there was production within twelve years of the start of the lease (Columns 3 and 4).

[Table 5 approximately here]

For leases far from existing production, we find that leases won by firms have similar drilling and production probabilities as leases won by individuals. Parcels won by firms had about a 1.1-1.4 percentage point higher probability (18%-30%) of drilling within 12 years of the lease start, but the difference is not statistically significant. Production probabilities are almost identical.

[18] Column (2) of Table 4 shows that proximity to nearby production is associated with a 47% increase in the probability of trade with the nearby producing firm when the initial winner is an individual, and a 54% *decrease* in the probability of trade with the nearby producing firm when the initial winner is a firm.

However, for leases close to existing production, we find that leases won by individuals perform much better than those won by firms: Leases won by firms had a 7.2-9.2 percentage point lower probability of being drilled than leases won by individuals. In addition, leases won by firms were 2.9-4.3 percentage points less likely to have production, though this result is only significant at the 10% level.

[Figure 2 approximately here]

We also plot these results, examining whether there was drilling within 1, 2, ..., 15 years of the start of the lease and whether there has been production within 3, 4, ..., 15 years of the start of the lease. Figure 2 graphs drilling and production probabilities for leases far from existing production, and shows that drilling probabilities over time are similar for leases won by individuals and firms. In contrast, Figure 3 plots results for leases close to existing production and shows that leases won by individuals are nearly twice as likely to be drilled as those won by firms, with similar differences for production outcomes.

[Figure 3 approximately here]

Discussion and Mechanisms

For leases far from existing production, we find that leases won by individuals have a much higher probability of trade than leases won by firms, but that leases won by individuals and firms have similar probabilities of drilling and production. Although these results are consistent with efficient secondary markets, they are not indicative. This is due both to economic and statistical reasons: First, our empirical specification does not allow us identify whether there are other inefficiencies that affect outcomes other than drilling and production probabilities, or that decrease drilling and production probabilities equally for both types of winners. Second, our standard errors imply that we may not be able to detect inefficiencies that lead to small drilling or production probability differentials.

In contrast, for leases close to existing production, we find that leases won by individuals have a higher probability of being drilled than leases won by firms, and we can clearly reject the hypothesis of secondary market efficiency.

We find evidence that these latter findings are driven by the presence of an informed buyer and the resulting information asymmetry: Table 4 above showed that trade patterns with the nearby producing firm differ markedly depending on whether the lease is assigned to an individual or a firm. In the Online Appendix, Section B.4 shows that any selling to the nearest producing firm more strongly predicts drilling and production than simply trade to any firm, and that this is especially true when the winner is an individual and when the lease is close to existing production. There we also show that conditional on production and trade to the nearby producing firm, point estimates of production amounts are higher for leases initially won by firms, reflecting the intuition from the model in Section 3 that buyers require a higher value of θ to trade with a firm than trade with an individual.

One mechanism that appears to play a smaller role in driving these results is sales to firms other than the nearby producing firms. Individuals are more likely to sell to other firms in general. Selling to a firm other than a nearby producing firm can still increase lease profitability, especially if that buyer already leases an adjacent but not yet producing parcel such that it can benefit from economies of scale or the ability to internalize information externalities from drilling (Lin, 2009; Hodgson, 2018). In Online Appendix Table B.13, we show that lease sales to firms are more likely to happen when the initial winner is an individual, which means that leases won by individuals may be more likely to benefit from such economies of consolidation. Then, in Online Appendix Table B.23, we show that selling to any firm is correlated with a higher probability of drilling and production. However, that table also shows that trade with a nearby producing firm is a much stronger predictor of drilling and production than trade with other firms, suggesting that that the major mechanism driving our results is the role of the informed nearby producing firm rather than sales to other firms.

Other mechanisms are less likely to explain our results. One alternative mechanism is the interaction of differential trade timing and changing oil prices: If mechanisms such as risk aversion or liquidity constraints lead individuals to sell their leases earlier than firms do, then low rates of drilling for leases won by firms may be explained by their delayed trade coupled with falling oil prices. We find that such trade timing mechanisms on their own are unlikely to drive our results: Firms delayed their trade relative to individuals at similar probabilities and lengths for both leases close to and far from existing production, but only for leases close to production do we find that those won by firms were less likely to be drilled than those won by individuals (see Table 3). We also show that our results are robust to controlling for oil prices (Online Appendix Section B.6). However, mechanisms that lead individuals to trade earlier may have interacted with the information asymmetry mechanism of an informed buyer: Online Appendix Section A.3 presents a model combining one trade timing mechanism (liquidity constraints) with a buyer's private information. Here, leases won by individuals have a higher probability of trade, earlier trade, and potentially a higher probability of drilling.

Differences in the composition of types is also unlikely to explain our results. For example, suppose that leases won by experienced winners are more likely to be drilled than those won by inexperienced winners, ceteris paribus. If individuals who win leases close to existing production tend to be more experienced than individuals who win other leases, and if firms who win leases close to existing production tend to be less experienced than firms who win other leases, then the drilling differentials we observe for leases close to production could be explained by how type composition changes with proximity to existing production. Online Appendix Section B.5 conducts an exercise that incorporates estimates of how more and less experienced individuals and firms differ in their probability of drilling as well as in their probability of entering leases close to existing production. We show that accounting for type differences does not explain our empirical findings.

Another potential mechanism that seems unlikely to drive our results is overly optimistic and uninformed individuals drilling excessively because they believed that drilling was more profitable than it actually was. Rather, we find that the vast majority of leases won by individuals and drilled were traded before they were drilled (see Online Appendix Table B.16). Even if we only count leases won by individuals as drilled if they were also traded, we still find that leases won by individuals have higher probability of drilling than leases won by firms. This implies that our results are not driven by individuals overoptimistically drilling on their own (see Online Appendix Table B.17.)

Finally, common pools are also unlikely to explain our findings for leases close to existing production. With common pools, incentives to drill are higher when adjoining parcels are not owned by the same agent because common pools lead to a race to drill and extract (Libecap and Wiggins, 1984; Chermak, Crafton, Norquist, and Patrick, 1999; Libecap and Smith, 2001; Lin, 2009). Because individuals are more likely than firms to sell to the nearby producing firm, a common pool incentive would predict a lower probability of lease drilling when the lease is won by an individual. Therefore, if common pools are present, our estimates would be a lower bound on what the drilling probability differential would be in the absence of common pools.

7 Conclusion

Using a lottery with randomized assignment, this article examines how initial assignment of a lease to an individual versus a firm affects trade, drilling, and production outcomes. We find that secondary market trade is more common and happens earlier if the initial lessee is an individual, consistent with the existence of active secondary markets. Among those leases that were far from existing production, those won by individuals have similar drilling and production outcomes as those won by firms.

However, for leases that were close to existing production, those won by individuals had higher probability of drilling than those won by firms. This finding is consistent with a model of information asymmetry where a nearby producing firm has private information about the value of the lease. Individuals with lower outside options were more likely to overcome these information asymmetry frictions than firms were, resulting in a higher probability of asset utilization. These effects are economically significant, with leases won by individuals approximately twice as likely to be drilled as leases won by firms.

This article uses a novel setting to examine a fundamental question in economics: How effectively do markets correct for misallocation? We show that in common value settings like oil where the buyer has private information, a higher seller value can have an adverse effect not only on trade but also on asset utilization.

	Full Sample		Restricted Sample	
	mean	st.dev.	mean	st.dev.
Number of entries	598.09	824.27	427.32	644.99
Area (sq. miles)	1.11	1.09	0.97	1.05
Number of firms among winners	0.19	0.42	1.00	0.00
Firm is first place winner	0.06	0.25	0.34	0.48
Nearby production indicator	0.22	0.42	0.21	0.41
Any reassignment within 5 years	0.64	0.48	0.51	0.50
Any reassignment within 12 years	0.75	0.43	0.66	0.47
Any reassignment to firm within 5 years	0.49	0.50	0.40	0.49
Any reassignment to firm within 12 years	0.64	0.48	0.56	0.50
Total trades within 5 years	1.35	1.73	1.03	1.44
Total trades within 12 years	2.28	2.83	1.81	2.37
Total trades to firms within 5 years	0.79	1.13	0.63	0.99
Total trades to firms within 12 years	1.54	2.16	1.26	1.84
Log time to first reassignment	6.16	1.09	6.39	1.13
Log time to first reassignment to a firm	6.48	1.09	6.67	1.11
Any drilling within 5 years	0.04	0.20	0.03	0.18
Any drilling within 12 years	0.08	0.28	0.07	0.26
Any production within 5 years	0.02	0.12	0.01	0.11
Any production within 12 years	0.03	0.18	0.03	0.17

Table 1: Summary statistics at the lease level. The first two columns describe the entire sample (10,762 leases). The second two columns describe the restricted sample where the first-, second-, and third-place winners consisted of one firm and two individuals (1,800 leases).

	Parcels won by: Individuals	Firms	Difference (p-value)
Number of Entries Mean	430.99	420.33	0.74
Number of Entries Variance	647.17	641.28	0.80
Acreage Mean	628.33	610.32	0.59
Acreage Variance	676.40	663.68	0.59
Nearby Production Mean	0.20	0.23	0.19
Nearby Production Variance	0.40	0.42	0.19

Table 2: Comparison of summary statistics for individuals and firms using the restricted sample where the first-, second-, and third-place winners consisted of one firm and two individuals. Statistics for parcels won by individuals are reported in Column (1), while Column (2) reports those won by firms. Column (3) reports the p-value from an equality test.

	(1)	(2)	(3)	(4)
	Reassign Probability		Log Time to Reassign	
Firm Winner (β_1)	-0.223***	-0.213***	0.642***	0.641***
	(0.027)	(0.025)	(0.077)	(0.064)
Nearby Production Flag (β_2)	0.024	0.017	0.020	-0.039
	(0.038)	(0.014)	(0.106)	(0.048)
Firm/Nearby Prod Interaction (β_3)	-0.053	-0.054	0.069	0.126
	(0.067)	(0.056)	(0.175)	(0.130)
Number of Entries & Acreage Controls	Yes	Yes	Yes	Yes
Month of Lottery Fixed Effects	Yes	Yes	Yes	Yes
R squared	0.157	0.131	0.161	0.115
$E(Y_i \mid F_i = 0, NearbyProd_i{=}0)$	0.736	0.762	6.210	6.137
Observations	1800	10762	1200	8120

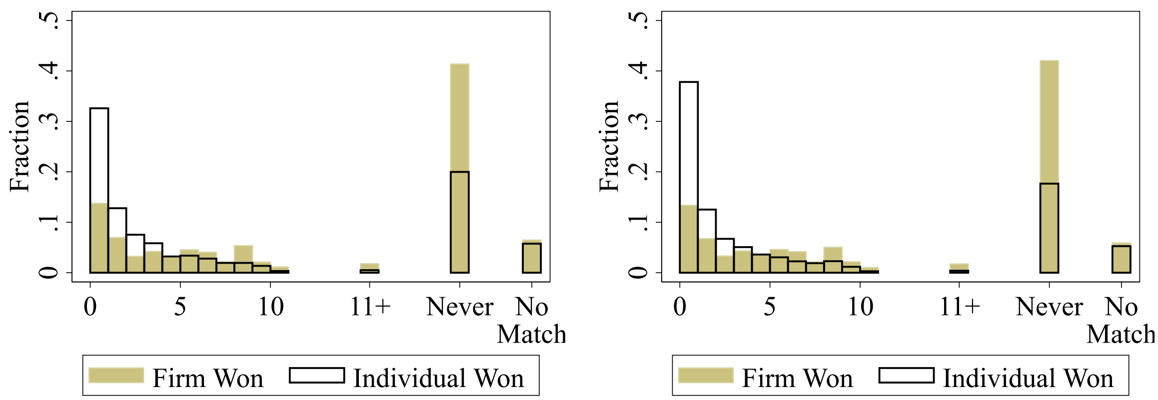
Table 3: This table's dependent variables are the probability of reassignment by twelve years (Columns 1 & 2) and the log length of time to reassignment, conditional on lease reassignment happening (Columns 3 & 4). Columns (1) & (3) use the restricted sample, while Columns (2) & (4) use the full sample. Nearby production is a binary indicator for any production within 2.6 miles of the section(s) the lease is located on. In this table and the remainder of the article, the symbols *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels respectively. Columns (3) and (4) do not correct for selection into reassignment. Point estimates using a Heckman two-step are similar.

	(1)	(2)	(3)	(4)
	Trade with Nearby Producing Firm			
Firm Winner	-0.025	-0.005	-0.019	0.015
	(0.027)	(0.019)	(0.048)	(0.034)
Nearby Production Flag	0.030	0.036***	0.039	0.040***
	(0.026)	(0.009)	(0.034)	(0.011)
Firm/Nearby Prod Interaction	-0.052	-0.075***	-0.060	-0.093**
	(0.040)	(0.026)	(0.064)	(0.046)
Full Sample	No	Yes	No	Yes
Conditional on Trade	No	No	Yes	Yes
Number of Entries & Acreage Controls	Yes	Yes	Yes	Yes
Month of Lottery Fixed Effects	Yes	Yes	Yes	Yes
R squared	0.114	0.047	0.135	0.044
$E(Y_i \mid F_i = 0, NearbyProd_i{=}0)$	0.078	0.077	0.101	0.095
p-value: $\beta_1 + \beta_3 = 0$	0.012	0.000	0.078	0.010
p-value: $\beta_2 + \beta_3 = 0$	0.448	0.113	0.698	0.240
Observations	819	5043	550	3965

Table 4: This table's dependent variable is whether a lease was reassigned to a firm that has nearby production. Columns (1) and (3) use uses our restricted sample and Column (2) and (4) use the full sample. Sample is limited to observations within 5.2 miles of existing production. Columns (3) and (4) condition on trade being observed. We allow matched reassignments to happen at any point during the lease.

	(1)	(2)	(3)	(4)
	Drilling Probability		Production Probability	
Firm Winner	0.014	0.011	-0.000	-0.000
	(0.013)	(0.011)	(0.007)	(0.005)
Nearby Production Flag	0.136***	0.111***	0.074***	0.058***
	(0.026)	(0.026)	(0.020)	(0.011)
Firm/Nearby Prod Interaction	-0.106***	-0.083***	-0.043*	-0.029
	(0.031)	(0.026)	(0.024)	(0.018)
Number of Entries & Acreage Controls	Yes	Yes	Yes	Yes
Month of Lottery Fixed Effects	Yes	Yes	Yes	Yes
R squared	0.114	0.078	0.086	0.061
$E(Y_i \mid F_i = 0, NearbyProd_i{=}0)$	0.046	0.060	0.017	0.022
p-value: $\beta_1 + \beta_3 = 0$	0.001	0.001	0.070	0.085
Observations	1800	10762	1800	10762

Table 5: This table's dependent variables are the probability of drilling by twelve years (Columns 1 & 2), and the probability of production by twelve years (Columns 3 & 4). Columns (1) & (3) use our restricted sample, while Columns (2) & (4) use the full sample. Nearby production is a binary indicator for any production within 2.6 miles of the section(s) the lease is located on.

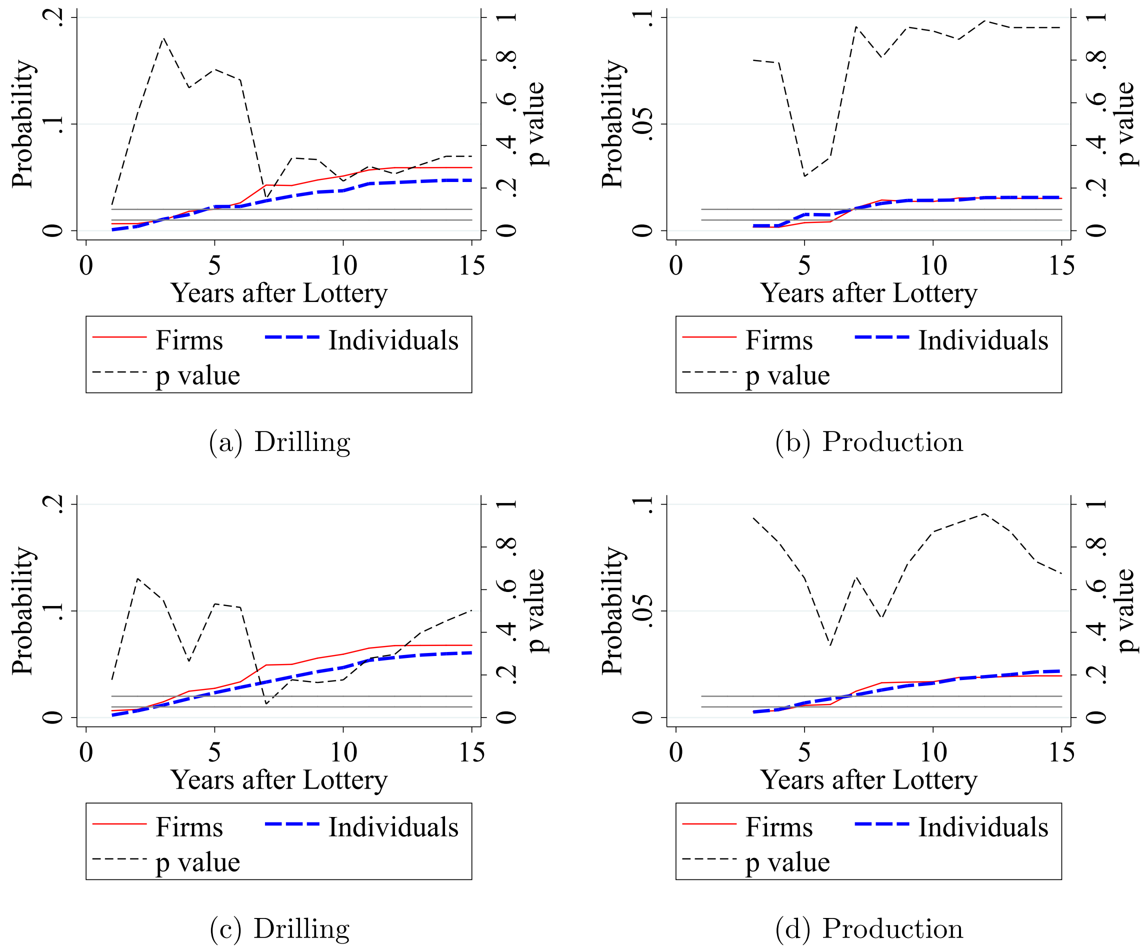


(a) Restricted Sample

(b) Full Sample

Figure 1: Histogram of the amount of time, in years, until a lease is transferred. The left panel is limited to leases where exactly one firm appeared among the first-, second-, and third-place winners. The right panel displays the full sample. Individuals are in black outlines and firms are in green. Leases that do not have a recorded transfer are in the "Never" category, while leases that could not be linked to the LR2000 data are in the "No Match" category.

Drilling and Production Results: Leases without Nearby Production



(a) Drilling

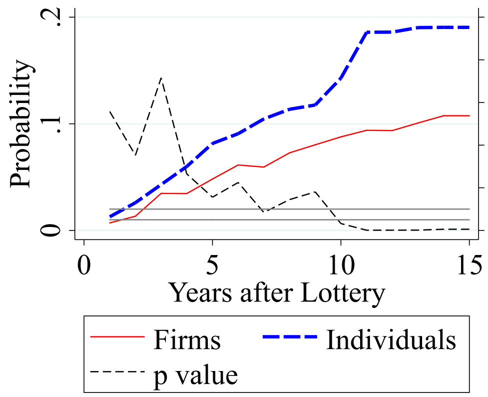
(b) Production

(c) Drilling

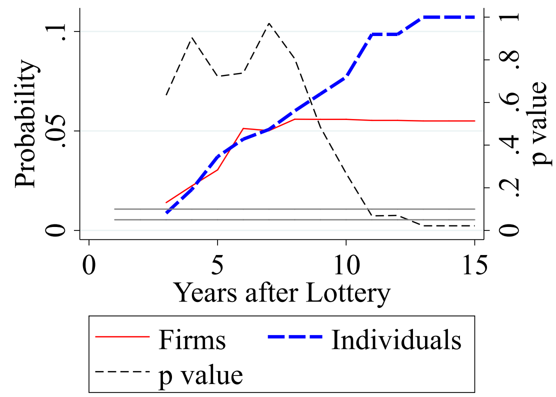
(d) Production

Figure 2: Leases far from existing production, comparing those won by individuals and those won by firms. Panels (a) and (b) use the restricted sample with one firm winner. Panels (c) and (d) use the full sample and control for endogenous entry using observables. Probabilities for leases won by individuals are $E(Y_i|F_i = 0, NearbyProd_i = 0)$; predicted probabilities for leases won by firms are $E(Y_i|F_i = 0, NearbyProd_i = 0) + \hat{\beta}_1$. The right vertical axis gives the p value of a test that the two means are not equal. The two horizontal lines indicate p values of 0.05 and 0.10.

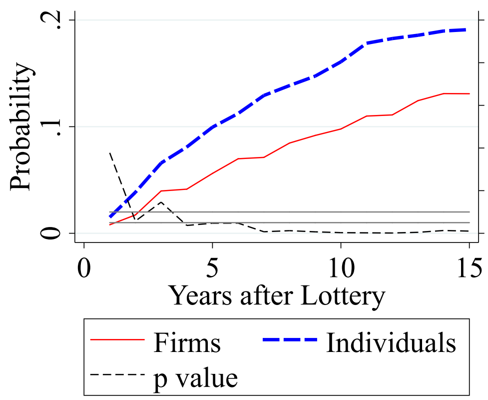
Restricted Sample Results: Leases with Nearby Production



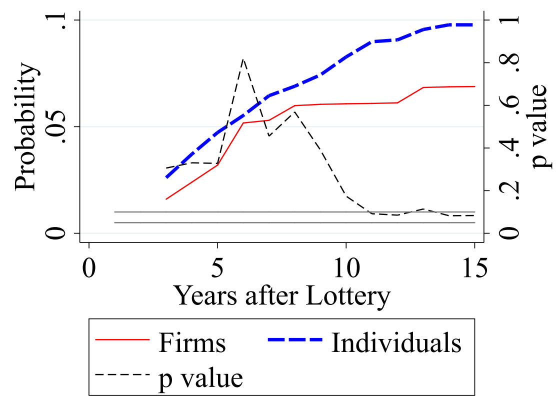
(a) Drilling



(b) Production



(c) Drilling



(d) Production

Figure 3: Leases close to existing production, comparing those won by individuals and those won by firms. Panels (a) and (b) use the restricted sample with one firm winner. In those panels, probabilities for leases won by individuals are $E(Y_i|F_i = 0, NearbyProd_i = 0)$; predicted probabilities for leases won by firms are $E(Y_i|F_i = 0, NearbyProd_i = 0) + \hat{\beta}_1$. Panels (c) and (d) use the full sample and control for endogenous entry using observables. In those panels, probabilities for leases won by individuals are $E(Y_i|F_i = 0, NearbyProd_i = 0) + \hat{\beta}_2$; predicted probabilities for leases won by firms are $E(Y_i|F_i = 0, NearbyProd_i = 0) + \hat{\beta}_1 + \hat{\beta}_2 + \hat{\beta}_3$. The right vertical axis gives the p value of a test that the two probabilities are not equal. The two horizontal lines indicate p values of 0.05 and 0.10.

Appendix A

In this section, we provide a graphical illustration of the model in Section 3 as well as formal proofs.

Graphical Illustration

Figure A.1 provides a graphical illustration of the informed buyer model in Section 3 under the specific distributional assumption that $\theta \sim U(0,1)$, illustrating how the probabilities of trade and drilling change with the initial lessee's drilling cost C_j and with the buyer drilling cost C_B. Panel (a) graphs the probability that trade happens, while panel (b) graphs the probability that drilling happens.

Panel (a) shows that the probability of trade is increasing in the initial lessee's drilling cost and decreasing in the buyer's drilling cost: For cases where $C_j \in (C_B, C_B + 0.5)$, the probability of trade lies between zero and one, whereas if $C_j \geq C_B + 0.5$ then the probability of trade is one and if $C_j \leq C_B$, the probability of trade is zero. Panel (b) shows a similar pattern for drilling. The one difference between panels (a) and (b) is that (b) also has an additional yellow triangle in the lower left which denotes the set of buyer and seller drilling cost values for which the seller will drill even if it does not receive an offer.

Shifts in the vertical direction show the comparative statics of how changing seller drilling cost changes expected outcomes, holding buyer drilling cost constant. Panel (b) shows that when seller drilling cost is sufficiently low (i.e., in that lower left yellow triangle), drilling happens regardless of whether there is an offer, and so a small increase in seller drilling cost will have no effect on the probability of drilling. However, for the range of seller drilling costs that are above the yellow triangle, an increase in seller drilling cost leads to an increase in the probability of drilling.

[Figure A.1 approximately here]

Formal treatment

We first discuss the comparative statics of how seller drilling cost affects the probability of trade, and then how it affects the probability of drilling. We make minimal assumptions about the distribution of θ, only assuming that $E(\theta|\theta \geq X)$ is continuous in X for all values X between the minimum and the maximum of the support of the pdf $f(\theta)$.

Recall that the buyer will either make an offer ($O_j = O_j^*$), where the size of the offer O_j^* will in equilibrium depend on seller j's cost C_j, or can make no offer ($O_j = \varnothing$). The probability that an offer is made will also depend, in equilibrium, on seller j's cost C_j.

Here we more formally define the offer O_j^* to account for cases where there are more than one potential value of X that sets $\max\{E(\theta|\theta \geq C_B + X) - C_j, 0\} = X$: First define the function $g(X, C_j)$ such that for an initial winner of cost C_j, $g(X, C_j) = 0$ implies that the initial winner's individual rationality constraint for accepting an offer is satisfied with equality:

$$g(X, C_j) = \max\{E(\theta|\theta \geq C_B + X) - C_j, 0\} - X \tag{2}$$

Then we can define $O_j^* \equiv O^*(C_j)$ more formally as:

$$O^*(C_j) = \min_{X \in \mathbb{R}} X \quad \text{s.t.} \quad g(X, C_j) = 0 \tag{3}$$

In other words, the offer that the buyer makes is the lowest possible value of X that satisfies the seller's individual rationality constraint with equality, meaning that the seller is indifferent between accepting the offer and rejecting the offer. If there are multiple values of X that satisfy this equation, the buyer will choose the smallest one because anything larger means the buyer is leaving money on the table.

If there is no value of X that sets $g(X, C_j) = 0$, then no offer would ever be made ($O^*(C_j) = \varnothing$).

Lemma 1. *$g(X, C_j)$ is continuous in X and C_j*

Proof. This follows from the continuity of $E(\theta|\theta \geq X)$ and the continuity of the max function. □

Lemma 2. *$g(0, C_j) \geq 0$. $g(X, C_j) > 0$ for all $X < 0$.*

Proof. Because of the max function, $g(X, C_j) \geq -X$. □

This lemma in turn implies that $O_j^* \geq 0$. This is intuitive: The initial winner's outside option includes the possibility of abandoning the lease. It would not be individually rational for the initial winner to accept an offer less than zero.

Lemma 3. *If $C_F < C_I$, then $g(X, C_I) \leq g(X, C_F)$ for all X in the support of $f(\cdot)$.*

Proof.

$$
\begin{aligned}
g(X, C_I) &\equiv \max\{E(\theta|\theta \geq C_B + X) - C_i, 0\} - X && (4)\\
&= \max\{E(\theta|\theta \geq C_B + X) - C_F - (C_I - C_F), 0\} - X && (5)\\
&\leq \max\{E(\theta|\theta \geq C_B + X) - C_F, 0\} - X && (6)\\
&\equiv g(X, C_F) && (7)
\end{aligned}
$$

□

Theorem 4. *If $C_F < C_I$ and if both $O^*(C_F)$ and $O^*(C_I)$ exist, then $O^*(C_F) \geq O^*(C_I)$.*

Proof. Proof by contradiction. Instead assume that $O^*(C_F) < O^*(C_I)$. Then by Lemma 3:

$$g(O^*(C_F), C_F) = 0 \geq g(O^*(C_F), C_I) \tag{8}$$

By Lemma 2, we know that $g(0, C_I) \geq 0$. Then by Lemma 1 and the intermediate value theorem, there must be at least one value $\bar{X} \in [0, O^*(C_F)]$ such that $g(\bar{X}, C_I) = 0$. Therefore, by the definition of O^*:

$$O^*(C_I) \leq \bar{X} \leq O^*(C_F) \tag{9}$$

which is a contradiction of the assumption that $O^*(C_F) < O^*(C_I)$. □

Theorem 5. *It may be the case that $O^*(C_I)$ exists while $O^*(C_F)$ does not exist, but if $O^*(C_F)$ exists, then $O^*(C_I)$ also exists.*

In other words, it may be the case that under some distributions of θ that the buyer would never be willing to make an offer, even for an arbitrarily high value of θ. However, if there is a value of θ sufficiently high that the buyer would make an offer to a firm, then there is a value of θ sufficiently high where the buyer would be willing to make an offer to an individual.

Proof. We first show that there is at least one distribution for which the individual could receive an offer while the firm does not receive an offer. Consider the exponential distribution, where if $\theta \sim$ exponential(λ), then:

$$E(\theta | \theta \geq X) = \frac{1}{\lambda} + X \tag{10}$$

Assuming an exponential distribution, we can write f as:

$$g(X, C_j) = \max\left\{\frac{1}{\lambda} + C_B + X - C_j, 0\right\} - X \tag{11}$$

It is clear that if $1/\lambda + C_B - C_j > 0$, then $g(X, C_j)$ is positive for all weakly positive values of X and therefore there will be no offer made.

If $1/\lambda + C_B - C_I \leq 0 < 1/\lambda + C_B - C_F$, then the individual may receive an offer but the firm will not. Here the only offer that the individual could receive is $O^*(C_I) = 0$.

The intuition of the exponential distribution is that the right tail is thick enough such that a one dollar increase in an offer also increases the seller's expected value of the lease by one dollar. As long as the seller's drilling cost is sufficiently low, the buyer can never make an offer sufficiently high for the seller to accept because any increase in offer leads to an equivalent increase in the seller's outside option.

For the second half, we show if $O^*(C_F)$ exists, then $O^*(C_I)$ also exists. This is essentially a corollary of Theorem 4: By Lemma 3, it must be that $g(O^*(C_F), C_I) \leq g(O^*(C_F), C_F) = 0$. By Lemma 2, we know that $g(0, C_I) \geq 0$. Then by Lemma 1 and by the intermediate value theorem, there must be at least one $\bar{X} \in [0, O^*(C_F)]$ where $g(\bar{X}, C_I) = 0$. Therefore, $O^*(C_I)$ exists.

$\square$

How will changes in seller drilling cost C_j affect the probability of production? The comparative statics will depend not only on the probability of trade but also on the probability of drilling in the event of no trade – e.g., whether $E(\theta|\theta < O^*(C_j) + C_B) - C_j$ is positive.

To show formally why seller drilling cost has an ambiguous effect on the probability of drilling, we focus on the range of seller drilling cost values C_j for which $O^*(C_j)$ is defined (e.g., there is a sufficiently high realization of θ such that the buyer would be willing to make an offer.)

The fact that $O^*(C_j)$ is weakly decreasing in C_j and that $E(\theta|\theta < Y)$ is increasing in Y implies that the profits from drilling in the event of not receiving an offer $(E(\theta|\theta < O^*(C_j) + C_B) - C_j)$ are decreasing in cost C_j. Therefore, there is some threshold value $\tilde{C}$ such that for a lease winner with drilling cost $\tilde{C}$ that does not receive an offer, the lease winner will be indifferent between drilling and not drilling.

$\tilde{C}$ is implicitly defined by the following equation:

$$E(\theta|\theta < O^*(\tilde{C}) + C_B) - \tilde{C} = 0 \tag{12}$$

For all values of $C_j < \tilde{C}$, the initial lease winner will drill if it does not receive an offer. For all values of $C_j > \tilde{C}$, the initial lease winner will not drill if it does not receive an offer.

This then allows us to examine the effect of seller drilling cost on the probability of drilling. If $C_F < \tilde{C} < C_I$, then a shift from C_F to C_I will lead to a decrease in the probability of drilling: At a cost of C_F there will be drilling regardless of trade because the seller will drill if it doesn't receive an offer, whereas at a cost of C_I there will only be drilling if there is also trade. In contrast, if $\tilde{C} < C_F < C_I$, then shifting from a seller drilling cost C_F to C_I will lead to an increase in the probability of drilling because it increases the probability of trade and because (for this range of cost values) drilling only happens if there is trade. Finally, if $C_F < C_I < \tilde{C}$, then a shift in seller driller cost C_F to C_I will have no effect on the probability of drilling because for all $C_j < \tilde{C}$, drilling happens regardless of whether there is trade.

Appendix B

This appendix includes additional information on the data and empirical analysis.

Data Sources and Identification of Firms and Individuals

Lottery records were scanned from paper records at the BLM office in Laramie, Wyoming. Paper records included information on what parcels would be offered in the lottery, including detailed survey information on the location of the parcels.[19]

[19] Online Appendix Figure B.1 presents a sample record.

Paper records also contain information on the first-, second-, and third-place winners as well as the total number of entries for a lottery. The first place winner has information both on name as well as address; the second- and third-place winners only have names. This data were publicly available from the Wyoming BLM.[20] Data were double-blind entered using a data digitization service and are guaranteed to be 99.95% accurate.

We identify firms by looking for words such as "Co.", "Corp.", "Corporation", "Inc.", "Ltd.", "Limited", "Associates", "Oil", "Gas", and "Industries" in the name of the winner. We also include as firms those that are obviously firms but not easily categorized from this rule (e.g. "Michigan Wisconsin Pipe Line").

We list first-place individuals as individuals rather than firms even if their address information suggests that they are associated with a firm (e.g., John Doe, Acme Co., Acme Wyoming 80000) We do this for two reasons. First, if these individuals had appeared as second- or third-place winners, we would not observe the address/firm information, and we would categorize them as individuals. Second, we cannot determine whether these individuals were entering the lottery on behalf of the firm or merely using the firm as a personal address. To the extent that this is an issue, our analysis will misclassify some firms as individuals. The Online Appendix (Section B.5) discusses results related to individuals who have similar addresses to firms. Because our dependent variable is binary, such errors will attenuate our coefficients towards zero.

We use BLM LR2000 records to find information on the lease buyer's identity. However, limitations of the LR2000 data make it difficult to perfectly identify buyers and therefore to construct measures of buyer types. These limitations include the fact that about 11% of lease buyer records in the LR2000 were blank or illegible, and that buyer names were often listed in an abbreviated manner.

[20] The University of Michigan IRB panel ruled that this data is not regulated.

In the Online Appendix (Table B.13 and Figure B.3) we examine the probability and timing of first trade to any firm. The above caveats imply that our measure of trade to any firm will have measurement error, and in particular understate the true extent to which leases were reassigned to firms.

Using the Restricted Sample to Ensure Exogeneity

Given the random draw, the probability that the lease is treated by being won by a firm is $N_F/(N_F + N_I)$, where N_F is the number of entries submitted by firms and N_I is the number of entries submitted by individuals. Because both N_F and N_I are potentially correlated with both observables and unobservables, whether a lease is won by a firm is also potentially correlated with both observables and unobservables.

Denote all parcels where the first-, second-, and third-place winners consisted of exactly one firm and two individuals (i.e., the restricted sample) as the set S. Conditional on a parcel being in S, there are three mutually exclusive possibilities: The list of first- through third-place winners is either firm-individual-individual (S_1), individual-firm-individual (S_2), or individual-individual-firm (S_3). The probabilities that the lease is in each of these three sets (S_1, S_2, S_3) are all functions of N_F and N_I.[21] The randomness of the lottery ensures that all three probabilities are equal ($p(S_1) = p(S_2) = p(S_3)$). Therefore, the probability that the first-place winner of a lease is a firm, conditional on the lease being in the set S, is:

$$p(S_1|S) = \frac{p(S_1)}{p(S)} = \frac{p(S_1)}{p(S_1) + p(S_2) + p(S_3)} = \frac{1}{3} \tag{13}$$

Thus, conditional on S, the probability that the lease is won by a firm is fixed at 1/3 and is therefore orthogonal to both observables and unobservables.

[21] For example, $p(S_1) = p(W_1 \in F) \cdot p(W_2 \in I|W_1 \in F) \cdot p(W_3 \in I|W_1 \in F, W_2 \in I) = (N_F/N)(N_I/(N-1))((N_I-1)/(N-2))$, where I is the set of individual entries for the lease, F is the set of firm entries for the lease, W_j is the jth winner, and $N \equiv N_F + N_I$.

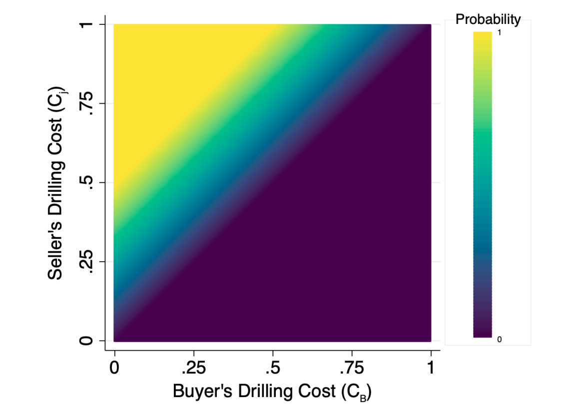
This same logic holds if we condition on any pre-existing lease characteristic such as proximity to nearby production. Because within the restricted sample the probability of assignment to a firm is exogenous and orthogonal, the interaction of the treatment F_i with any pre-existing lease characteristic identifies the treatment effect conditional on that lease characteristic. Therefore in Equation 1, $\beta_1 = E(Y|\text{winner is a firm, far from production}) - E(Y|\text{winner is an individual, far from production})$ and $\beta_1 + \beta_3 = E(Y|\text{winner is a firm, near production}) - E(Y|\text{winner is an individual, near production})$. Both β_1 and $\beta_1 + \beta_3$ have causal interpretations that are specific to leases that are far from existing production and leases that are close to existing production, respectively.

Evidence of Endogenous Entry

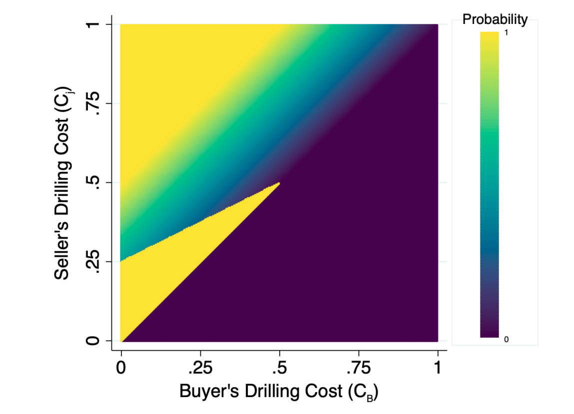
Table B.1 presents evidence of endogenous entry: Whether the winner is a firm and the total number of firms that appear is negatively correlated with the total number of entrants and the acreage of the lease. Table B.2 shows these correlation tables when limited to the restricted sample. There we find that whether the winner is a firm is not meaningfully correlated with acreage nor total number of entrants.

[Table B.1 approximately here]

[Table B.2 approximately here]



(a) Trade



(b) Drilling

Figure A.1: These figures show the probability of trade (panel a) and probability of drilling (panel b) for the informed buyer model of Section 3 under the assumption that $\theta \sim U(0, 1)$.

	1	2	3	4	5	6	7
1: Number of entries	1.00						
2: Area	0.41	1.00					
	(0.00)						
3: Reassign within 12 years	0.21	0.09	1.00				
	(0.00)	(0.00)					
4: Drill within 12 years	0.20	0.08	0.10	1.00			
	(0.00)	(0.00)	(0.00)				
5: Produce within 12 years	0.17	0.02	0.07	0.63	1.00		
	(0.00)	(0.01)	(0.00)	(0.00)			
6: Number of firms that win	-0.10	-0.06	-0.10	-0.03	-0.02	1.00	
	(0.00)	(0.00)	(0.00)	(0.01)	(0.08)		
7: First-place winner is firm	-0.06	-0.04	-0.15	-0.02	-0.02	0.58	1.00
	(0.00)	(0.00)	(0.00)	(0.10)	(0.08)	(0.00)	

Table B.1: Correlations between selected variables for each observation using the full sample. Each parentheses reports the p value of a test where the null hypothesis is that the true correlation is zero.

	1	2	3	4	5	6	7
1: Number of entries	1.00						
2: Area	0.40	1.00					
	(0.00)						
3: Reassign within 12 years	0.20	0.10	1.00				
	(0.00)	(0.00)					
4: Drill within 12 years	0.20	0.09	0.11	1.00			
	(0.00)	(0.00)	(0.00)				
5: Produce within 12 years	0.17	0.03	0.06	0.63	1.00		
	(0.00)	(0.27)	(0.01)	(0.00)			
6: Number of firms that win	.	.	.	.	.	.	
	.	.	.	.	.		
7: First-place winner is firm	-0.01	-0.01	-0.23	-0.00	-0.02	.	1.00
	(0.74)	(0.59)	(0.00)	(1.00)	(0.51)	.	

Table B.2: Correlations between selected variables for each observation using the restricted sample. Each parentheses reports the p value of a test where the null hypothesis is that the true correlation is zero.

References

Akee, R. (2009). Checkerboards and Coase: The effect of property institutions on efficiency in housing markets. *Journal of Law and Economics 52*, 395–410.

Akerlof, G. A. (1970). The market for "lemons": Quality uncertainty and the market mechanism. *The Quarterly Journal of Economics 84*, 488–500.

Angrist, J. D. and J.-S. Pischke (2008). *Mostly Harmless Econometrics: An Empiricist's Companion*. New Jersey: Princeton University Press.

Ausubel, L. M., P. Cramton, and R. J. Deneckere (2002). Bargaining with incomplete information. In R. J. Aumann and S. Hart (Eds.), *Handbook of Game Theory, Vol 3*, Chapter 50, pp. 1897–1945. Amsterdam: North-Holland.

Biewick, L. R. (2011). Geodatabase of wyoming statewide oil and gas drilling activity to 2010. U.S. Geological Survey Data Series 625.

Bleakley, H. and J. Ferrie (2014). Land openings on the Georgia frontier and the Coase theorem in the short- and long-run. `http://www-personal.umich.edu/~hoytb/Bleakley_Ferrie_Farmsize.pdf`.

Bureau of Land Management (1983). *The Federal Simultaneous Oil and Gas Leasing System: Important Information about The "Government Oil and Gas Lottery"*. Bureau of Land Management.

Chermak, J. M., J. Crafton, S. M. Norquist, and R. H. Patrick (1999). A hybrid economic–engineering model for natural gas production. *Energy Economics 21*(1), 67–94.

Coase, R. H. (1960). The problem of social cost. *The Journal of Law and Economics 3*, 1–44.

Coates, J. (1985). U.S. oil-lease lottery target of fraud probe. *Chicago*

Tribune. http://articles.chicagotribune.com/1985-05-05/news/8501270705_1_leases-lottery-interior-department.

Compiani, G., P. Haile, and M. Sant'Anna (2020). Common values, unobserved heterogeneity, and endogenous entry in u.s. offshore oil lease auctions. *Journal of Political Economy 128*, 3872–3912.

Conley, T. G. (1999). GMM estimation with cross sectional dependence. *Journal of econometrics 92*(1), 1–45.

Covert, T. R. (2015). Experiential and social learning in firms: The case of hydraulic fracturing in the Bakken shale. Working Paper.

Covert, T. R. and R. L. Sweeney (2019). Relinquishing riches: Auctions vs. informal negotiations in texas oil and gas. Working Paper 25712, NBER.

Deneckere, R. and M.-Y. Liang (2006). Bargaining with interdependent values. *Econometrica 74*(5), 1309–1364.

Fairfax, S. K. and C. E. Yale (1987). *Federal Lands: A Guide to Planning, Management, and State Revenues*. Washington, D.C.: Island Press.

Hendricks, K. and R. H. Porter (1988). An empirical study of an auction with asymmetric information. *The American Economic Review 78*, 865–863.

Hendricks, K. and R. H. Porter (1996). The timing and incidence of exploratory drilling on offshore wildcat tracts. *The American Economic Review 86*(3), 388–407.

Hodgson, C. (2018). Information externalities, free riding, and optimal exploration in the UK oil industry. Working Paper.

Lewis, E. (2019). Patchwork policies, spillovers, and the search for oil and gas. *American Economic Journal: Economic Policy 11*(1), 380–405.

Libecap, G. D. and J. L. Smith (2001). Regulatory remedies to the common pool: The limits to oil field unitization. *The Energy Journal 22*(1), 1–26.

Libecap, G. D. and S. N. Wiggins (1984). Contractual responses to the common pool: Prorationing of crude oil production. *The American Economic Review 74*(1), 87–98.

Lin, C.-Y. C. (2009). Estimating strategic interactions in petroleum exploration. *Energy Economics 31*(4), 586–594.

Lin, C.-Y. C. (2013). Strategic decision-making with information and extraction externalities: A structural model of the multistage investment timing game in offshore petroleum production. *Review of Economics and Statistics 95*(5), 1601–1621.

McKie, J. W. (1960). Market structure and uncertainty in oil and gas exploration. *The Quarterly Journal of Economics 74*(4), 543–571.

Myerson, R. B. (1985). Analysis of two bargaining problems with incomplete mechanisms. In A. E. Roth (Ed.), *Game Theoretic Models of Bargaining*, Chapter 7, pp. 115–147. Cambridge: Cambridge University Press.

Myerson, R. B. and M. A. Satterthwaite (1983). Efficient mechanisms for bilateral trading. *Journal of Economic Theory 29*, 265–281.

Porter, R. H. (1995). The role of information in U.S. offshore oil and gas lease auctions. *Econometrica 63*(1), 1–27.

Samuelson, W. (1984). Bargaining under asymmetric information. *Econometrica 52*(4), 995–1005.

Samuelson, W. (1985). A comment on the Coase theorem. In A. E. Roth (Ed.), *Game Theoretic Models of Bargaining*, Chapter 15, pp. 321–339. Cambridge: Cambridge University Press.

Schweinzer, P. (2010). Sequential bargaining with common values. *Journal of Mathematical Economics 46*, 109–121.

Vissing, A. (2017). One-to-many matching with complementary preferences: An empirical study of market concentration in natural gas leasing. Working Paper.