Essays on the Economics of the Natural Gas Leasing Market

by

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Dissertation submitted in partial fulfillment of the requirements for the degree of
Doctor of Philosophy in the Department of Economics
in the Graduate School of Duke University
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Abstract

Natural gas extraction is a prevalent and growing source of energy supply in the United States and around the world, and the focus of my research is understanding the natural gas leasing market that allows firms to amass rights to the mineral estate from which they extract natural gas. In Texas, a major source of natural gas resources, the mineral rights are privately owned, and firms must negotiate with private landowners for the rights to drill for and extract those minerals. The negotiated leases are legally binding contracts that restrict firm behavior during the drilling and production phases of natural gas well development. The leases that firms and landowners sign are critical in protecting them against exposure to health risks and the other negative features of drilling activity (noise, disruption, etc.). The research presented quantifies the value of these leasing contracts and models the leasing market between firms and landowners bilaterally negotiating the contents of the leases. The first piece studies a mechanism that models how firms negotiate with individual landowners and identifies the observable characteristics driving their decision-making, both where to sign a lease and with which landowner. The second piece captures the value of more protective leasing contracts for the landowners using a property value hedonic method. The third piece explores whether the leasing quality is equitably distributed across all types of households living in Tarrant County Texas, my area of study. Below I detail the the methods and questions addressed by each chapter individually.

As a consequence of technological innovation in the oil and natural gas industry over the last 20 years, firms have increased access to oil and natural gas reserves trapped in tight-shale formations. New wells are now drilled in more densely populated regions. In the first chapter, the lease negotiations between firms and landowners are modeled as a two-sided, one-to-many matching model where firms' preferences over sets of parcels are complementary. With this model, I study the direct and indirect effects of firms' geographic market concentrations. Firms value concentration directly because it shortens the time between leasing mineral rights and profiting from natural gas sales. Lease concentration also has an indirect effect: firms with higher concentrations are able to sign less costly leases, suggesting that concentration leads to market power. I use the estimated model to analyze the effects of changes in the market structure and policies that restrict the quality of leases signed. I am able to predict the effects of these policies on firms' and landowners' values of negotiating, and the changes in the spatial distributions of leasing behavior. I find that homogeneous and high quality leases increase landowners' values, while the effect for firms is ambiguous, and overall, fewer leases are signed when all leases are restricted to be homogeneous.

Royalty payments are a potential source of benefit to homeowners, and contractual restrictions on firms' drilling and production activities that are negotiated in leases are an important tool by which the industry is regulated. This chapter demonstrates how the value of lease clauses to homeowners can be recovered from the hedonic price gradient in the market for split-estate houses. Additionally, we show how split-estate status can be recovered from lease records and transaction data using string matching techniques. However, we note that the distribution of split-estate house prices is truncated, which may engender selection bias. We show how the dual-gradient hedonic model can be used to recover an expression for the willingness-to-pay for lease clauses using the full-estate housing market. Combining data describing both the full and split housing markets overcomes any potential selection problems and yields consistent estimates of the willingness-to-pay for lease clauses. Our hedonic results provide a measure of the benefits to homeowners from the regulations negotiated in leases and suggest that factors affecting the outcomes of lease negotiations will have pecuniary impacts on homeowners. Further, we use our willingness-to-pay measures to construct an index of lease clause quality that is used to test an environmental justice hypothesis: are there significant differences in lease quality across race groups after conditioning upon income and other observable factors.

Finally, the third chapter explores factors driving the tract-level, heterogeneity in lease quality for mineral rights owners transferring their mineral rights to natural gas firms for the purpose of drilling and extracting natural gas. The data consists of tract-level aggregates of lease terms, our measures of lease quality, and tract-level census data from leasing. We find that greater lease quality is negatively correlated with higher concentrations of minority households when controlling for tract-level characteristics. Based on our findings, we propose policies reducing the observed heterogeneity in lease quality, and subsequently, reduce exposure to the negative effects of living nearby active well sites.

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Acknowledgements

Thank you to my advisor, Christopher Timmins, for his guidance, support, and encouragement. Thank you also to my committee members, James Roberts, Curtis Taylor, Modibo Sidibe, and Richard Newell. Thank you to the participants at the Duke University Industrial Organization Lunch seminar for thoughtful comments and suggestions regarding my research.

Thank you also to Tom Milldrige at Duke Computing and Ryke Longest at Duke Law School for their helpful discussion and advice. Thank you to personnel at the Texas Railroad Commission and the Tarrant County Appraiser Office for guidance in collecting the well and housing/parcel data. Thank you to Sergio Correia for a great introduction to Python and web-scraping techniques used to collect the primary source of leasing data.

Finally, thank you for the long standing love and support from my friends and family.

1

One-to-Many Matching with Complementary Preferences: An Empirical Study of Natural Gas Lease Quality and Market Power

1.1 Introduction

This paper studies the privately negotiated leases that restrict firm behavior as they are drilling wells and extracting natural gas. I am interested in understanding how firms decide where and with whom to sign those leases with varying levels of firm restrictions. I do so by analyzing the determinants of the lease payoffs using a one-to-many matching model with a match externality and novel data describing the lease negotiations in Tarrant County Texas, my area of study. In my data, I find empirical evidence that firms directly and indirectly value signing leases that are geographically concentrated, or firms' leasing market shares. The direct effect stems from firms lowering their coordination costs required to begin profiting from natural gas sales, and indirectly, with more concentrated leases, firms are able to negotiate fewer concessions for landowners thereby lowering their marginal costs to extract natural gas from the mineral estate. To quantify the empirical effects of firms' market shares, I build a two-sided model of the lease negotiations as a one-to-many matching model with a match externality whereby a firm in my data may have complementary preferences for sets of leases. The model captures the bilateral negotiations between firms and landowners by estimating the effect of the endogenously determined market share and separate preferences for firms and landowners negotiating in the leasing market. I use the estimated model to answer the following questions: first, what are the observable determinants of matches between firms and landowners and the subsequently negotiated lease quality. Second, I explore how the market for leases responds to policies restricting lease quality or to changes in the market structure.

Natural gas leases are legal documents negotiated and signed between landowners and firms that temporarily transfer the mineral rights to the firms to explore for and extract natural gas. Drilling firms must own the rights to all of the subsurface mineral acreage from which they extract natural gas, and in densely populated neighborhoods, full ownership translates to hundreds of lease negotiations with private landowners. Leases are composed of legal restrictions that guide firm practices as they drill and produce oil or natural gas from a well that is extracting from the landowners' mineral estates. They are the primary legal defense for landowners protecting themselves from drilling disamenities, which include excessive noise, surface damage, and traffic, among other legal and environmental risks.[1] The ability to negotiate added lease clauses guards against disruptive behavior associated with well development for up to 30 years.

Of primary interest is modeling the direct effect of firms' "economies of leasing"

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[1] During the period of study, Texas was a "home rule" state that allowed local municipalities to regulate through ordinances that did not supersede state-level regulations. Municipalities had actively responded to increased urban drilling by passing local ordinances that restricted industry behavior, though not uniformly. As of spring, 2015, House Bill 40 negates local ordinances unless commercially reasonable calling restrictive regulations into legal question. `https://stateimpact.npr.org/texas/2015/07/02/after-hb-40-whats-next-for-local-drilling-bans-in-texas/`

on the negotiated outcomes. Firms value their own market concentration directly because having leases signed across densely spaced parcels reduce the time and effort required to apply for a permit to begin extracting and profiting from natural gas sales. For instance, it is often the case that several firms sign leases in a single market and so must coordinate with one another in order to apply for permits to begin drilling.[2] I capture the direct effect of concentration on the lease negotiations by modeling concentration as a match externality in a one-to-many match between firms and landowners. Because of this externality, the firm's value of a particular match reflect the entire assignment of matches across Tarrant County through the additional benefits afforded to firms that are able to lease parcels in highly concentrated areas.

The matching model affords estimation in the presence of firms' competition for leases, bilateral decision-making across pairs of firms and landowners, and a multi-dimensional bargaining outcome. First, participants have unobserved or endogenous choice sets, whereby their ability to match with their most preferred partners depends on the preferences and actions of all market participants. From the perspective of firms, leases signed by their competitors change the choice of landowners (or parcels) available to them. Second, leases are bilaterally negotiated between firms and landowners. Both sides of the market can form different sets of acceptable pairings, rejecting those partners that do not satisfy their own individual rationality constraints. Additionally, each side of the market has heterogeneous preferences over the feasible firm and landowner pairings, and these differing preferences are captured by the model.[3] Third, the model is structured to estimate preferences for

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[2] There are several unidentifiable scenarios in the data. A single firm may buy all of the necessary leases from the competing firms or all firms coordinate as royalty interest holders (or entities profiting in proportion to their ownership stake) while a single firm becomes the operator.

[3] The ability to estimate separate preferences for firms and landowners is achieved by assuming the model has non-transferable utility, or that I estimate the model with two exogenously given utility functions that dictate firms' and landowners' preferences.

the observable pecuniary and non-pecuniary attributes of lease.[4]

When market structure enters negotiation values as a match externality, parcels of sub-surface minerals may be complementary in firms' preferences. This relationship is especially important for parcels that would otherwise be low-valued but are located near to high-value parcels. If the complementarity between parcels is sufficiently strong to compensate for the negative attributes of a particular parcel, then the firm's preference for the aforementioned parcel will depend on the firm's ability to lease a large share of parcels located nearby. In general, complementary preferences generate instability in areas where firms are competing for a small share of leases that are only valuable when leased in conjunction with other nearby parcels. Intuitively, one can imagine that leases located on the periphery of the future extraction location are not initially valued very highly by firms. However, a firm taking the dominant share in that market would eventually value that property enough to extend an offer to the landowner because they would need the marginal property to apply for the permit to drill. This is pertinent to the natural gas industry because the state regulator requires that firms amass a large, contiguous acreage before applying for a permit to drill a well.

To my knowledge, this paper is the first in the empirical matching literature to estimate a one-to-many, non-transferable utility matching model with a match externality that may induce complementary preferences for firms signing sets of leases. The effect of the concentration externality is estimated using a myopic estimation function approach that assumes firms have boundedly rational beliefs following the empirical work of Uetake and Watanabe (2013) and Baccara et al. (2012). The other empirical details draw from one-to-many matches estimated by Agarwal (2014) and

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[4] The current analysis does not capture trade-offs between a royalty rate (fraction of money owed to the landowner when the extracted natural gas is sold) and inclusion of specific legal and surface clauses. However, there is reduced form evidence that royalty rate and clause inclusion are positively correlated. Intuitively, a lease preferable to landowners in pecuniary terms is also preferable in non-pecuniary.

Boyd et al. (2013).

In addition to capturing the direct effect of "economies of leasing," the analysis identifies a market power relationship between concentration and lease quality, where firms sign less costly leases in markets where they own a large share of the leases.[5] I empirically motivate the market power relationship using ordinary and two-staged least squares methods.

With the matching model, I conduct counterfactual analyses and measure the resulting changes to the market structure and negotiation values when firms are no longer allowed to exercise market power in the leasing market. Uniform leasing is a regulatory tool suggested in the policy and law literature that requires firms to sign homogeneous leases. The counterfactual requires firms to sign uniform leases of medium and high costs (those leases with the greatest number of landowner concessions). Under uniform leasing, my model predicts that fewer leases are signed, market concentration decreases, and landowners' negotiation values increase by a large amount. Firms' negotiation values change ambiguously, whereby some firm types benefit and others do not, and on average, the change is insignificant. The exercise demonstrates that uniform leasing that requires more landowner concessions benefit landowners without a high cost to firms.

The natural gas leasing market is an ideal setting to apply this model because the firms' leasing concentrations are an important and endogenous factor in their strategic leasing decisions. The Barnett Shale, partially underlying Tarrant County, is an active area of natural gas development, requiring large-scale hydraulic fracturing extraction techniques. It is also home to much of the recent technological development in the industry. In addition to accessing natural gas trapped in shale,

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[5] Beginning with the cross-industry analyses of Bain (1951) and Bain (1956), industrial organization literature has studied the effects of market power on industry outcomes. More recent, industry-specific studies, such as Porter (1983), Bresnahan (1987), and Nevo (2001), have expanded the empirical study of market power.

technological development freed firms to extract gas from beneath more densely populated areas, like portions of Tarrant County that include the city of Fort Worth. As a consequence, firms sign a greater number of leases to drill wells located nearer to residential areas as compared to more traditional drilling practices that are restricted to more rural areas. The data describe outcomes of negotiations occurring in both rural and urban regions of the county between 2003 and 2013. The data include characteristics describing firms, landowners, and the parcels of land negotiated, along with descriptions of the leasing documents signed between pairs of firms and landowners. When I map the data to my model, I define lease quality using the following attributes: royalty rates, or the fraction of future gas sales owed to landowners when the well begins producing, one-time bonus payments,[6] and specific clauses written into the leases restricting aspects of the drilling process.

I contribute to the existing literature along three dimensions. First, I gather a novel and unique data set. Second, I use that data set to estimate a one-to-many match model with an externality and assuming non-transferable utility. Third, I contribute to the literature that studies the environmental impact of shale gas by modeling the private lease negotiations between and firms and landowners.

In particular, this paper estimates a model assuming non-transferable utility.[7,8,9] The origin of this literature in economics dates to Gale and Shapley (1962) who proved that the deferred acceptance algorithm finds a stable equilibrium. Roth and

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[6] Very few leases report bonus payments; however, imputed bonuses from the small sample are used in some of my analyses. They are described in greater detail in the data section (5).

[7] The empirical matching literature is primarily composed of two strands: the transferable and non-transferable utility models. Chiappori and Salanie (2014) survey how these empirical strands differ with a particular focus on the one-to-one match setting.

[8] There are important developments in the transferable utility models including econometrics work by Jeremy Fox in Fox (2008) and Fox and Yang (2012). Further, Fox and Bajari (2013) estimate a transferable utility model with complementary preferences.

[9] In large market settings where the two sides of the market not imbalanced, Lee and Yariv (2014) find that very little efficiency is lost from the stable solution that assumes no transfers as compared to the solution with transfers in a one-to-one match.

Sotomayor (1992)[10] offers a canonical review of the two-sided matching literature's evolution, which is vast in both theoretical development and real-world application including the mechanism matching residents to hospitals after medical school,[11] students to public schools,[12] and teachers to schools.[13]

Topically, this paper adds to the growing literature in environmental economics concerned with shale gas development. Among those papers targeted to the effects of leasing, Holmes et al. (2015) models the sequence of decisions as firms lease mineral acreage and vie to operate the well. Porter (1995), Fitzgerald (2010), and Lewis (2015) study land auctions in areas where the mineral rights are owned by state and federal governments while Libecap and Wiggins (1985) document the ineffectiveness of unitization leasing agreements between firms. Timmins and Vissing (2015) study the heterogeneous distribution of protective leases across households using an environmental justice argument. A growing contribution from the housing price hedonics literature identifies risks incurred by households living near to shale gas development (Muehlenbachs et al. (2015); Gopalakrishnan and Klaiber (2014); James and James (2014a); Boxall et al. (2005); Hill (2013)). Several researchers have documented different aspects of firms learning through drilling activity (Levitt (2009); Kellogg (2011); Covert (2014)). This is among the first papers quantifying the quality of the privately negotiated natural gas leases and modeling the private negotiations

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[10] Roth (2008) is an update to the non-transferable utility matching literature.

[11] A version of the deferred acceptance algorithm is currently applied to the matching of residents to hospitals as doctors finish medical school, first proposed by Alvin Roth in a series of papers written throughout the mid to late 80's (Roth (1982) and Roth (1984a), and Roth and Peranson (1999), among many others). Agarwal (2014) matches residents to hospitals imposing vertical preferences on one side of the market to study salary determination in resident-to-hospital matches.

[12] Researchers have adapted and applied the model to match to students to public schools as in Abdulkadiroğlu and Sonmez (2003), Abdulkadiroğlu et al. (2005a), and Abdulkadiroğlu et al. (2005b), among others.

[13] Boyd et al. (2013) models teachers matching to schools to capture the heterogeneous preferences of both sides of the market (teachers preferences for schools and visa versa), an exercise that produced more intuitive results than those achieved using more standard methods.

between firms and landowners in the natural gas industry.

Section 2 describes the institutional details, which are followed by the exposition of the estimated lease negotiation model in section 3 and estimation strategy in section 4. The data are described in section 5 and estimates of the reduced form models are reported in section 6. Section 7 reports the estimates of the one-to-many matching model, section 8 describes a counter-factual analysis using the estimated models, and section 9 concludes.

1.2 Institutional Details

1.2.1 Hydraulic fracturing

It is reported that the supply of shale gas to total US natural gas production jumped from 1.6 percent in 2000 to 23.1 percent by 2010 with increasing projections (Richardson et al. (2013)). Technological innovation in the oil and natural gas industry has increased access to reserves trapped in tight-shale formations like the Barnett Shale underlying Tarrant County, Texas. The combination of large-scale hydraulic fracturing,[14] horizontal drilling techniques, and more precise 3-D seismic surveying techniques have unleashed access to otherwise unattainable resources with increased efficiency. The Barnett Shale formation is home to some of the first commercially viable wells drilled as a consequence of these integrated technologies – wells dating to the early 1990's when Mitchell, a pioneer applying hydraulic fracturing techniques to the commercial extraction of natural gas, was supported by a subsidy from the federal government to drill and hydraulically fracture horizontal wells.

Hydraulic fracturing involves injecting fluids[15] at high pressures into the drilled well such that the rock cracks and produces artificial fissures throughout the strata.

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[14] Hydraulic fracturing has been in active use since the 1950s, and before the formal process developed, oil well operators used other artificial forms of stimulation to extract oil and gas (Zeik (2009)).

[15] Potential fracturing fluids include water, diesel oil, nitrogen foam, water with acid.

The fracturing fluid contains proppants, like quartz sand grains, that keep the fissures open well after the fracturing fluid has returned to the wellhead once the pressure is released. Horizontal drilling techniques with laterals measuring roughly 3000 to 5000 feet ensure that large quantities of shale are exposed to the artificial stimulation generated by hydraulic fracturing while boring fewer holes to drill wells (Zeik (2009); King (2011)). Further, the fracturing stages can take place iteratively over the life of the well or all at once, allowing the firm more freedom to pace natural gas extraction with other operation decisions or market conditions.

1.2.2 Regulatory Structure

The oil and natural gas industry is regulated at federal, state, and local levels of government although regulation has historically been done mostly by the states. The state of Texas has a long history of conventional well development reaching back to 1866 when the first well was drilled in Nacogdoches County, Texas.[16] The oil and natural gas industry in Texas is regulated by the Texas Railroad Commission (TRC), an organization established in 1891 to regulate the rail industry. Beginning in 1917, their regulatory scope expanded to oversee additional industries related to oil and natural gas. The TRC has jurisdiction over the "exploration, production, and transportation of oil and gas prior to refining or end use,"[17] and they exercise their jurisdiction by enforcing rules written in Chapter 3 of the Texas Administrative Code (2015b).

States, the entity with the most authority over the industry, regulate well location and spacing, drilling methods and requirements, plugging and disposal methods, and site restoration (Richardson et al. (2013)). The federal government protects air and surface water quality, and endangered species. Since 2012, the Environmen-

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[16] `http://texasalmanac.com/topics/business/history-oil-discoveries-texas.`

[17] Natural Resources Code (2015a) Section 91.101-.1011

tal Protection Agency requires that wells use “green completion” techniques that lower VOC emissions (Agency (2011)). Municipalities may exercise jurisdiction over industry operations by passing local ordinances, as well.

The lease phase is largely unregulated with the exception of rules regarding how royalty rates are set and paid out to interest holders over the life of the well. The TRC requires royalty rates of at least one eighth of the gross production of gas (Natural Resources Code (2015a), Sec. 32.1072). In addition, there are rules that establish payment windows during production and reporting requirements (Natural Resources Code (2015a), Sec. 91.401).

The negotiated leases can serve landowners as supplementary regulatory mechanisms, protecting their property and aesthetics, and mitigating their exposure to negative externalities during the drilling and production phases of well development. Supplementation is necessary because the TRC does not regulate aspects of the drilling process like excessive noise and traffic, and legal aspects of mineral ownership and transference, use of certain equipment (e.g. compression stations). They do not require pre- water and soil testing,[18] and they have more lax proximity restrictions.[19] While there are some local ordinances targeted to these issues, the rules are heterogeneous across space and do not protect all landowners.

The fact that disruptive aspects of drilling and production are not rigorously regulated is problematic for landowners transferring their mineral rights to firms because the mineral estate dominates. A dominant mineral estate bestows the following interests including the right to develop the mineral estate (ingress and egress); to lease; and to receive bonus payments, delay rentals and royalty payments (Vanham and Riley (2011)). A signed natural gas lease temporarily transfers the mineral rights to

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[18] In other states, firms require pre-drilling water testing of sources located within a distance buffer of the proposed well.

[19] In Texas, the set-back 200 feet but there is no restriction for proximity to water sources

third parties, and they have access to as much land as is necessary to explore and drill; they may remove trees and fences to make way for well and equipment, and the wellpad itself can take up to one acre of land; and they may erect pipelines to transport the natural gas off the property (Rahm (2011)). Additionally, the mineral estate owner may use water from the leased land to carry out operations[20] (given that the use is not wasteful) and inject waste water into sub-surface formations.[21,22]

Further, the mineral estate owner is not responsible for full restoration of the property,[23] nor are they required to pay surface damages as long as the damage is not unreasonable. Activities identified as reasonable include constructing roads to access the well and buildings, locating the access point at the lessee's discretion (within the bounds of any local, state or federal regulation), and accessing the fresh water source of the surface estate for exploitation and any secondary recovery methods (although underground fresh water is owned under the surface estate[24]). Conversely, excessive road building, use of leaking equipment, and use of unauthorized parts of the property to conduct operations are considered unreasonable.

In some instances, the estates are severed, or the mineral and surface estates are owned by different individuals. Severed estates are common in the state of Texas,[25] and a severed estate limits the ability of surface estate owners to protect themselves through a negotiated lease. By the dominance of the mineral estate, firms are only required to negotiate with the mineral estate owner, and as a consequence, a surface

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[20] The mineral estate is able to use as much surface as is reasonably necessary to access the mineral estate by *Warren Petroleum Corp. v. Martin,* 271 S.W.2d 410 (Tex. 1954)

[21] Unless specified in the deed, the water rights fall to the surface owner but they are accessible with reasonable use by the mineral estate (Vanham and Riley (2011)).

[22] Water withdraw is permitted for surface water but not groundwater, and the party owning the mineral rights has access to both sources for their operations, in the case of well development that uses hydraulic fracturing techniques.

[23] *Warren Petroleum Corp. v. Monzingo,* 304 S.W.2d 362 (Tex. 1957)

[24] *Sun Oil Co. v. Whitaker,* 483 S.W.2d 808 (Tex. 1972)

[25] *Benge v. Scharbauer,* (259 S.W.2d 166 (Tex. 1953).

estate owner may have even less protection when the mineral rights are leased to extract natural gas. This potentially amplifies the issues experienced by the surface estate owner.[26] This issue is not directly addressed in the current analysis, but should be considered when framing leases as supplemental to absent regulation since the effectiveness may be diminished for properties with severed estates.[27]

There are means for landowners to protect their property and limit their exposure to negative drilling externalities that include existing statutes like the *Accommodation Doctrine* and negotiating stricter leases with firms prior to commenced drilling. Since 1993, surface estate owners can use the *Accommodation Doctrine* to ensure that new drilling activity does not interfere with the existing surface estate uses given that there exists an alternative means for the mineral estate owner to pursue development.[28] Surface damage clauses can be designed to restrict firms' activities throughout the life of the well or impose more comprehensive clean-up and restoration standards once production has ceased. The Appendix C.2 lists and describes other potential lease clauses that can be negotiated into the contracts.

Much of the legal literature is focused on potential state and federal regulations to curb the environmental risks incurred by the increased prevalence of unconventional well development techniques like hydraulic fracturing (Olmstead and Richardson (2014); Konschnik and Boling (2014)). Some literature consults industry experts about their perceived priorities for regulation (Krupnick and Gordon (2015)), while Richardson et al. (2013) extensively explores the existing state of heterogeneous regulatory standards across states.

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[26] Industry people have indicated that even if a surface damage clause is not required by state law, firms will sign them to protect themselves in the future.

[27] Joint work with Christopher Timmins uses the split estates that are most confidently identified in the data, and this is an area for future expansion of the negotiation model.

[28] First addressed in *Getty Oil Co. v. Jones,*470 S.W.2d 618, 621 (Tex. 1971) and later substantiated and formalized in *Tarrant County Water Control & Improvement Dist. No. 1 v. Haupt, Inc.,* 854 S.W.2d 909, 911 (Tex. 1993), (Merrill and Merrill (2013a)).

1.3 Matching Model

In the natural gas leasing market, firms negotiate with many landowners to sign sets of leases that temporarily relinquish the mineral estates to firms for natural gas exploration and extraction. I model the observed, negotiated outcomes as a one-to-many matching between firms and landowners spread across Tarrant County, Texas. The matches are determined by firms' and landowners' negotiation values, which include pecuniary and non-pecuniary attributes specific to each potential pairing, and the relative preferences between all participating firms and landowners. Firms' spatial concentration is determined endogenously in the model, and to capture firms' values for "economies of leasing," spatial concentration enters firms' negotiation values as a match externality. Match externalities exist when the negotiation values of one or both sides of the market reflect the assignment in the market, not just the value derived from the individual pairings. In the model, firms value signing closely spaced leases, or "economies of leasing," since (nearly) contiguous acreage allows firms to more easily and quickly apply for a permit to begin drilling and extracting natural gas.

The model assumes that the observed match between firms and landowners is an equilibrium in the lease market where firms extend offers to landowners, and the assignment is simulated through the deferred acceptance algorithm. A simulated match between firms and landowners forms a pairwise stable equilibrium if it satisfies agents' individual rationality constraints and a no blocking condition. In a market where agents' preferences are not restricted, there may be multiple equilibria or none. In the lease setting, adding a concentration externality to negotiation values may result in complex preferences, thereby compromising the existence of a stable equilibrium. In the one-to-many matching framework, the theoretical literature proves equilibrium existence when preferences for individual parcels are substitutable; however, in a finite setting, complementarity across parcels may generate an instability. I use theory describing the equilibrium outcomes of a one-to-many match with complementary preferences in a large market setting to justify the estimation of the lease model.

In the next subsection, a simple model of firms matching to landowners describes the different types of firm preferences, and how the firm preferences are complicated by the presence of the concentration externality. The subsequent subsections describe the specific components of the negotiation values underlying firm and landowner preferences, the equilibrium concept, and the estimation and identification strategies.

1.3.1 Simple Model

Estimating the one-to-many matching between firms and landowners is complicated by modeling the concentration externality because the term induces complementarity between sets of parcels located in the same market (from the firm's perspective). This section describes how complementarity is induced in a simple framework describing the lease match between two firms and three landowners. Additionally, it addresses issues specific to the one-to-many match setting where firms have preferences over both singleton and sets of leases.

For any given market, there can be more than one active firm, and I begin by assuming that there is only one market with two active firms, XTO and Chesapeake, signing leases with three landowners denoted as $\{x_1, x_2, x_3\}$. For simplicity, assume that all three leases are signed by one of the two firms, and the firm and landowner preferences for signing leases are strict. XTO signs two leases while Chesapeake signs one, and the firm and landowner preference relations over singleton leases follow.

$$\text{XTO} : x_1 \succ x_2 \succ x_3$$

$$\text{Chesapeake} : x_1 \succ x_3 \succ x_2$$

$$x_1 : \text{XTO} \succ \text{Chesapeake}$$
$$x_2 : \text{Chesapeake} \succ \text{XTO}$$
$$x_3 : \text{XTO} \succ \text{Chesapeake}$$

Because XTO signs more than one lease, preferences are well-defined when the firms' preferences over sets of leases is specified. Matches are defined by $\mu(x)$ that maps the preferences of firms and landowners to the sets of feasible assignments between the two sides of the market. The simplest and most intuitive preference relation over sets of leases is responsiveness.

Definition:[29] For an assignment $\mu(F)$ and a preference relation $P^{\#}(F)$ over sets of leases and $P(F)$ over singletons, a firm's preference relation for sets of leases is *responsive* if, for $\mu'(F) = \mu(F) \cup \{x\} \backslash \{x'\}$ where $x' \in \mu(F)$ and $x \notin \mu(F)$, then the firm prefers $\mu'(F)$ to $\mu(F)$ if and only if F prefers x to x'.

When preferences are responsive, XTO's ranking over sets of preferences follows naturally from the ranking over singleton leases as demonstrated below where XTO values the pair $\{x_1, x_2\}$ over $\{x_1, x_3\}$ since $x_2 \succ x_3$.

$$\text{XTO} : \{x_1, x_2\} \succ \{x_1, x_3\} \succ \{x_2, x_3\}$$

In addition to responsiveness, preferences can take on more complex representations like substitutability and complementarity across available parcels. Responsiveness is a special case of substitutability, which is intuitively the case when a firm prefers a lease even when other available leases become unavailable.

Definition:[30] For a firm with preferences over the sets of leases, X containing x and x', and choices, $Ch(X)$, the preferences are *substitutable* if $x \in Ch(X)$, then $x \in Ch(X \backslash x')$.

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[29] Adapted from Roth and Sotomayor (1992)

[30] Adapted from Roth and Sotomayor (1992)

Roth and Sotomayor (1992) show that the set of stable matches is non-empty when firms' preferences are substitutable, and their proof uses the deferred acceptance algorithm to find a stable equilibrium. In the model presented and assuming that firms extend offers to landowners, deferred acceptance results in the following stable match: $\{\text{XTO}, x_1\}, \{\text{Chesapeake}, x_2\}, \{\text{XTO}, x_3\}$.[31,32]

The second type of complex preferences, complementarity, presents a challenge to finding an equilibrium in a finite setting. Complementary preferences are represented by the following change in preferences for firms and landowners (disregarding the third parcel, x_3).[33]

$$\text{XTO} : \{x_1, x_2\} \succ \varnothing$$
$$\text{Chesapeake} : x_1 \succ x_2 \succ \varnothing$$
$$x_1 : \text{XTO} \succ \text{Chesapeake}$$
$$x_2 : \text{Chesapeake} \succ \text{XTO}$$

In the example, if XTO signs leases with both parcels, it is blocked by a match between Chesapeake and x_2; however, if XTO does not sign any lease and x_1 is matched to Chesapeake, XTO can coalesce with both x_1 and x_2, leaving Chesapeake with no leases. This cycle repeats and creates an instability.

Using a more generalized notation, complementarity in the lease market occurs when the effect of share tips the total value of a parcel from negative to positive as in the following inequalities (1.1) where $N^{m,j}$ is the count of leases signed by firm j

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[31] Deferred acceptance with firms extending offers proceeds in the following sequence: 1. XTO offers leases to x_1 and x_2 while Chesapeake offers to x_1; 2. x_1 and x_2 hold the offers from XTO while x_1 rejects Chesapeake; 3. Chesapeake offers a lease to x_3; 4. x_3 holds the offer from Chesapeake; 5. because there are no more offers, all landowners accept their existing and most preferred offers.

[32] Kelso and Crawford (1982) prove that when preferences are substitutable and strict, the deferred acceptance algorithm finds the *firm-optimal* equilibrium when firms extend offers to landowners. Roth (1984b) shows that the reverse holds for the other side of the market, meaning the deferred acceptance algorithm finds the *landowner-optimal* equilibrium when landowners extend offers.

[33] The example is adapted from Che et al. (2014).

in market m, $N^{m,n}$ is the total count of leases available in market m of size n,[34] and $v_j(x_i)$ is the value of parcel i to firm j where $v_j(x_i) < 0$.

$$\begin{aligned} v_j(x_i) + \beta \frac{N^{m,j}}{N^{m,n}} &\geqslant 0 \quad \text{for } i \leqslant n \\ v_j(x_i) + \beta \frac{\tilde{N}^{m,j}}{N^{m,n}} &< 0 \text{ for } \tilde{N}^{m,j} < N^{m,j},\ i \leqslant n \end{aligned} \tag{1.1}$$

The first inequality suggests that a firm is willing to sign a lease with landowner x_i located in market m because the firm's concentration of leases in that market is large enough to compensate for the negative attributes of the property while the second inequality suggests that the concentration effect is not sufficient compensation. Intuitively, there may be leases with low acreage or that are located on the periphery, and when evaluated independently, the leases are not valuable to the firm. However, if that firm signs a large concentration of leases in that market, the value of the low attribute parcels increase because, in the lease setting, firms with large concentrations in a single market can move to the permitting and drilling phases more quickly and begin profiting from the natural gas sales.

The potential for jumps between non-compensating and compensating effects of concentration mimic the instability described in the simple model with complementary firm preferences. When preferences are complementary, an equilibrium may not exist in a finite, small market setting; however, theoretical results prove that an ϵ-stable equilibrium exists as the size of the market grows. The empirical model does not restrict negotiation values in a way that eliminates complementarity, and I use theoretical results to justify the estimated equilibrium in the presence of preference complementarity.

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[34] More simply, $\frac{N^{m,j}}{N^{m,n}}$ is the share of leases signed by firm j in market m with a market size of n.

1.3.2 Lease Model Set-up

In each geographic market, there are sets of active firms denoted by $j \in \mathcal{J} \equiv \{1, ...J\}$ and landowners denoted by $i \in \mathcal{N} \equiv \{1, ...N\}$, where each parcel i is unique in the data. Firms and landowners decide whether a feasible match is acceptable, and their preferences for matches are based on negotiation values: v_{ij} denotes firm j's negotiation value for parcel i, and u_{ij} denotes landowner i's value for a lease negotiated with firm j. The negotiation values are composed of pecuniary and non-pecuniary attributes of a specific firm and landowner leasing match. Each firm and landowner ranks their preferences over all acceptable matches. Given their preference rankings, the "competition" for matches begins and the firms sign leases with landowners based on the relative rankings of each participants' preferences for match partners. A successful match between a firm and landowner is characterized by pair signing a lease.

The negotiation values embed the value of the contract, or lease quality, offered to each landowner. The support of potential lease qualities available to firm j is denoted θ_{ij}, $\forall i \in \mathcal{N}$ and the outside option to not lease is denoted $\{o\}$. Implicitly, firms decide whether to lease and how many leases to sign over the full decision support, $\mathcal{D}_j$.

$$\mathcal{D}_j = \cup_{i \in \mathcal{N}} \{\theta_{ij}\} \cup \{o\}$$

Symmetric to firms, landowners[35] have the option to sign a lease with firm j when firm j extends an offer to them or opt out entirely. The landowner's decision support is denoted by $\mathcal{D}_i$.

$$\mathcal{D}_i = \cup_{j \in \mathcal{J}} \{\theta_{ij}\} \cup \{o\} \text{ for all } j \text{ offering leases to } i$$

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[35] I simplify the description by using "landowner" to refer to the mineral rights owner. In reality, distinguishing between the mineral rights owner and the surface estate owner is important when the estates are severed (two separate owners). However, I do not address this industry feature directly in the model and use landowner in a more general way.

The model assumes that a measure of spatial market concentration, $share_j^m$, is positively valued by firms, or rather, firms value "economies of leasing." Firms value signing leases in regions where they are able to accumulate a high concentration of densely spaced leases because it shortens the time and effort required to obtain a permit for drilling a well. Additionally, the reduced form findings suggest firms value concentration because they are able to offer and sign lower quality (and less costly) leases. The corollary in industrial organization is that firms are more likely to mark-up prices in markets where they have market power. In the lease setting, concentration is measured by the firms' shares of leases signed in a market, and $\theta_{ij}^{*} \neq 0$ denotes a signed lease by firm j and landowner i.

$$share_j^m = \frac{\sum_{i\in\mathcal{N}^m} \mathbb{1}_{\{\theta_{ij}^{*}\neq 0\}}}{\sum_{i\in\mathcal{N}^m, j\in\mathcal{J}^m} \mathbb{1}_{\{\theta_{ij}\neq 0\}}}$$

Each firm signs a set of leases, and in the data, we observe the number of leases signed by each firm in each geographic market, $\bar{q}_j^m$. Geographic markets are wellpad clusters, and they are defined in the data section. In the the model, $q_j^m \equiv \sum_{i\in\mathcal{N}^m} \mathbb{1}_{\{\theta_{ij}^{m*}\neq 0\}}$ is endogenously determined by firms offering leases to landowners based on their preference ranking and leases being accepted by landowners based on their preference ranking until there are no remaining offers to extend.

1.3.3 Negotiation Values

This section describes the negotiation value functions underlying the preference relations for firms and landowners participating in the leasing market, which are used to estimate the model.

Negotiation values are monetized using the expected revenue that comes from drilling a well, producing natural gas, and selling it at market prices. The royalty rates specified in the leases determine how future profits are split between firms and royalty interest-holders like the landowners granting access to their mineral estates. In addition to expected revenue, there are proxies for the cost of including additional lease clauses and non-pecuniary values that influence firms' rankings of one parcel over another. Important non-pecuniary variables include parcel size, proximity to a future wellpad location, and a measure of existing, nearby well activity.[36]

Lease quality is described by terms like royalty rate and inclusion of sub-sets of protective clauses. The reduced form evidence suggests that lease quality is negatively related to firms' market concentrations, and this relationship is captured in the matching model through the equations in (1.2). Separately, royalty rate and clause quality are determined as functions of observable parcel characteristics, X_i, firm characteristics, Z_j, and firm market concentration, $share_j^m$, and the parameter set $\Theta^{quality} = \{\alpha_1^{royal}, \alpha_2^{royal}, \alpha_3^{royal}, \alpha_1^{clause}, \alpha_2^{clause}, \alpha_3^{clause}\}$ is estimated prior to the matching model in presented specification and it controls for an endogenous share using an instrumental variable, the count of nearby producing wells prior to leasing.

$$\begin{aligned} \hat{\theta}_{ij}^{royal} &= \alpha_1^{royal} X_i + \alpha_2^{royal} Z_j + \alpha_3^{royal} share_j^m \\ \hat{\theta}_{ij}^{clause} &= \alpha_1^{clause} X_i + \alpha_2^{clause} Z_j + \alpha_3^{clause} share_j^m \end{aligned} \tag{1.2}$$

Firms maximize their negotiation values using equation (1.3), which includes the money metric capturing the expected revenues from drilling a well and extracting minerals from the lease, $\Lambda_{firm}(\hat{\theta}_{ij}^{royal})$,[37] a function of own, parcel, and market attributes, $f(Z_j, X_i; \delta)$, the firm's market concentration, $share_j^m$, and lease quality, which is treated as a cost to firms in equation (1.3).

$$v_{ij}(Z_j, X_i, share_j^m) = \Lambda_{firm}(\hat{\theta}_{ij}^{royal}) + f(Z_j, X_i; \delta) + \delta_1 share_j^m - \delta_2 \hat{\theta}_{ij}^{clause} + \eta_{ij} \tag{1.3}$$

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[36] The existing well activity represents the state of the world beginning in 2003, the year most the lease data begins.

[37] $\Lambda_{parcel}(\hat{\theta}_{ij}^{royal})$ enters the landowner's value of the lease, as well, but is calculated to capture the landowner's royalty share of future well production. The method to calculate this future flow value is described in the data section.

$f(Z_j, X_i; \delta)$ captures the observable characteristics of firms and landowners for each potential match. In the specifications presented, the effects of land area and proximity to the future wellpad locations are estimated in firms' negotiation values. Including a distance measure to a future wellpad location might be problematic if we assume it is endogenously determined. However, due to institutional factors and geographic limitations of leasing and drilling in urban regions, assuming wellpad location is exogenous is more reasonable. The TRC is tasked with maintaining proper well spacing, and in the case of Texas, subdivision developers assign empty parcels for potential drilling. Finally, the model controls for existing infrastructure located near to the negotiated lease at the time of the decision. These terms capture economies of scale realized by firms with wells already drilled in the surrounding area attributable to knowledge about the shale, institutional knowledge if the wellpad is located in a city with local ordinances specific to natural gas extraction, and potential cost sharing benefits across wellpads.

Landowners are observed signing at most one lease, and they maximize their negotiation values based on lease quality and other firm characteristics in equation (1.4).

$$u_{ij}(Z_j, X_i, share_j^m) = \Lambda_{parcel}(\hat{\theta}_{ij}^{royal}) + \gamma_1 X_j^m + \gamma_2 \hat{\theta}_{ij}^{clause} + \xi_{ij} \tag{1.4}$$

In the primary specification, the effect of observable characteristics estimated from landowners' negotiation functions include the firms' sizes as roughly proxied by the count of wells drilled as of 2003, when the lease data begins.

Each negotiation value function informs the preference rankings of firms for individual parcels and, conversely, the preference ranking of landowners for firms. Both negotiation value functions also include an unobserved "match-level" shock, η_{ij}^m and ξ_{ij}^m, that are assumed uncorrelated with observables, unobserved to the econometrician, and observed by firms and landowners. The unobservables represent attributes of the lease or negotiation known to firms and landowners, respectively, that make the lease, property, or negotiation more or less attractive to the two parties. For example, a landman might have an excellent sales pitch that results in a positive shock to the landowner's value of signing a lease. From the perspective of firms, the parcel may have an observably beneficial attribute not captured by the data, like a space for drilling a well that is unencumbered by trees.

The estimation method is based on taking different draws of unobservable attributes from standard normal distributions, calculating the firms' and landowners' negotiation values, establishing the two sets of rankings based on those negotiation values, and running the Gale-Shapley deferred acceptance algorithm where the firm extends offers to landowners to find a stable match. The determinants of stability in the presence of match externalities follow in the next section.

1.3.4 Pairwise Stable Outcomes

Based on the negotiation values, firms and landowners rank their preferences over all feasible (sets of) matches, and an equilibrium match between both sides of the market is found through the deferred acceptance algorithm. This section describes the equilibrium in a one-to-many match setting with an externality along with the results that characterize the equilibrium in the context of the model set-up.

The equilibrium concept identifying the model is pairwise stability. Pairwise stability is achieved when there does not exist two agents from each side of the market preferring to match with one another over their observed match. Since firms are matching with multiple landowners, the total value to firm j's matches is given by $V_j(\theta_j^*, share_j^{m*}) = \sum v_{ij}(\theta_{ij}^*, share_j^{m*})$, where $\theta_j^* \subset \mathcal{D}_j$ is the set of contracts offered by firm j and accepted by landowners, $share_j^{m*}$ is the estimated concentration for firm j in market m, and $\mathcal{D}_j$ is the set of all possible contract sets considered by firm j.

Definition: *Pairwise Stability* is defined in terms of firm utility, v_{ij}, and parcel utility, u_{ij}, for firm j and landowner i, and an estimated firm market concentration, $share_j^{m*}$.

1. *Individual rationality* :
   (a) Firms:
      i. $v_{ij}(\theta_{ij}^{*}, share_j^{m*}) \geqslant 0$ for all parcels i matching with firm j
      ii. $\nexists\, \tilde{\theta}_j \subset \mathcal{D}_j$ s.t. $V_j(\tilde{\theta}_j, share_j^{m*}) \geqslant V_j(\theta_j^{*}, share_j^{m*})$
   (b) Parcels: $u_{ij} \geqslant 0$.
2. *No blocking* : $\nexists\, j' \subset \mathcal{J}$ and $\nexists\, i' \subset \mathcal{N}$ such that
   (a) Firms: $V_{j'}(\theta_j^{*}\backslash\{i\} \cup \{i'\}, share_j^{m*}) \geqslant V_{j'}(\theta_j^{*}, share_j^{m*})$
   (b) Parcels: $u_{i'j'} \geqslant u_{i'j}$

The first individual rationality condition requires firms and landowners have positive negotiation values for each potential match in their acceptable sets. Firms have the added restriction that there not be another available set of contracts preferred to the matched set θ_j^{*} given the value of $share_j^{m*}$. The second no blocking condition states that there does not exist a firm, j', and landowner, i', pair preferring to match with each other over their observed matches. Since the model includes a positive externality, the stability condition must hold for the estimated assignment, $share_j^{m*}$.

A pairwise stable match is achieved through the application of the deferred acceptance algorithm. Gale and Shapley (1962) first showed that deferred acceptance finds a pairwise stable match in the one-to-one setting with strict preferences, and that the equilibrium is *offerer-optimal* (the offerer prefers the *offerer-optimal* equilibrium to any other feasible equilibrium). Kelso and Crawford (1982) later proved a similar finding in the one-to-many setting when preferences are strict and substitutable. Hatfield and Milgrom (2005) unified these frameworks using contracts in a one-to-many match and proved side-optimality.[38] In all cases, firms' preferences are assumed substitutable across available parcels; however, as described in the simple model, negotiation values modeling "economies of leasing" as a match externality may result in complementary preferences where equilibrium existence is less certain.

With the following theorems, I am addressing two theoretical issues when estimating a model with complex preferences for firms and heterogeneous preferences for both firms and landowners: existence and multiplicity of equilibrium. Under firms' complementary preferences, equilibria are more difficult to describe. Che et al. (2014) show that in a large market with a continuum of parcel types, an equilibrium exists, and when parcel types are finite, deferred acceptance converges to an ϵ-stable (approximate) equilibrium.[39,40] Their result does not characterize the equilibrium solution using side-optimality (for example, *offerer-optimal*). These results underly the equilibrium found in the present model, and the following paragraphs describe the application of these results in more detail.

Equilibrium, or stability, is achieved through the iterated application of an operator mapping the preferences of firms and landowners onto itself. Assume that $GS(\mathcal{N}, \mathcal{J}, share_j^{m*})$ is a function that maps a set of preferences onto itself ($GS : \mathcal{N} \text{ x } \mathcal{J} \rightarrow \mathcal{N} \text{ x } \mathcal{J}$) where $GS(\mathcal{N}, \mathcal{J}, share_j^{m*})$, and the mapping operator represents Gale-Shapley's deferred acceptance algorithm. In the presented model, the deferred acceptance algorithm is initiated with firms' sets of most preferred leases, and as each firm extends offers to landowners according to their preference rankings, landowners proceed to reject their least preferred offers until no firm offers remain.

Che et al. (2014) proves a fixed point in a continuum economy using Kakutani-

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[38] The theory of one-to-many matching with substitutable preferences has been studied broadly and thoroughly in the literature, and these are just a few, influential examples.

[39] Other matching theory addressing the properties of continuum economies include Azevedo and Leshno (2014) and Azevedo and Hatfield (2012).

[40] Other matching theory describing the effects of complementarity and peer effects include Pycia (2012); Echenique and Yenmez (2007).

Fan-Glicksberg fixed point theorem over a functional space. Application requires continuous preferences that guarantee a continuous operator, but it does not restrict preferences in a way that guarantees a monotone operator like in the one-to-many matching with substitutes literature.[41] Continuous firm preferences implies that preferences vary continuously as the set of available leases varies.

Definition: A firm's preferences are *continuous* if, for a sequence of preference orderings $(X_k)_{k\in\mathbb{N}}$ as $X_k \to X$, $Ch(X_k) \to Ch(X)$.

Because the result for a large and finite market stems from the continuum economy, the existence theorem requires notation for a sequence of economies indexed by q, $\mathcal{N}_q$, where as q goes to infinity, the finite economies converge to the continuum. Borrowing their notation, I define an ϵ-stable matching in the lease market.[42]

Definition: A matching $\mu(x)$ in an economy $\mathcal{N}_q$ is *ϵ-stable* if, for any firm j and matching μ'_j in the set of feasible matches in economy $\mathcal{N}_q$ that blocks μ, $v_j(\mu'_j) < v_j(\mu_j) + \epsilon$.

Their result in the continuum economy is used to justify an ϵ-stable approximate equilibrium in a large, finite market for leases as stated in the following theorem.

Theorem: *Che et al. (2014) (Thm. 7)* Fix any $\epsilon > 0$ and a sequence of parcel types $(\mathcal{N}^q)_q$ (economies) that converges to a continuum of types. For any sufficiently large q, there exists an ϵ-stable matching in $\mathcal{N}^q$.

As the number of parcel types increase, there exists an ϵ-stable matching that describes the increasingly small changes between outcomes with an instability under

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[41] In the matching with substitutes literature, Tarski's fixed point theorem can be used to prove existence since substitutable preferences form a complete lattice.

[42] I use the notation $\mathcal{N}_q$ to represent the sequence of finite economies to mimic the model notation. The largeness of the market stems from the large number of parcels matching to a smaller number firms.

complementary preferences. The ϵ-sized effects of the small instability become trivial as the market grows. In the small model example, the instability is large because XTO gets all or nothing. However, as the market for leases grows, the instability is generated on the margin where small changes in the number of leases signed by any given firm perpetuate the instability while the majority of firms' shares are stable.

This section characterizes the equilibrium used to point-identify a model that likely has multiple pairwise stable outcomes given the sets of firm and landowner preferences. By imposing that firms offer first, I estimate the model using a single equilibrium found using the deferred acceptance algorithm. The theorem presented characterizes the equilibrium in settings where firms' preferences may be complementary across available parcels. In lieu of finding a stable equilibrium, the theorem allows for ϵ-stability in a market where the marginal effects of instability grow increasingly trivial as the market size grows.

1.3.5 Assumptions

The model set-up and implementation rely on several assumptions or simplifications, and they are detailed in this section.

The estimated model assumes utility is non-transferable, and non-transferable utility refers to the joint maximization of the two sides' separate and exogenous utility functions. The assumption allows preferences to be estimated separately for both firms and landowners. In the transferable utility set-up, the objective is to maximize a joint surplus. Transferable utility models assume that utility can be transferred at a constant exchange rate, and in some implementations, researchers know how the surplus is split between the two sides of the market, but not always. In the leasing market, there are expected and, in a small sample, observable transfers as a result of lease negotiations. Because of small sample issues, bonuses are either represented in the matching model through unobservable, match-level shocks or are imputed from a small sample regression of bonuses on observable match-level characteristics. The royalty revenues are embedded in the model set-up through a term describing the future expected royalty revenue and are used to monetize the non-pecuniary terms in the negotiation values. The royalty rates represent a future surplus split between firms and landowners.[43] In addition to managing these data complications, the non-transferable utility assumptions allows this paper to focus on the heterogeneous incentives driving each side of the market to participate and match with partners, which is of interest in a market where the two sides have presumably very different perspectives on the outcomes both in the context of the lease signed and the implications of the lease born over the life of a drilled well.

In the analysis, the lease clauses are treated as homogeneous. The data are rich in terms of the types of clauses extracted from the legal documents; however, to simplify the implementation of the model, bundles of lease types are used to estimate, and in particular, the model uses the "disamenity" bundle described in the data section, which encompasses noise, water, and environmental restrictions. Each bundle weights each clause the same regardless of whether a clause has more or less value to a landowner. Future analyses with this model will use more of the richness in the data, and one option is to use the property value hedonics estimates from Timmins and Vissing (2015) since the marginal value estimates capture the home buyers' weights for specific clauses.

In this industry, the firm signing the original lease may not be the firm that drills the well. In some cases, the firms may be "landmen," or third party participants whose function is to amass mineral acreage that they may sell to operators or use to take royalty interest stakes in future wells. In general, there is a secondary market for leases that is not a part of the model set-up. The matches used to estimate the

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[43] The surplus split is also uncertain, depending on whether a well is drilled to extract from the mineral estate or not. For now, the model abstracts from this uncertainty.

model are the first matches observed for each landowner, and the model assumes that any transfers occurring after the original negotiation are fairly compensated based on the expected revenue from a well and costs to lease as described by the model.

Split estates are an institutional feature of the industry not formally captured by the current analysis. As described in the institutions section, a split estate implies that the landowner signing the lease may not be the person experiencing the negative aspects of nearby drilling. This inconsistency could distort the protectiveness of the lease signed since the incentives are different for individuals living far away from the well site. Timmins and Vissing (2015) is able to identify models that capture potential distortion from this aspect of leasing. The current modeling framework can develop in this direction, as well, to fully capture the effect of split estates in the negotiated outcomes.

1.4 Identification and Estimation

This section describes the estimation strategy used to identify the two-sided, one-to-many match with a concentration externality. To begin, I describe the myopic estimation function approach used to approximate the effect of the concentration externality. The subsequent sections describe the moments used to identify the parameters of the model and the estimation strategy.

1.4.1 Myopic Estimation Function

The payoffs of negotiation values with an externality depend on both the payoff of a specific match and the entire assignment of matches through the effect of the concentration externality, $share_j^m$. In the model, $share_j^m$ is endogenously determined based on the the outcomes of the match. For each potential blocking pair, agents must consider the payoffs of the deviating pair in addition to the entire re-assignment of participants as a consequence of blocking. Changes in share affect negotiation values both directly and indirectly. When a firm j leases more in a market m, firm j's negotiation values for all parcels in that market increase. Firm j leasing more in market m decreases the number of leases signed by other firms $j' \neq j$, thereby decreasing j''s negotiation values for all parcels in m. Further, firm j leasing more in market m implies that j leases fewer parcels in market $m' \neq m$.

To estimate an effect of the concentration externality, the model assumes that agents have boundedly rational beliefs about all other participants' actions and estimates the model using a myopic estimation function.[44,45] In practice, myopic estimation assumes that each agent believes all other agents will sign the total number of leases they are observed signing in the data. The estimator penalizes guesses of the parameter values that do not replicate the equilibrium market structure as observed in the data.[46]

1.4.2 Identification

Point-identification of the model stems from the equilibrium selection mechanism that assumes firms extend offers. Assuming firms extend offers is intuitive in this market setting where it is not the industry norm for landowners to approach firms with lease offers.[47]

The one-to-many matching framework enables using within-group variation to identify the preferences for observable characteristics in the model, in addition to the standard statistical moments. Agarwal (2014) uses within group moments to identify

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[44] Uetake and Watanabe (2013) and Baccara et al. (2012) estimate models using a myopic estimation function.

[45] The empirical myopic estimation function approach follows from the theory proposed by Sasaki and Toda (1996) and Hafalir (2008). Other theoretical matching with externalities literature include Bando (2012) and Pycia and Yenmez (2015).

[46] Among the moments used to estimate the model are the differences in observed and simulated market concentrations for each firm and geographic area in the data.

[47] Two-sided, one-to-many matching models usually have multiple stable equilibrium unless researchers impose an equilibrium selection mechanism or restrict preferences (Agarwal (2014)).

variation in a model where one side of the market exhibits vertical preferences.[48] Similar to his argument, the simulated model uses within firm variation to identify the preferences for observable components of the model like land size, proximity to a future well site, and proximity to existing well infrastructure in Tarrant County.

The effect of concentration externality, $share_j^m$, is identified by comparing the estimated $\widehat{share}_j^m$'s from running the deferred acceptance algorithm to the actual market structure observed in the data. Similarly, the estimated lease qualities are identified through moments comparing the estimated values, $\hat{\theta}_{ij}^{royal}$ and $\hat{\theta}_{ij}^{clause}$, to the observed firm-level averages.

1.4.3 Estimation

This section describes the estimator used to identify the model, the moments, and the simulation technique for a match with externalities. The Appendix A.1 description includes added details about inference for the estimated parameter set and other computational details.

The model is estimated using a minimum distance estimator as in the match model estimated by Agarwal (2014) (McFadden (1989); Pakes and Pollard (1989); Gourieroux and Monfort (1997)), where the estimated parameter set $\hat{\Omega}$ minimizes the simulated objective function (1.5). The moments of the observed data are denoted $\hat{m}$ while the average moments from the set of simulated outcomes are denoted $\hat{m}(\Omega)$.[49]

$$||\hat{m} - \hat{m}^S(\Omega)||_W^2 = (\hat{m} - \hat{m}^S(\Omega))' W (\hat{m} - \hat{m}(\Omega)) \tag{1.5}$$

Several types of moments are used to estimate the model including statistical moments of the data, moments that use within group (or firm) variation, and those that identify the model using the endogenously determined $share_j^m$ and lease quality.

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[48] The identification argument follows work in Agarwal and Diamond (2014) which is able to show that a one-to-many match is identifiable when both sides of the market have vertical preferences.

[49] The parameter estimates reported use an identity weight matrix which results in consistent estimates; however, efficiency is increased with a weight matrix noted in Appendix A.1.

1. Statistical moments

    (a) The joint distribution of observable characteristics of matches between firms and landowners (which includes the mean and variance of matched firms and landowners, and the covariance between matched firm and landowner characteristics):

    $$\hat{m}^m_{jd} = \frac{1}{N^m} \sum_{i \in \mathcal{N}^m} \mathbb{1}_{\{\theta_{ij} \neq 0\}} X_i Z_j \tag{1.6}$$

    (b) Within-firm mean and variance in landowner characteristics:

    $$\hat{m}^m_{wv} = \frac{1}{N^m} \sum_{i \in \mathcal{N}^m} (X_{i,k} - \frac{1}{\mathbb{1}_{\{\theta_{ij} \neq 0\}}} \sum X_{i',k})^2 \tag{1.7}$$

2. Market structure moment

    $$\widehat{share}^m_j = \frac{\sum_{i \in \mathcal{N}^m} \mathbb{1}_{\{\theta^*_{ij} \neq 0\}}}{\sum_{i \in \mathcal{N}^m, j \in \mathcal{J}^m} \mathbb{1}_{\{\theta_{ij} \neq 0\}}} \tag{1.8}$$

3. Lease quality moment where the count of leases signed by firm j in market m will be denoted N^m_j

    $$\begin{gathered} \frac{1}{N^m_j} \sum_{i \in \mathcal{N}^m} \mathbb{1}_{\{\theta_{ij} \neq 0\}} \hat{\theta}^{royal}_{ij} (\widehat{share}^m_j) \\ \frac{1}{N^m_j} \sum_{i \in \mathcal{N}^m} \mathbb{1}_{\{\theta_{ij} \neq 0\}} \hat{\theta}^{clause}_{ij} (\widehat{share}^m_j) \end{gathered} \tag{1.9}$$

For all moments, the objective function minimizes the distance between the calculated moments in the data and the average moments across all simulations, and each moment is calculated for each geographic market defined in the data. The set of statistical moments accounts for the assortive behavior between the two sides of the market, and the within firm variance takes advantage of the one-to-many feature of firms observed matching to sets of parcels (Agarwal (2014)). The market structure and lease quality moments aid in identifying the market structure relationships embedded in the model.

Estimating the model requires simulating the matches between firms and landowners for each draw of the unobserved heterogeneity, η_{ij}^{s} and ξ_{ij}^{s}.[50] The deferred acceptance algorithm (Gale and Shapley (1962)) facilitates a pairwise stable matching for each draw. The simulated draws are taken from a Halton sequence to reduce the computational magnitude of the problem.[51] Given the simulated draws, the estimation sequence proceeds:

1. **Calculate negotiation values:** For each draw of the error terms (η_{ij}^{s} and ξ_{ij}^{s}) and assuming that $share_{0,j}^{m} = share_{j}^{m}$ that is observed in the data, calculate firm and landowner negotiation values.
2. **Rank firm and landowner preferences:** Determine the accepted sets of match partners for each firm and landowner, then rank the accepted sets based on the negotiation values.
3. **Deferred acceptance match ($\mathcal{J}$-optimal):**
    - (a) Firms extend offers to their most preferred landowners.
    - (b) Landowners accept their most preferred offer.
    - (c) Firms continue extending offers in rank order of their preferences for landowners.
    - (d) Landowners hold their most preferred offers and reject all others.
    - (e) Continue offering and accepting until pairwise stability is reached.

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[50] The m superscript is exchanged for a s superscript to simplify notation since i is unique in the data across markets and s indicates the simulation draw for each term.

[51] Train (2000) Train (2009) describes the use of Halton draws.

4. **Calculate the new share, $\widehat{share_j}^m$:** The outcome of the deferred acceptance algorithm is the set of matches between firms and landowners across geographic markets that can be used to calculate an estimated share, $\widehat{share_j}^m$.
5. **Calculate moments:** Use the estimated $\widehat{share_j}^m$ and participant characteristics resulting from the simulated match to calculate the simulated moments.

This sequence is performed for each guess of the parameter set, Ω, and for each draw of the s simulated draws, η_{ij}^s and ξ_{ij}^s, where the simulated draws are constant for each guess of the parameter set. After estimating the model, the equilibrium parameters are verified by ensuring the market shares for firms across Tarrant County are stable.

1.5 Data

The estimated model relies on data that describes a series of one-to-many matches between firms and landowners spread across Tarrant County, Texas and spanning the years 2003 to 2013. Those years bound the large influx of natural gas production in the region as a consequence of technological innovation in the industry. There are three primary sources of data used in the analysis: lease data that describes the specific terms of the leasing documents; well permitting and production data occurring between 1990 and 2013 that describes firms' operating activities; and housing data that describes the parcel attributes and physical locations across Tarrant County.

The data set is constructed at the parcel level, which requires matching each leasing document to a parcel using string matching techniques, and finding observations from the lease and housing data that match on names and addresses. To control for potential economies of scale and firm characteristics, the parcels must also be mapped to nearby well activity that is firm specific. This is achieved by measuring the distance between leased parcels and nearby well production at the date the lease is signed within a defined buffer of the parcels' geographic location (2000 meter buffer). Below I describe the primary sources of the data and refer readers to Appendix C.1 for more detailed descriptions of how the data were collected and assembled.

1.5.1 Lease Data

Leases are publicly (and digitally) available documents filed with the county clerk's office. For each contract signed between firms and landowners, we observe the identities of the the firms and landowners signing the leases, the date the lease was signed, the acreage of the mineral estate, and coarse geographic descriptors as reported by Drilling Info, a private aggregator of oil and gas industry data.[52] Each leasing contract is composed of primary and auxiliary clauses. Primary clauses are included in all leases and consist of royalty rates, or the fraction owed to the landowner once a well begins selling natural gas extracted from their mineral estate, the term length, or the period of time a firm has to drill a well before the rights to the mineral estate are relinquished to the landowner, and bonuses, or fixed payments owed to landowners when the lease is signed. For many of the leases signed, I observe the royalty rate and term length, and Table 1.1 reports the primary terms summary statistics.

However, only two percent of the bonus payments are observed in our data sample, and most of those leases were signed in 2008 predominantly by nine firms.[53,54] Table 1.2 summarizes the bonus values we observe, and the second panel reports the frequency of leases signed by the firms with the largest shares in the bonus data.

Auxiliary clauses are not necessarily found in all leasing documents and are some-

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[52] My access to Drilling Info is through the Duke University Energy Initiative.

[53] Firms and landowners are not required to report bonuses with the Tarrant County Clerk office. Below, I describe how those bonuses are used in some empirical specifications.

[54] Additional bonus sample t-tests are reported in Appendix C.1, comparing the characteristics of the samples with and without reported bonus values.

time even appended to end of standardized leasing forms used in the industry. The auxiliary clause data originates from two sources: the "Drilling Down" series (Urbina (2011)) published by the *New York Times* and the Tarrant County Clerk's office. For roughly one third of the sample, there are pdf files converted to text files that are text-mined for instances of specific language describing many types of clauses that can be negotiated into leases. Table 1.3 lists the types of clauses extracted from the text files, and detailed descriptions of the clauses can be found in Appendix C.2 along with more details in Appendix C.1 about how the data was constructed using text extraction techniques. The models in the current analysis rely on bundles of clause types, and Table 1.3 classifies the individual clauses in the bundle types used in the analysis. Tables 1.4 and 1.5 breaks down the sample of leases by firm by summarizing the leases signed with and without auxiliary clauses and identifying the firms in data that are landmen. Table 1.6 summaries the mean and standard deviation for each clause type in the data and clause bundles constructed from the data.

Following the general summary statistics are Figures 1.1 to 1.7 describing the heterogeneity in lease quality by firm across the leasing years in the data, concentrating on the years 2006 to 2011. The points describe the predicted values from a regression of the lease quality measures on firm and year fixed effects, and for each point, the confidence interval band describes the precision of the estimates.

1.5.2 Well Data

There are publicly available data describing every permitted and producing well in the state of Texas, along with monthly well production values; this data can be accessed through both Drilling Info and the Texas Railroad Commission (TRC)[55]. Each well observation includes important dates like the date the permit was issued

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[55] `http://www.rrc.state.tx.us/`

by the TRC, and spud, completion, and first production dates. They also report the operator of the well, the size of acreage permitted, and lateral depths and lengths, among other well characteristics.

Each permit (and well) is geographically identified and is mapped to leasing activity based on proximity to the lease parcels at the date the lease is signed. This allows me to calculate the count of nearby wells for each firm (and their competitors) in the data when they are deciding where to sign leases capturing potential economics of scale.

Often several wells will be drilled in close proximity, which is classified as a wellpad. Using horizontal drilling techniques, horizontal laterals will extend in radial directions from the wellpad, which allows firms to extract from a much larger sub-surface acreage while entering the sub-surface though a much smaller wellpad footprint. I cluster wells into wellpads by identifying wells drilled within 63 meters of one another. Wellpads are likely to be a more precise measure of nearby activity when there are many laterals drilled in very close proximity.

1.5.3 Housing Data

The Tarrant County appraiser's office supplied map files of all parcels in the county along with files delimiting city, subdivision, water source, and abstract boundaries.[56] Further, they supplied appraisal and reported sale values[57] for each property type going back to 2008, a data set that also includes house and property characteristics like parcel and house size, the count of room types, and whether the unit is residential, among other descriptive characteristics. The analysis focuses on single-family, residential properties that are matched to leases using a series of string matching techniques based on the names of buyers, sellers, and owners (if it differs from either

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[56] `http://www.tad.org/gis-data`

[57] Texas is a non-disclosure state, so sale values are not required to be reported.

the buyer or seller) and addresses. Table 1.7 describes the parcel characteristics in the data.

The match between houses (or parcels) and leases allows for a more precise definition of the lease location and, subsequently, proximity to firms' existing infrastructure, which are important variables in the analysis capturing the value of firms' economies of scale. Further, precise lease locations allow me to group the leases into clusters assigned to specific wellpads that extract natural gas from leased mineral estates, which is described in the next section.

1.5.4 Miscellaneous Data

In addition to the primary data sources and constructed variables described above, the analysis includes pricing. The pricing data used to construct the future expected income from a producing well is the three month average future value of natural gas prices based on the delivery date at the Henry Hub in Louisiana and reported by Bloomberg.

1.5.5 Variable Construction

There are several variables constructed from observed leasing activity and used in the empirical analysis, and this section briefly describes how the the variables are calculated and their purpose. I describe how leases (parcels) are assigned to wellpads that extract natural gas from their mineral estate, the measures of firm competition, and measures of future expected income from an active well site.

Each horizontal well has a horizontal lateral extracting from beneath clusters of parcels; however, the data describing leasing and permits is not easily merged based on a unique identification number. Rather, the leases are approximately assigned to wellpads based on the proximity of leases (parcels) to the nearest wellpad: for each parcel, it is assigned to the nearest wellpad. There are some parcel clusters not located near to a wellpad observed in the data as not all of Tarrant County has active well sites in the sample. These parcels are clustered together and assigned a unique identification number in lieu of a wellpad assignment. These clusters are kept because, while they do not have an active well site, they may have a well in future periods.

Firm market concentration is a primary variable in the analysis since I am concerned with the relationship between concentration and negotiated lease quality. Market concentration is measured by share of leases signed by a firm in a geographic region, and lease quality is measured according to the number of protective clauses from the perspective of landowners. Ordinary least squares and instrumental variable models are estimated using several types of market concentration variables including absolute firm shares across space, cumulative shares across time and space, and the Herfindahl-Hirschman Index, which is an aggregate measure of market concentration.[58] Since there are usually multiple firms signing leases within a wellpad cluster, I calculate firm market shares at the wellpad level. However, the regressions are also run with concentrations measured at the abstract, or two kilometer squares delimited by the Tarrant County Appraiser Office, and the results are relatively robust to this variation in the market definition. Table 1.8 reports the summaries of active firms and competition variables for the constructed wellpads.

The observed gas production values are used to calculate a money metric representing the future expected royalty payments that monetize the non-pecuniary preferences estimated in the matching model. The wells in the data, annotated $w = \{1, ...W\}$, each produce natural gas for an observable period beginning at $t = 0$, or the month of first production. Natural gas production has a steep decline rate in that a bulk of the natural gas is produced early in the well's life and then tapers off. The quantity produced in a month, q_{wt}, is multiplied by the average monthly price of

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[58] Herfindahl-Hirschman Index for firm j with share s_{jt}^{m} in market m at period t: $H_t^m = \sum_{j=1}^{J^m}(s_{jt}^{m})^2$.

natural gas, p_t^{ng}.[59] Then the revenue earned over the life of a well is $\sum_{t=1}^{T} q_{wt} p_t^{ng}$, and I calculate a variable in my data to approximate the expected profit from owning a lease once a well is drilled and is producing natural gas.

For each well, the royalties are split between the working and royalty interests of the well whereby the royalty rate is between 20% and 25% of the commercially producing revenue. I can approximate how this is divvied up between the two interests for the following royalty rate offered to landowner i, r_i. Further, the royalty interest is pro-rationed based on the size of the parcel, a_i, leased in relation to the total area from which the well is producing. I appeal to the housing literature in economics to calculate a flow revenue from owning a royalty interest in a well and annualize the total revenue by multiplying the well revenue by five percent. The sum of the revenue for the two parties over the life of a producing well follows:

$$\begin{aligned}\text{Grantee revenue}: &\ \Lambda_{firm} \equiv 0.05 * (1 - r_i) a_i \sum_{t=1}^{T} q_{wt} p_t^{ng}\\ \text{Grantor revenue}: &\ \Lambda_{parcel} \equiv 0.05 * r_i a_i \sum_{t=1}^{T} (q_{wt} p_t^{ng})\end{aligned}$$

The current revenue values do not account for costs accrued to producers from drilling the well or any forgone opportunity costs of investing after the minerals are leased but before the well is drilled. Further, not all leases result in producing wells, and subsequent royalty income, though we do observe that 66 percent of leases are drilled in our data sample.

Some specifications include a predicted fixed bonus payment in the money metric that is the result of a simple linear regression model using the observed set of bonus payments. For these specifications, the money metric becomes:

$$\begin{aligned}\text{Grantee revenue}: &\ \Lambda_{firm} \equiv 0.05 * (1 - r_i) a_i \sum_{t=1}^{T} q_{wt} p_t^{ng} - \widehat{bonus}_{ij}\\ \text{Grantor revenue}: &\ \Lambda_{parcel} \equiv 0.05 * r_i a_i \sum_{t=1}^{T} (q_{wt} p_t^{ng}) + \widehat{bonus}_{ij}\end{aligned}$$

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[59] The price is a three-month average future natural gas price.

Table 1.9 reports the regressions that generate predicted bonus values for each potential firm and landowner pair in the matching model. The bonus regression controls for the median income of an area; a quadratic in parcel size; indicator variables controlling for rural parcels, whether it was signed in 2008, and firm identity; and a firm concentration variable.

1.6 Estimates: Instrumental Variable Models

This section establishes the negative relationship between firms' lease concentration and lease quality using ordinary and two-staged least squares models. Firms' lease concentrations are measured by the share of the number of leases signed in a wellpad area.[60] Lease quality is defined by more protective leases from the perspective of landowners and is measured using the royalty rates, primary term lengths (in months),[61] and auxiliary clause data described in greater detail in the data section and Appendix C.2. The industrial organization literature is often concerned with endogeneity between measures of concentration and the outcome variable, and this issue is mitigated using the proposed instrument: the count of nearby producing wells as of 2003, predating the leasing data. Unobservable factors affecting lease quality, like the landowners' negotiation savvy or access to legal support, might be correlated with concentration in a world where more savvy causes landowner to hold out for better lease offers from competing firms. Ordinary least squares captures the negative relationship between concentration and more protective leases; however, the coefficients are smaller in comparison to the two-staged least squares specifications.

The instrument is designed to have predictive power for measures of firm concen-

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[60] Wellpad areas are the clusters of parcels located nearest to the sites of a future wellpad. Wellpads are defined in more detail in the data section along with a description of how they are matched to individual parcels.

[61] The primary term length is the number of months a firm has to drill a well before the minerals revert back to the landowner.

tration while being uncorrelated with lease quality, the outcome variables of interest. It is composed of the count of producing wells in abstracts located near the wellpad of interest as of the year 2003, predating the majority of leasing activity and where abstracts are geographical delineations of Tarrant County defined by the Tarrant County appraiser office.[62] It accounts for all wells drilled in the nearby abstracts regardless of which operator is performing the work. In Texas, firms are required to report monthly production values to the Texas Railroad Commission, and permitting documents are filed with the agency such that there is full information about existing drilling activity across all industry participants. Firms are more likely to lease in areas of the county where there are either proven reserves or known infrastructure for transporting natural gas, like pipelines. However, there is little reason to think that factors affecting lease quality are directly correlated with count of producing wells at 2003 located in nearby abstracts since the instrument draws on spatial and temporal differences. Further, I used a series of overidentification checks to test the instrumental variable exogeneity assumption.[63]

The relationship between firm concentration and lease quality is explored using several definitions of concentration that include both firm-specific and aggregate measures. *Firm cumulative share (month)* captures the cumulative share of the leases signed across months, and a Herfindahl-Hirschman Index (HHI)[64] is defined using cumulative sum of firms' shares signed across months.[65]

Good lease quality is measured from the perspective of landowners in that it is

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[62] Abstracts parse the county into squares of roughly two kilometers-squared though there is variation across the county.

[63] Thank you to Dr. Federico Bugni and Dr. Jia Li for helpful suggestions regarding instrument validation.

[64] Herfindahl-Hirschman index: $\sum_{j=1}^{J^m} share_{jt}^2$ where $share_{jt}$ is the cumulative share of leases signed by firm j in period t.

[65] Appendix A.2 includes specifications using the total count of firms leasing in a wellpad to proxy for competition, and these results complement the concentration results by suggesting that an area with more active firms is correlated with higher quality leases.

assumed that landowners prefer a higher royalty rate, a shorter primary term length, more good clauses (legal, surface, environmental, and water protection bundles), and fewer "bads." The following analysis regresses the defined measures of lease quality on concentration measures and other controls to capture the relationship between firm concentration and the types of leases they sign. The model is re-estimated with an instrumental variable to control for the potential endogeneity between firm concentration and other unobservables affecting the lease quality outcomes. Each regression controls for year and firm fixed effects.[66]

1.6.1 OLS

The basic OLS specification regresses lease quality measures on a constant, measures of concentration ($share^m_{jt}$), observable parcel and firm characteristics (X_{ij}), and firm and year fixed effects (μ_{firm} and μ_t), and assumes a normally distributed disturbance (ϵ_{ijt}) as described in equation (1.10). Parcel and firm characteristics includes measures of parcel size, proximity to the future wellpad site (lies within a 1000-meter buffer of the future wellpad site), and a dummy measuring whether the parcel is located in a rural region of Tarrant County.[67]

$$LeaseQuality_{ijt} = \alpha_0 + \alpha_1 share^m_{jt} + \alpha_2 X_{ij} + \mu_{firm} + \mu_t + \epsilon_{ijt} \tag{1.10}$$

The OLS results are reported in Tables 1.10 and 1.11. Table 1.10 reports results for firm-level cumulative concentration, $share^m_{jt}$, and Table 1.11 reports results using a cumulative Herfindahl-Hirschman Index. Both specifications suggest that the

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[66] Regressions abstracting from time reveal similar relationships between concentration and measures of lease quality when using an instrumental variable. These models use measures of total firm concentration and instrument with the count of nearby producing wells drilled before 2003 (logged), the year most of the lease data begins, and the results are reported in the Appendix A.2. I use these results to generate the lease quality data for some specifications of the matching model that control for endogenous share as a determinant of quality.

[67] Additional specifications that include signing order are reported in Appendix A.2; however, the results are largely the same.

royalty rate decreases and the term length increases as firms amass a greater concentration of leases in regions of Tarrant County. The effect of concentration on lease clause bundles exhibits a complimentary pattern in that concentration is negatively related to the frequency of more protective clauses and is positively related to the frequency of "bads."

Land size is correlated with a lower frequency of lease clauses, both more and less protective, in addition to leases located within a 1000-meter buffer of the future wellpad site and rural regions of Tarrant County.

1.6.2 IV

The ordinary least squares estimates ignore any endogeneity between concentration and the outcome variables, or measures of lease quality. The following specifications mitigate potential endogeneity issues by instrumenting concentration with the lagged count of nearby producing wells (logged).

Tables 1.12 and 1.13 report the model results using an instrumental variable. The relationships between quality and concentrations are strengthened compared to the OLS results. The signs for each category of lease clause remain consistent across the ordinary and two-staged least squares specifications, but the magnitudes increase significantly when instrumenting the concentration variables. Conversely, the effects of concentration on royalty rate and term length are diminished whereby concentration is weakly correlated with royalty and the effect on term length is insignificant.

1.6.3 Bonuses

As referenced in the data section, we observe bonuses for two percent of the data. Table 1.9 reports the ordinary least squares regression for the small sample of bonus values. Similar to the ordinary and two-staged least squares models of lease quality presented above, the bonus regressions include a measure of firm concentration. The estimated coefficient is negative and significant, and this result further substantiates the claim that concentration is negatively related to lease quality.

1.7 Estimates: Matching Models

This section presents the results of the matching model that endogenizes the $share_j^m$ as a match externality and fixes the lease quality negotiated between pairs.[68] All coefficients have a monetary interpretation since the effects are normalized by the coefficient of the future income from a producing well.[69] Further, the data are standardized using the z-score technique, so each coefficient can be interpreted as the resulting effect on firms' (parcels') negotiation values from a change in one standard deviation of the observable variable.[70] Largely, the estimated coefficients are as expected by the model where firms value "economies of leasing," firms value lease quality as a cost, and landowners value lease quality as a benefit.

The first set of model results are presented in Table 1.14. The estimated coefficients describe an equilibrium of the model, which is verified by repeatedly solving the model until the market shares converge after estimation is complete. In this model, the $share_j^m$ for each firm in each geographic market is determined endogenously through the deferred acceptance assignment between firms and landowners. The *Lease Clause Bundle* variables are exogenously given. As reported in the first set of results in Table 1.14, Firms value "economies of leasing," or $\delta_1 > 0$. Additionally, lease quality is valued as a cost ($\delta_2 < 0$) to firms and as a benefit to landowners ($\gamma_2 > 0$). Of the observable determinants of firm preferences, *Proxim-*

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[68] The presented specifications use a fixed value of lease quality that is observed in the data. However, I have specifications that use a predicted value of lease quality controlling for an endogenous share that is an observable determinant of quality, and the results are not very different.

[69] $\Lambda_{firm} \equiv 0.05 * (1 - r_i) a_i \sum_{t=1}^{T} q_{wt} p_t^{ng} - \hat{bonus}_{ij}$ and $\Lambda_{parcel} \equiv 0.05 * r_i a_i \sum_{t=1}^{T} (q_{wt} p_t^{ng}) + \hat{bonus}_{ij}$

[70] The raw data is standardized using the z-score technique, $\frac{x - mean(x)}{std(x}$.

*ity*LargeOperator* has the largest average effect of -1.56 (δ = -2.485) followed by the direct effect of concentration[71], which has an average effect of 0.115 (δ_1 = 6.902).

In the second model specification, I account for the marginal preferences of an additional firm type, landmen, and measure the effect of a parcel being located near to a large pipeline.[72] The value of land size and proximity to a future well site are interacted with whether the signing firm is a landman or not. In the second specification, the effect of "economies of density" is amplified, landmen do not value land size while they do value proximity to a future well site, and all firms value parcels located nearer to large pipelines.

Among the other controls in the models, the results suggest that operating firms consistently value land size. The negative coefficient on land size without an interaction is likely due to the urban setting where firms are competing to lease many small parcels. Finally, firms consistently value existing infrastructure based on the positive coefficient for *Existing well count (2003)* .[73]

Firms' concentrations are identified as a mechanism affecting the lease quality outcomes, and I begin by using the estimates to evaluate the changes in firm and parcel negotiation values as concentration changes. The second model specification is used to measure the changes to negotiation values when "economies of leasing" is devalued and a merger is simulated. These exercises explore the implications of the concentration externality on the outcomes of the model as measured by the spatial distribution of leasing activity and the negotiation values for firms and landowners. In the current specifications, the effect of "economies of leasing" is a partial effect

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[71] The average effect multiplies the average values of the variables in the data by the respective coefficients from the model to approximate the relative magnitude of the effects across observable determinants.

[72] *Proximity to pipeline* is calculated as the inverse distance where distance is measured in meters.

[73] Because the model is estimated abstracting away from time, the well infrastructure variable is calculated up to the year 2003, before the leasing data begins.

because lease quality is held fixed.[74]

Devaluing "economies of leasing" mechanically requires setting the coefficient on firm concentration to zero ($\delta_1 = 0$). The remaining observable characteristics driving the leasing decisions are firm and parcel attributes and the lease quality values. Table 1.15 reports average concentrations and negotiation values by market and firm along with the calculated differences between the estimated and the counterfactual outcomes. Devaluing "economies of leasing" decreases the mean concentration by 0.04 units as reported in panel A, column (7), of Table 1.15 when concentration is measured by the Herfindahl-Hirschman index. Both the mean and median differences report the p-value of an appropriate test statistic capturing whether or not the distributions are equal. The rank sum test measuring the difference in medians indicates that the concentration distributions are different and shifted left when there is no "economies of density." Firms' average negotiation values are measured across firm and market. Under the current scenario, firms' median negotiation values decrease significantly. *Parcel Negotiation Values (Ind.)* is the average negotiation values across all parcels independent of the firm, and the mean and median individual negotiation values decrease, as well.

The second set of results in panel B of Table 1.15 report the effects of a more concentrated market through a simulated merger between select firms and landmen. This counterfactual is motived by observations that some landmen are loosely affiliated with specific operators, and some smaller firms transfer their leasing rights to larger, dominant firms post-leasing and pre-permitting phases.[75] A world where only drilling operators are able to lease has fewer post-leasing transfers and no landmen

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[74] In future versions of the model, I would like to endogenize the lease quality terms as functions of concentration, as well.

[75] I collected anecdotal evidence of firm affiliations and transfers occurring in Texas during the modeled leasing period. The information is approximate and does not identify specific properties or exact payments between firms.

extracting rent from the market. Conversely, fewer firms signing leases has measurable implications for spatial concentration that is captured by the model. The experiment assumes that sub-groups of firms sign leases as one unit by taking on the characteristics of the dominant firm and evaluates the resulting market outcomes. In panel B of Table 1.15, the concentration increases with the merger, and firms have increased average negotiation values while parcels' values decrease as measured by the mean and median negotiation values.

Table 1.16 captures the changes in the entry patterns of firms across type by reporting the number of markets entered by each firm type in each scenario. The differences indicate that firms are entering more markets across all types resulting in less spatial concentration when there is no "economies of leasing," and the converse holds in the merger setting. In both scenarios, on average, more leases are signed as indicated by the values for *Total Lease Diff. Signed*where firms sign an additional 6,033 leases (an increase of 11%) when there is no "economies of leasing" and an additional 3,209 (an increase of 5%) leases in the merger setting. In the model, this could occur when firms have more of their earlier offers accepted at the end of the game (resulting fewer rejections at a point in the game when they have very acceptable few offers remaining to extend).

1.8 Counterfactual Analysis

The counterfactual analysis captures the implications of policies that affect lease quality in the leasing market by testing the effects of requiring higher quality leasing standards. In the industry, leasing practices and lease jurisdiction is largely unregulated by state agencies. Pairs of firm and landowner negotiators are responsible for incorporating clauses that increase the breadth of environmental testing, limit the use of some chemicals, dampen disruptive traffic or well activity, and delineate the liability for some of the damages occurring during the life of the well. Private leasing practices are likely a relic of an older industry relegated to rural areas where the concentrated drilling activity is not located near to densely spaced residences. However, technological development has increased access to minerals located beneath densely populated neighborhoods leading more households to sign natural gas leases and, in some instances, to more exposure to the disamenities of active wells. The counterfactual experiments are designed to address questions about changes in the industry resulting from policies that directly impact the leasing phase. They explore the market outcomes when more uniform leasing standards are imposed by evaluating the changes in outcomes when firms sign incrementally different sets of clauses (e.g. more environmental standards). For each counterfactual experiment, I measure the changes in the spatial concentration of leasing activity and negotiation values for firms and landowners. The counterfactuals use the second specification estimates from Table 1.14 and the counterfactual results are reported in Tables 1.17, 1.18, 1.19, and 1.20.

The lease quality counterfactuals measure the changes to market structure when firms offer incrementally better lease quality in comparison to their observed lease quality. In the data, firms not offering an environmental protection clause will now sign a lease with that clause added. The estimates are used to determine how the added clause affects concentration and the average negotiation values. The second change to lease quality imposes uniformity by requiring all leases to have the same count of clauses. Instead of increasing the lease quality by a single clause for all firms not offering that clause, the bundles contain either all or half of the disamenity clauses such that any lease offered to a landowner is the same.[76] Each counterfactual is compared to a baseline scenario in which the lease quality and royalty rates are fixed to be the levels observed in the data. The baseline and counterfactual models

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[76] Royalty rate is also fixed at 0.25, and counterfactual results reporting the change in outcomes when only royalty is fixed are reported in Appendix A.3.

impose individual rationality constraints.[77]

The first lease counterfactual adds a single clause to every bundle of clauses not already including it. In particular, all bundles now include an added environmental clause, and the results are reported in panel C of Table 1.17. The average firm and parcel negotiation values and leasing concentration increases under this scenario as indicated in columns (7) and (8) comparing the mean and median values between the counterfactual and baseline scenarios. The difference in firms' median negotiation values is a weakly significant with a rank test p-value of (0.10), and all other median differences are strongly significant. Panel C of Table 1.20 describes the increasing concentration by firm type. Landmen have the largest percent change, decreasing the count of different markets entered by (-0.45). However, under this scenario, the average count of leases signed increased by (0.083), which may be a result of two factors. First, the leasing costs are not increased for all firms, so many of the negotiation values will remain the same as the baseline scenario, satisfying the individual rationality constraint. Second, among those firms with increased costs from a higher quality lease, their offers may be accepted more often by landowners (and not rejected late in the game when they have fewer offers to extend).

The second and third experiments increase the lease quality by imposing uniformity across all leases signed. The first uniform lease experiment stipulates that all firms offer half of the disamenity clauses and a 0.25 royalty rate, and the second uniform lease experiment stipulates firms offer the full set of clauses and a 0.25 royalty rate. The effects on concentration and negotiation values are presented in panels D and E of Table 1.18. Concentrating more on the median differences (column (8)), concentration decreases by a small amount in both uniform leasing scenarios. The differences in firms' median negotiation values is positive though small and insignif-

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[77] There are additional counterfactual results in Appendix A.3 that impose all leases be signed as observed in the data.

icant. The positive difference is likely attributable to gains accrued by firms with the highest average negotiation values across markets.[78] Finally, parcel negotiation values increase with uniform leasing standards, and they increase by more when the lease quality standards are higher (Table 1.19, panel E).

To capture which firm types benefit from uniform leasing standards, the lower part of each panel reports the differences in mean and median negotiation values for firms across markets and by type. As reported in Appendix A.3, firms negotiation values do not increase overall, and the effects for firm averages across markets is not significant. The lower panels reveal that landmen benefit from the policy, along with smaller firms and operators. Additionally, firms signing leases in larger markets do not benefit as denoted by the significant, decreased median in the counterfactual scenario. While not all firm types benefit from uniform leasing policy, on average, there is not a significant difference, and the differences are more than compensated by the gains to landowners.

Table 1.20, panels D and E, describe the changes in concentration and leasing activity under uniform lease standards. In particular, firms of all types sign leases in fewer markets; however, the results in Tables 1.18 and 1.19 indicate that median concentration decreases. The decreased concentration is further substantiated by a decrease in total leasing activity, and further, firms sign fewer total leases (on average) when the standards are more strict (panel E), signing 4127 fewer leases than the baseline scenario.

Concentrating on firms' responses to uniform leasing standards, concentrations decrease, there are fewer signed leases, and their average negotiation values across space are largely unchanged. When lease quality is not homogeneous, firms may

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[78] In Appendix A.3, this result is explored further by using a different baseline scenario that removes all leases that are observed to never produce natural gas. The differences in firms spatial median negotiation values is positive and significant, and using the parcel-level firm negotiation values, the gains are accrued to the firms with the highest and median-level negotiation values.

concentrate leasing activity in areas where they are able to sign lower quality (less costly) leases. Standardizing lease quality through a uniform leasing policy increases firms' costs and removes some of their incentive to spatially concentrate, and the counterfactual reflects the resulting changes in firm behavior. Firms sign fewer total leases at they become more costly, and they spatially concentrate their leasing activity less. Firms' average negotiation values increase but not significantly, nor do they increase for all firm types. This is result is surprising since firms value leases as costs, and the counterfactual imposes both homogeneous and higher quality leases on the firms. To explain why firms' negotiation values do not change on average or at the median, I decompose the effects of potential observable determinants on the firm and parcel negotiation values.

The future productivity of the well associated with the leases matters more when firms' leasing costs are higher and homogeneous. I explore this hypothesis using post-counterfactual regressions reported in Table 1.21. I first construct a dataset composed of the individual lease negotiation values (average values from the simulations) and parcel-level characteristics. I regress the estimated firm and parcel negotiation values on those characteristics and tract fixed effects. The effect of quantity of *Gas production* on firms' negotiation values is positive and significant in the counterfactual scenarios, with a slightly stronger effect for high quality leases. These counterfactuals approximate the signing patterns of firms when they have the freedom to not sign leases for parcels with a very low negotiation value.[79] Further, the counterfactuals exclude parcels that never have natural gas extracted from the mineral estate in the data. The baseline allows firms to compete for those low quality leases, as observed in the data, and those results are reported in columns (5) and (6) of Table 1.21. I find that in a market with heterogeneous lease costs and low-quality

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[79] Results leaving these low-valued parcels in the leasing market are reported in Appendix A.3, and they exhibit similar patterns to the presented scenario.

leases, the expected future production has a negative and significant effect on negotiation values. This result suggests that firms have more efficient behavior when quality is homogeneous by leasing more productive parcels, and the effect is greater as the leases become more costly.

1.9 Conclusion

The analysis presents a method of estimating a one-to-many matching model with a match externality that induces complementary firm preferences for sets of leases. The model effectively captures the expected relationships including the firms' positive effect from "economies of leasing," the firms' cost to lease, and the landowners' benefit to lease.

The model facilitates exploration of counterfactual scenarios where lease quality is restricted and finds that requiring higher quality leases does not necessarily decrease the firms' average negotiation values across markets. Whether the policy is beneficial or not to firms depends on firm types. However, the changes to firms' negotiation values is small in comparison to the measured gains for landowners when there are uniform leasing standards. Further, the negotiation values for firms and landowners are decomposed across observable characteristics under different the counterfactual scenarios and a baseline. The results suggest that under uniform leasing, negotiation values are explained by future expected production (along with other observables and controls), and the effect increases marginally as the cost increases. The final analysis suggests that firms will behave more efficiently by signing leases based on expected production rather than signing leases where they are cheaper when restricted by uniform lease quality.

Table 1.1: Lease Primary Terms Summary Statistics

Panel A : Summary Statistics

	Obs	Mean	Std. Dev.
Land (sqft)	240,187	14,570	31,685
Royalty	147,895	0.230	0.024
Term length (months)	232,161	42.86	11.78

Panel B : Correlations

	Land (sqft)	Royalty	Term length (months)
Land (sqft)	1		
Royalty	-0.0176	1	
Term length (months)	-0.0927	-0.2271	1

Table 1.2: Bonus Sample Summary Statistics

Panel A : Bonus Summary

	Obs	mean	Std. dev	Min.	Max
Bonus	5,050	16,026.66	6,107.39	100	25,000

Panel B : Firm Freq.

Firm	Obs.	Firm	Obs.
Axia	725	Four seven	758
Carrizo	248	Grande	77
Chesapeake	39	Hillwood	51
Conglomerate	173	Hollis Sullivan	78
Dale	846	XTO	2,019

Table 1.3: Lease Quality Auxiliary Clause Bundles

Quality	Clauses	Quality	Clauses
Royalty		Externality bundle	
Term length (in months)			Environmental
Legal bundle			Noise restriction
	Force majeure		Freshwater protection
	Pugh		Surface casing restriction
	Insurance, indemnity		Compression station restriction
	Reporting	Water bundle	
	Offset well		Environmental
“Bads” bundle			Freshwater protection
	Subsurface easement		Surface casing restriction
	Injection fluid		
	Free water access		
Surface bundle			
	No surface access		
	Surface restrictions		
	Surface damage		

Table 1.4: Data Samples with Auxiliary Clauses by Firm

Firm Name	No Aux. Clause	Auxiliary Clause	Landman	Lease Count
Adexco	612	28	0	640
Antero	525	217	0	742
Aspect	808	4	0	812
Axia Land	4128	2020	1	6148
Boterra	337	10	0	347
Caffey	12120	11	1	12131
Carrizo	15355	1040	0	16395
Cheaha Land	899	167	1	1066
Cherokee	450	36	0	486
Chesapeake	33268	9068	0	42336
Cheyenne	36	156	0	192
Chief	153	76	1	229
Circle	576	56	0	632
Collins Young	2113	1	0	2114
Conglomerate	52	266	0	318
Dale	40493	24424	1	64917
David Arrington	279	5	0	284
Ddjet	3874	2370	0	6244
Deephaven	146	0	1	146
Devon	71	168	0	239
Edge Barnett	171	0	0	171
Edge Lease	2388	13	1	2401
Emercor Land	101	0	0	101
Finley	389	46	0	435
Fleet	734	1265	0	1999
Fort Worth Energy	3706	363	0	4069
Four Seven	6829	3523	1	10352
Fsoc	161	0	0	161
Glencrest	292	125	0	417
Grande	1306	362	0	1668

Table 1.5: Data Samples with Auxiliary Clauses by Firm

Firm Name	No Aux. Clause	Auxiliary Clause	Landman	Lease Count
Granite	274	12	1	286
Harding	1274	904	0	2178
Hillwood	22	467	0	489
Hollis Sullivan	3537	943	0	4480
Keystone	990	24	0	1014
Llano Royalty	494	2	1	496
Lv	713	0	0	713
Marsh	192	1	0	193
Marshall Young	164	4	0	168
Midcontinent	134	4	0	138
Mmg	158	1	0	159
Newark	819	0	1	819
Paloma Barnett	10628	6093	0	16721
Potestas	1125	78	0	1203
Prime Resource	430	2	0	432
Quicksilver	216	18	0	234
Rall	1036	0	0	1036
Range	38	437	0	475
Snow	608	319	0	927
Thornton	146	2	0	148
Thunderbird	271	520	0	791
Tidewell	139	1	0	140
Tierra	120	18	0	138
Titan	5757	80	0	5837
Tworock	447	0	0	447
Vantage Fort Worth	1327	1	0	1328
Vargas	83	17	0	100
Western Production	1364	24	0	1388
Whitestone	3	134	0	137
Woodcrest	274	103	0	377
Xto	12282	6721	0	19003
Total	177,437	62,750		240,187

Table 1.6: Lease Clause and Bundle Statistics

Clause/Bundle	Mean	Std. Dev.	Clause/Bundle	Mean	Std. Dev.
Legal Bundle	0.23	0.22	Disamenity Bundle	0.18	0.25
Force Majuere	0.53	0.5	Environmental Restriction	0.34	0.47
Pugh Clause	0.42	0.49	Noise Restriction	0.32	0.47
Offset Well	0.13	0.34	Freshwater Protection	0.03	0.17
Insurance, Indemnity	0.08	0.27	Surface Casing	0.01	0.12
Reporting	0.01	0.11	Compression Station	0.005	0.07
Surface Bundle	0.56	0.23	Water Bundle	0.13	0.19
No Surface Access	0.79	0.41	Freshwater Protection	0.03	0.17
Surface Restriction	0.12	0.32	Surface Casing	0.01	0.12
Surface Damage	0.79	0.41	Environmental Restriction	0.34	0.47
Bads Bundle	0.21	0.18			
Subsurface Easement	0.6	0.49			
Injection Fluid	0.02	0.14			
Free water	0.02	0.13			
Observations	62,750				

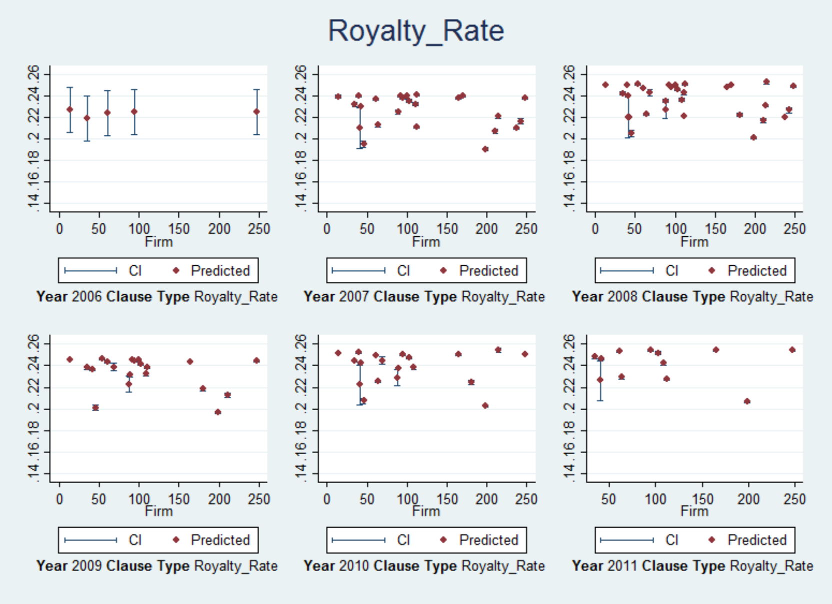

FIGURE 1.1: Predicted Royalty (year, firm)

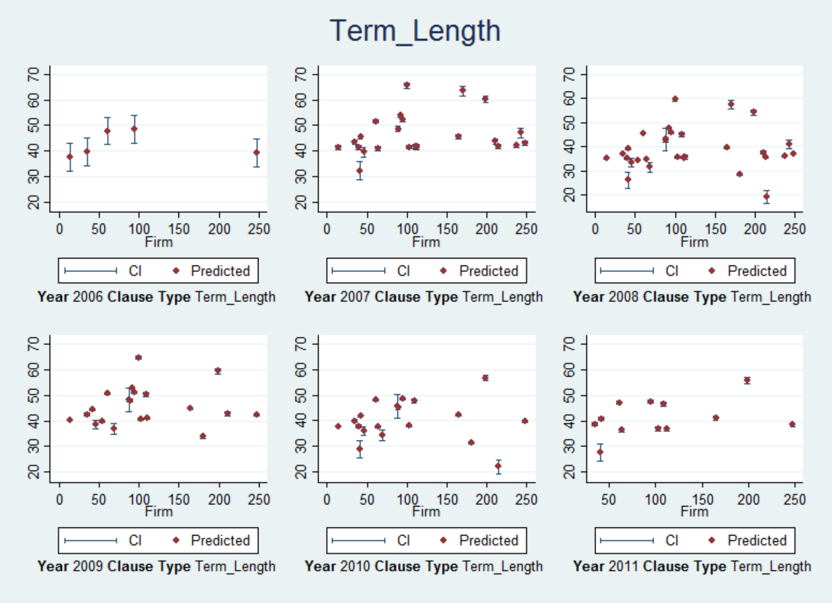

FIGURE 1.2: Predicted Term Length (year, firm)

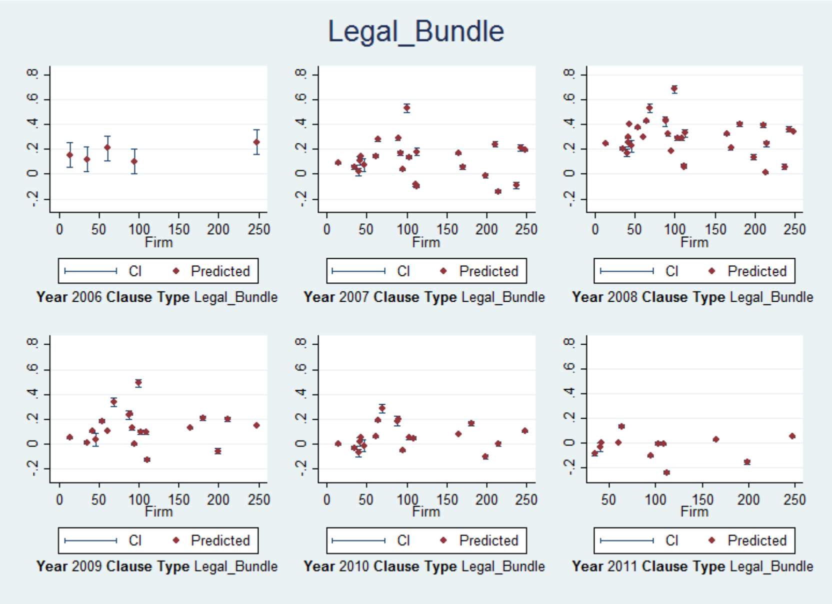

FIGURE 1.3: Predicted Legal Clauses (year, firm)

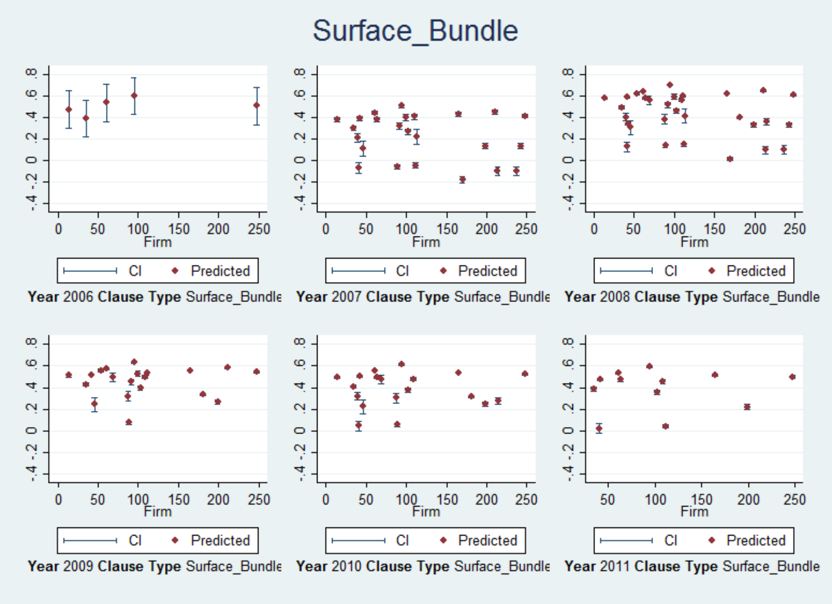

FIGURE 1.4: Predicted Surface Clauses (year, firm)

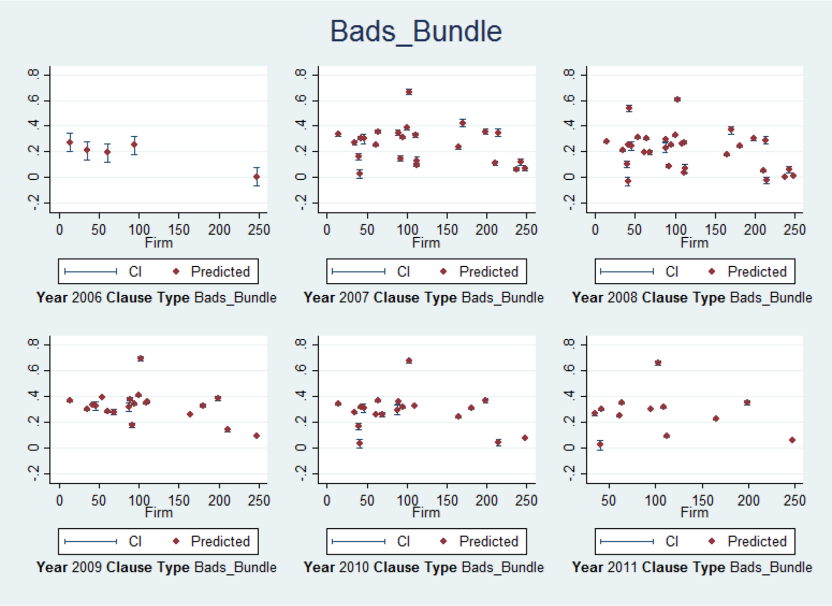

FIGURE 1.5: Predicted “Bads” Clauses (year, firm)

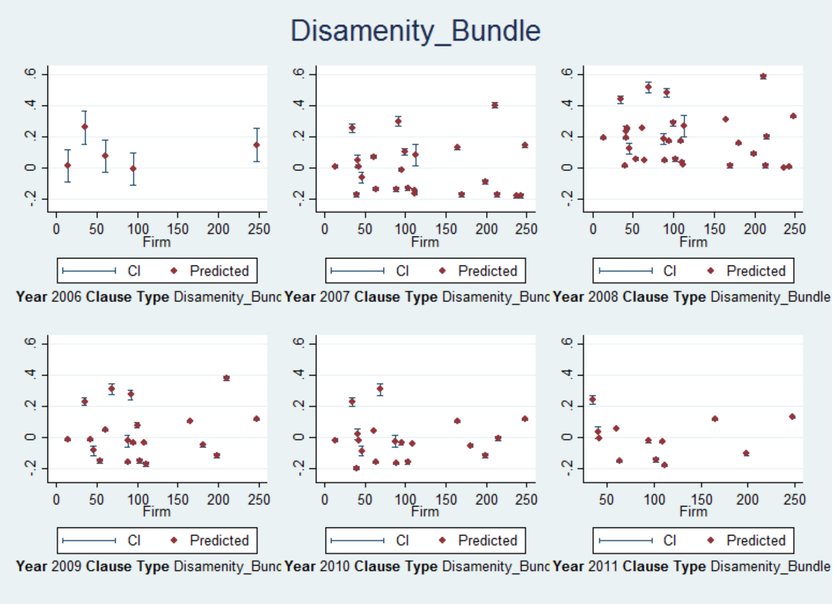

FIGURE 1.6: Predicted Disamenity Clause (year, firm)

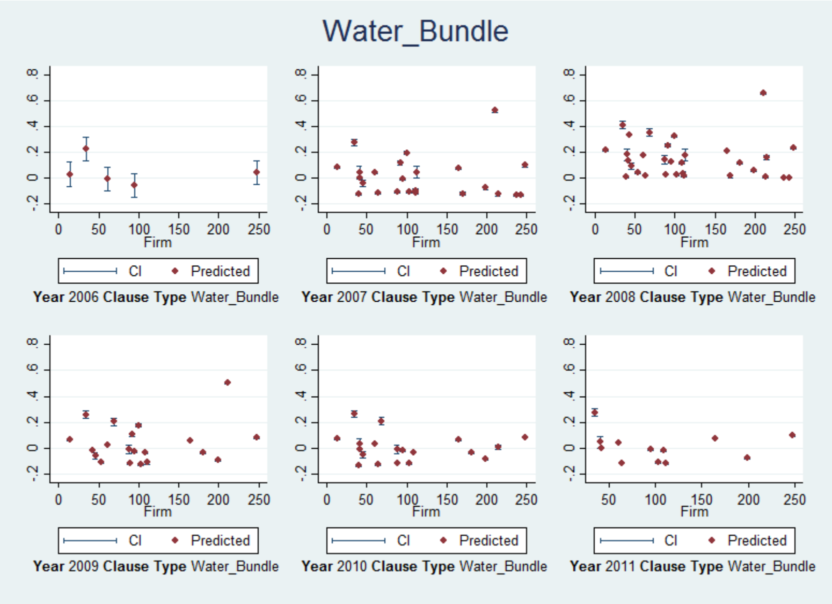

FIGURE 1.7: Predicted Water Clauses (year, firm)

Table 1.7: Parcel Characteristics Summary Statistics

	Obs	Mean	Std. Dev.	Min	Max
Land (sqft)	240,187	14,570.49	31,685.14	100	72,6145
Dist. to Wellpad (meters)	240,187	918.42	581.87	0.039	57,871
Dist. Buffer (< 1000m)	240,187	0.827	0.378		
Rural (dummy)	240,187	0.018	0.132		
Groundwater (dummy)	225,763	0.643	0.479		
Split Estate (dummy)	138,290	0.117	0.321		

Table 1.8: Competition (mean) Wellpad Summary Statistics

	Obs	Mean	Std. Dev.	Min	Max
Total Lease Count	1442	160.97	304.26	10	2752
Firm Lease Count	1442	13.39	15.02	1.22	110.18
Firm Count	1442	8.51	6.02	1	34
Landmen Count	1442	2.27	1.62	0	9
Firm Share	1442	0.2	0.17	0.03	1
Leases Signed by Landmen	1442	0.38	0.32		

Table 1.9: Bonus regression

	(1)		(2)	
Dependent Var = Bonus (1e-4)	Est.	(Std. Err.)	Est.	(Std. Err.)
Firm cum. share (wellpad)	-0.153***	(0.025)	-0.078***	(0.029)
Large Operator	0.001	(0.161)	0.770***	(0.041)
Landman	0.964***	(0.320)	0.810***	(0.040)
Land (sqft/1e6)	2.853***	(0.759)	8.293***	(1.009)
Land (sqft/1e6) ^{2}	-7.036***	(2.052)	-20.866***	(2.822)
Rural Dummy	-0.605***	(0.104)	-0.582***	(0.109)
Signed by Axia	0.141	(0.276)		
Signed by Conglomerate	0.371**	(0.160)		
Signed by Chesapeake	0.344**	(0.134)		
Signed by Dale	-0.123	(0.276)		
Signed by Four Sevens	0.451	(0.276)		
Signed by Grande	1.442***	(0.184)		
Signed by Hillwood	-0.263	(0.164)		
Signed by Hollis Sullivan	-0.530***	(0.161)		
Signed by XTO	1.212***	(0.018)		
Constant	0.609***	(0.159)	0.814***	(0.038)
Observations	5,034		5,034	
R-squared	0.478		0.142	

Table 1.10: OLS: Firm Cumulative Share

	(1) Royalty rate	(2) Term (month)	(3) Legal	(4) Surface
Firm Cum. Share	-0.006***	1.675***	-0.005*	-0.024***
	(0.000)	(0.073)	(0.003)	(0.003)
Parcel plot size (sqft/1e6)	0.038***	-15.625***	-0.051*	-0.104***
	(0.002)	(0.698)	(0.028)	(0.032)
Within 2000m of centroid	0.001*	0.637***	-0.037***	-0.028***
	(0.000)	(0.158)	(0.005)	(0.005)
Rural Dummy	0.002***	-1.319***	-0.028***	-0.025***
	(0.000)	(0.155)	(0.007)	(0.007)
Observations	148,056	232,482	62,769	62,769
R-squared	0.413	0.391	0.312	0.309

	(5) Bads	(6) Externality	(7) Water	(9) Full set
Firm Cum. Share	0.046***	-0.029***	-0.015***	-0.039***
	(0.002)	(0.003)	(0.002)	(0.003)
Parcel plot size (sqft/1e6)	0.120***	-0.080***	0.002	-0.139***
	(0.023)	(0.030)	(0.026)	(0.031)
Within 2000m of centroid	0.054***	-0.054***	-0.028***	-0.072***
	(0.005)	(0.007)	(0.005)	(0.007)
Rural Dummy	-0.011**	-0.043***	-0.034***	-0.040***
	(0.005)	(0.008)	(0.006)	(0.008)
Observations	62,769	62,769	62,769	62,769
R-squared	0.296	0.293	0.306	0.336
Firm FE	yes	yes	yes	yes
Period FE	yes	yes	yes	yes
Var	No inst.	No inst.	No inst.	No inst.

Table 1.11: OLS: HHI

	(1) Royalty rate	(2) Term (month)	(3) Legal	(4) Surface
HHI (cum, month)	-0.003***	1.023***	-0.018***	-0.014***
	(0.000)	(0.038)	(0.002)	(0.002)
Parcel plot size (sqft/1e6)	0.039***	-16.149***	-0.044	-0.098***
	(0.002)	(0.703)	(0.028)	(0.032)
Within 2000m of centroid	0.000	0.825***	-0.034***	-0.028***
	(0.000)	(0.157)	(0.005)	(0.005)
Rural Dummy	0.001***	-1.331***	-0.023***	-0.024***
	(0.000)	(0.154)	(0.007)	(0.007)
Observations	148,056	232,482	62,769	62,769
R-squared	0.414	0.392	0.313	0.309

	(5) “Bads”	(6) Externality	(7) Water	(100) Full Set
HHI (cum, month)	0.032***	-0.027***	-0.017***	-0.037***
	(0.001)	(0.002)	(0.001)	(0.002)
Parcel plot size (sqft/1e6)	0.106***	-0.069**	0.009	-0.124***
	(0.023)	(0.030)	(0.026)	(0.031)
Within 2000m of centroid	0.054***	-0.053***	-0.027***	-0.070***
	(0.005)	(0.007)	(0.005)	(0.007)
Rural Dummy	-0.014***	-0.039***	-0.030***	-0.033***
	(0.005)	(0.008)	(0.006)	(0.008)
Observations	62,769	62,769	62,769	62,769
R-squared	0.299	0.295	0.308	0.339
Firm FE	yes	yes	yes	yes
Period FE	yes	yes	yes	yes
Var	No inst.	No inst.	No inst.	No inst.

Table 1.12: 2-SLS: Firm Cumulative Share

	(1) Royalty rate	(2) Term (month)	(3) Clause
Panel A: 1^{st} Stage			
Count Nearby Prod. Wells (2003,log)	0.084***	0.088***	0.105***
	(0.006)	(0.005)	(0.008)
F-stat	1634	2257	950

Panel B: 2^{nd} Stage

	(1) Royalty rate	(2) Term (month)	(3) Legal	(4) Surface
Firm Cum. Share	0.042***	-1.083	-0.121**	-0.091**
	(0.005)	(1.712)	(0.051)	(0.041)
Parcel plot size (sqft/1e6)	0.047***	-16.219***	-0.056**	-0.107***
	(0.003)	(0.793)	(0.028)	(0.032)
Within 2000m of centroid	-0.004***	0.995***	-0.024***	-0.020***
	(0.001)	(0.272)	(0.008)	(0.007)
Rural Dummy	-0.008***	-0.795**	-0.009	-0.014
	(0.001)	(0.360)	(0.012)	(0.010)
Observations	148,056	232,482	62,769	62,769
R-squared	0.133	0.387	0.293	0.303

	(5) Bads	(6) Externality	(7) Water	(9) Full set
Firm Cum. Share	0.123***	-0.283***	-0.182***	-0.264***
	(0.038)	(0.044)	(0.032)	(0.056)
Parcel plot size (sqft/1e6)	0.124***	-0.093***	-0.006	-0.150***
	(0.023)	(0.033)	(0.028)	(0.033)
Within 2000m of centroid	0.045***	-0.026***	-0.010*	-0.047***
	(0.007)	(0.009)	(0.006)	(0.010)
Rural Dummy	-0.024***	-0.001	-0.006	-0.002
	(0.009)	(0.012)	(0.009)	(0.013)
Observations	62,769	62,769	62,769	62,769
R-squared	0.283	0.220	0.254	0.289
Firm FE	yes	yes	yes	yes
Period FE	yes	yes	yes	yes

Table 1.13: 2-SLS: HHI

	(1) Royalty rate	(2) Term (month)	(3) Clause
Panel A: 1^{st} Stage			
Count Nearby Prod. Wells (2003,log)	0.131***	0.127***	0.080***
	(0.011)	(0.010)	(0.015)
F-stat	169	299	124

Panel B: 2^{nd} Stage

	(1) Royalty rate	(2) Term (month)	(3) Legal	(4) Surface
HHI (cum, month)	0.027***	-0.750	-0.159**	-0.119**
	(0.003)	(1.193)	(0.074)	(0.054)
Parcel plot size (sqft/1e6)	0.035***	-15.865***	0.006	-0.060
	(0.003)	(0.725)	(0.041)	(0.039)
Within 2000m of centroid	-0.001*	0.876***	-0.012	-0.012
	(0.001)	(0.162)	(0.013)	(0.010)
Rural Dummy	-0.007***	-0.758*	0.027	0.012
	(0.001)	(0.415)	(0.028)	(0.021)
Observations	148,056	232,482	62,769	62,769
R-squared	0.001	0.386	0.210	0.257

	(5) “Bads”	(6) Externality	(7) Water	(9) Full set
HHI (cum, month)	0.162***	-0.371***	-0.239***	-0.037***
	(0.052)	(0.086)	(0.060)	(0.002)
Parcel plot size (sqft/1e6)	0.060*	0.054	0.088**	-0.124***
	(0.031)	(0.052)	(0.039)	(0.031)
Within 2000m of centroid	0.033***	0.000	0.007	-0.070***
	(0.010)	(0.016)	(0.011)	(0.007)
Rural Dummy	-0.060***	0.082**	0.048**	-0.033***
	(0.019)	(0.033)	(0.023)	(0.008)
Observations	62,769	62,769	62,769	62,769
R-squared	0.169	0.190	0.023	0.339
Firm FE	yes	yes	yes	yes
Period FE	yes	yes	yes	yes

Table 1.14: Match Estimates with Endogenous Firm Share

		(1)		(2)	
Variable Desc.	Coefficient	Estimate	Std. Error	Estimate	Std. Error
Firm Negotiation Values					
Land size (sqft)	δ	-3.467	(0.041)	-0.830	(0.092)
Land size*Large Operator	δ	3.327	(0.017)	7.534	(0.052)
Land size*Landman	δ			-4.756	(0.052)
Proximity to well (within 1km)	δ	-0.947	(0.026)	-7.461	(0.048)
Proximity*Large Operator	δ	-2.485	(0.054)	-2.790	(0.073)
Proximity*Landman	δ			9.465	(0.039)
Existing well count (2003)	δ	1.192	(0.016)	3.205	(0.055)
Proximity to pipeline	δ			2.131	(0.070)
Firm Lease Concentration	δ_1	6.902	(0.024)	13.959	(0.045)
Lease Clause Bundle	δ_2	-1.237	(0.042)	-2.981	(0.125)
Landowner Negotiation Values					
Lease Clause Bundle	γ	3.672	(0.021)	5.673	(0.048)
J-stat		0.081		0.025	
Critical Value (χ-square)		53.384		70.994	

Table 1.15: Counterfactual: No “Economies of Leasing” and Merger Simulation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Est.^{a}			CF^b			Mean^c	Median^a
	Mean	Med.	95^{th}	Mean	Med.	95^{th}	Diff.(P-val.)	Diff.(P-val)
Panel A : No “Economies of Leasing”								
HHI	0.26 (0.17)	0.21	0.66	0.22 (0.13)	0.19	0.45	-0.04 (0.57)	-0.02 (0.00)
Firm Neg. Value	0.52 (5.43)	0.10	7.66	0.24 (6.57)	0.07	6.8	-0.28 (0.53)	-0.03 (0.00)
Parcel Neg. (Ind.)	2.52 (5.36)	0.64	10.5	2.35 (5.58)	0.47	10.72	-0.17 (0.52)	-0.17 (0.00)
Panel B : Merger								
HHI	0.26 (0.17)	0.21	0.66	0.39 (0.17)	0.38	0.72	0.13 (0.25)	0.17 (0.00)
Firm Neg. Value	0.52 (5.43)	0.10	7.66	0.67 (6.36)	0.13	7.35	0.16 (0.48)	0.04 (0.00)
Parcel Neg. (Ind.)	2.52 (5.36)	0.64	10.5	0.85 (4.85)	-0.43	6.85	-1.66 (0.74)	-1.07 (0.00)

[a] Mean (standard deviation), median, and 95^{th} percentiles of the estimated model.

[b] Mean (standard deviation), median, and 95^{th} percentiles of the counterfactual model.

[c] Difference in the mean values between the counterfactual and estimated models, and in parentheses, the p-value of the Mann-Whitney two-sample statistic for non-normally distributed and unmatched data. The hypothesis is testing whether two independent samples are from the same distribution.

[d] Difference in the median values between the counterfactual and estimated models, and in parentheses, the p-value of the ‘k-sample test on the equality of medians’ statistic for non-normally distributed and unmatched data.

Table 1.16: Counterfactual: No "Economies of Leasing" and Merger Simulation *(Continued)*

Panel A : No "Economies of Leasing"

	Large Firm	Large Operator	Landman
Markets (Est)[a]	1950	855	1905
Markets (CF)[b]	2231	922	2253
	Diff. (Pct. Δ)	Diff. (Pct. Δ)	Diff. (Pct. Δ)
Diff. Markets	281 (0.144)	67 (0.078)	348 (0.183)
Total Lease Diff. Signed	6033.9 (0.111)		

Panel B : Merger

	Large Firm	Large Operator	Landman
Markets (Est)	1950	855	1905
Markets (CF)	1060	799	1016
	Diff. (Pct. Δ)	Diff. (Pct. Δ)	Diff. (Pct. Δ)
Diff. Markets	-890 (-0.456)	-56 (-0.065)	-889 (-0.467)
Total Lease Diff. Signed	3209.9 (0.059)		

[a] Count of markets entered by each firm type in the estimated model.

[b] The differences in the count of markets entered between the counterfactual and estimated model by firm type, and in parentheses, the percent change between the counterfactual and estimated model.

Table 1.17: Counterfactual: Added Environmental Clause

Panel C : Added Env. Clause

	(1)	(2)	(3)	(4)	(5)	(6)
	Est.[a]			CF[b]		
	Mean	Med.	95^{th}	Mean	Med.	95^{th}
HHI	0.18 (0.14)	0.13	0.51	0.28 (0.28)	0.14	0.96
Firm Neg. Value	0.43 (5.14)	0.10	5.99	0.89 (5.62)	0.12	8.27
Parcel Neg. (Ind.)	3.65 (5.93)	0.99	14.34	12.42 (9.95)	14.36	29.83

	(7)	(8)
	Mean[c] Diff.(P-val)	Median[a] Diff.(P-val)
HHI	0.11 (0.42)	0.01 (0.00)
Firm Neg. Value	0.45 (0.49)	0.02 (0.10)
Parcel Neg. (Ind.)	8.77 (0.26)	13.37 (0.00)

[a] Mean (standard deviation), median, and 95^{th} percentiles of the estimated model.

[b] Mean (standard deviation), median, and 95^{th} percentiles of the counterfactual model.

[c] Difference in the mean values between the counterfactual and estimated models, and in parentheses, the p-value of the Mann-Whitney two-sample statistic for non-normally distributed and unmatched data. The hypothesis is testing whether two independent samples are from the same distribution.

[d] Difference in the median values between the counterfactual and estimated models, and in parentheses, the p-value of the 'k-sample test on the equality of medians' statistic for non-normally distributed and unmatched data.

Table 1.18: Counterfactual: Uniform Leasing of Medium Quality

Panel D : Half Set of Clauses + 0.25 Royalty

	(1)	(2)	(3)	(4)	(5)	(6)
		Est.^{a}			CF^b	
	Mean	Med.	95^{th}	Mean	Med.	95^{th}
HHI	0.18 (0.14)	0.13	0.51	0.26 (0.32)	0.07	0.96
Firm Neg. Value	0.43 (5.14)	0.10	5.99	0.52 (6.4)	0.11	11.33
Parcel Neg. (Ind.)	3.69 (5.95)	1.01	14.47	15.65 (9.52)	20.02	29.04

	(7)	(8)
	Mean^c Diff.(P-val)	Median^a Diff.(P-val)
HHI	0.08 (0.62)	-0.06 (0.00)
Firm Neg. Value	0.08 (0.52)	0.01 (0.45)
Parcel Neg. (Ind.)	11.96 (0.16)	19.00 (0.00)

Firm Negotiation Values by Type

	(1)	(2)	(3)	(4)	(5)	(6)
		Est.^{a}			CF^b	
	Mean	Med.	95^{th}	Mean	Med.	95^{th}
Non-landman	0.06 (4.53)	0.06	3.76	0.3 (5.69)	0.07	8.73
Landman	1.39 (6.34)	0.38	8.57	1.12 (8.03)	0.51	17.63
Non-Large Firm	0.17 (3.69)	0.09	3.23	0.54 (4.32)	0.14	7.64
Large Firm	1.12 (7.66)	0.24	13.47	0.46 (9.34)	-0.01	18.27
Non-Large Oper.	0.48 (4.51)	0.12	5.83	0.62 (5.82)	0.15	9.96
Large Oper.	0.09 (8.36)	-0.25	15.42	-0.10 (9.10)	-0.62	16.21
Small Well Cluster	0.35 (5.14)	0.08	5.80	0.78 (7.06)	0.09	16.47
Large Well Cluster	0.77 (5.11)	0.28	7.80	-0.24 (3.83)	0.18	1.75

	(7)	(8)
	Mean^c Diff.(P-val)	Median^a Diff.(P-val)
Non-landman	0.24 (0.51)	0.01 (0.42)
Landman	-0.27 (0.53)	0.13 (0.07)
Non-Large Firm	0.37 (0.48)	0.05 (0.00)
Large Firm	-0.65 (0.58)	-0.25 (0.00)
Non-Large Oper.	0.14 (0.50)	0.03 (0.00)
Large Oper.	-0.19 (0.57)	-0.37 (0.00)
Small Well Cluster	0.43 (0.51)	0.01 (0.37)
Large Well Cluster	-1.01 (0.57)	-0.10 (0.00)

Table 1.19: Counterfactual: Uniform Leasing of High Quality

Panel E : Full Set of Clauses + 0.25 Royalty

	(1)	(2)	(3)	(4)	(5)	(6)
	Est.^{a}			CF^b		
	Mean	Med.	95^{th}	Mean	Med.	95^{th}
HHI	0.18 (0.14)	0.13	0.51	0.23 (0.29)	0.06	0.89
Firm Neg. Value	0.43 (5.14)	0.10	5.99	0.49 (6.22)	0.11	11.43
Parcel Neg. (Ind.)	3.69 (5.95)	1.01	14.47	15.72 (9.24)	21.04	28.29

	(7)	(8)
	Mean^c Diff.(P-val)	Median^a Diff.(P-val)
HHI	0.06 (0.65)	-0.07 (0.00)
Firm Neg. Value	0.05 (0.52)	0.01 (0.61)
Parcel Neg. (Ind.)	12.03 (0.16)	20.03 (0.00)

Firm Negotiation Values by Type

	(1)	(2)	(3)	(4)	(5)	(6)
	Est.^{a}			CF^b		
	Mean	Med.	95^{th}	Mean	Med.	95^{th}
Non-landman	0.06 (4.53)	0.06	3.76	0.29 (5.52)	0.07	8.71
Landman	1.39 (6.34)	0.38	8.57	1.05 (7.82)	0.47	17.08
Non-Large Firm	0.17 (3.69)	0.09	3.23	0.52 (4.18)	0.13	7.62
Large Firm	1.12 (7.66)	0.24	13.47	0.42 (9.10)	-0.01	17.57
Non-Large Oper.	0.48 (4.51)	0.12	5.83	0.59 (5.64)	0.15	9.91
Large Oper.	0.09 (8.36)	-0.25	15.42	-0.10 (8.87)	-0.61	16.90
Small Well Cluster	0.35 (5.14)	0.08	5.80	0.74 (6.85)	0.08	16.10
Large Well Cluster	0.77 (5.11)	0.28	7.80	-0.26 (3.72)	0.18	1.69

	(7)	(8)
	Mean^c Diff.(P-val)	Median^a Diff.(P-val)
Non-landman	0.23 (0.51)	0.01 (0.41)
Landman	-0.34 (0.53)	0.09 (0.15)
Non-Large Firm	0.35 (0.49)	0.04 (0.00)
Large Firm	-0.70 (0.58)	-0.24 (0.00)
Non-Large Oper.	0.10 (0.51)	0.03 (0.02)
Large Oper.	-0.19 (0.57)	-0.36 (0.00)
Small Well Cluster	0.39 (0.51)	0.00 (0.87)
Large Well Cluster	-1.02 (0.57)	-0.10 (0.00)

Table 1.20: Counterfactual: Participation Changes

Panel C : Added Env. Clause

	Large Firm	Large Operator	Landman
Markets (Est)[a]	1948	842	1955
Markets (CF)[b]	1242	566	1074
	Diff. (Pct. Δ)	Diff. (Pct. Δ)	Diff. (Pct. Δ)
Diff. Signed	-706 (-0.362)	-276 (-0.328)	-881 (-0.451)
Total Lease Diff. Signed[c]	4483.3 (0.083)		

Panel D : Half Set of Clauses + 0.25 Royalty

	Large Firm	Large Operator	Landman
Market Count (Est)	1948	842	1955
Market Count (CF)	854	381	691
	Diff. (Pct. Δ)	Diff. (Pct. Δ)	Diff. (Pct. Δ)
Diff. Signed	-1094 (-0.562)	-461 (-0.548)	-1264 (-0.647)
Total Lease Diff. Signed	-2334.5 (-0.043)		

Panel E : Full Set of Clauses + 0.25 Royalty

	Large Firm	Large Operator	Landman
Market Count (Est)	1948	842	1955
Market Count (CF)	836	373	676
	Diff. (Pct. Δ)	Diff. (Pct. Δ)	Diff. (Pct. Δ)
Diff. Signed	-1112 (-0.571)	-469 (-0.557)	-1279 (-0.654)
Total Lease Diff. Signed	-4127 (-0.076)		

[a] Count of markets entered by each firm type in the estimated model.

[b] The differences in the count of markets entered between the counterfactual and estimated model by firm type, and in parentheses, the percent change between the counterfactual and estimated model.

[c] The differences in the count of leases signed between the counterfactual and estimated model, and in parentheses, the percent change between the counterfactual and estimated model.

Table 1.21: Post-Match Regression of Negotiation Values

	(1)	(2)	(3)	(4)	(5)	(6)
	Medium Quality Lease		High Quality Lease		Baseline Model	
	Firm	Parcel	Firm	Parcel	Firm	Parcel
Gas production (1e-6)	0.060***	-0.204***	0.072***	-0.185***	-0.038***	0.047***
	(0.006)	(0.009)	(0.006)	(0.009)	(0.008)	(0.006)
Rural Dummy	0.936*	-2.777***	1.205**	-2.206***	4.778***	0.613***
	(0.531)	(0.629)	(0.541)	(0.622)	(0.668)	(0.181)
Dist. To Pipeline (Inv.)	0.009***	0.001**	0.009***	0.001**	0.010***	0.001**
	(0.001)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)
Constant	-1.785***	11.388***	-1.257***	10.934***	9.168***	1.345***
	(0.348)	(1.056)	(0.294)	(1.018)	(0.460)	(0.108)
Observations	50,831	50,831	50,831	50,831	50,831	50,831
R-squared	0.452	0.617	0.447	0.617	0.503	0.402
Tract FE	yes	yes	yes	yes	yes	yes

2

Valuing Leases for Shale Gas Development with Christopher Timmins, Duke University

2.1 Introduction

Natural gas that is extracted from tight-shale formations[1] by using large-scale hydraulic fracturing and horizontal drilling techniques has increased the domestic energy supply significantly in the recent past. These technological changes in the in oil and natural gas industry have freed drilling firms to operate wells in tight-shale plays that were otherwise inaccessible both in terms of the ability to extract reserves from the geological formations and the reserve locations under densely populated neighborhoods. As a consequence, more urban and suburban households are exposed to nearby drilling activity, which may have negative ramifications for health and property values. Negative aspects of the drilling and extraction processes include groundwater or soil contamination caused by radioactive salts and metals or by the

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[1] Tight-shale describes the geological properties of the strata containing the oil or natural gas. Traditional reservoirs are permeable and porous such that when tapped, the natural fissures allow the resource to flow naturally to wellhead. Tight-shale formations are neither permeable or porous, and they require artificial stimulation through hydraulic fracturing techniques that create fissures in the strata that allow the resource to flow to the wellhead. Additional technological details follow in Appendix B.1.

chemicals used to the treat the wells,[2] higher levels of air pollution from well activity,[3] noise, road damage, and accidents and air pollution resulting from increased truck traffic.[4]

Traditionally, the hedonic literature extracts values of non-market (dis)amenities, like environmental quality or nuisance, from property values. The environmental justice literature connects environmental quality to demographics, attempting to disentangle whether demographics lead to lower environmental quality or polluting behavior (Banzhaf and McCormick (2007)). Our paper uses the natural gas leasing market in Tarrant County Texas, overlaying the Barnett tight-shale formation, to explore the hedonic values of legal contracts that restrict firm behavior in a way that decreases the negative implications of nearby drilling activity. Second, we use our analysis to explore whether shale gas development is an environmental justice question. In particular, are drilling firms signing fewer clauses that restrict negative drilling behavior with minority households? These questions are increasingly relevant for the growing number of households exposed to the potential risks associated with shale gas development as the U.S. relies more on shale gas as a source of energy.

Understanding whether there is environmental injustice may not be as simple as measuring whether there is disproportionate exposure to shale risks among minority households because exposure also depends on the rules and regulations guiding development. Under the U.S. legal structure, homeowners can be protected from the external costs of drilling in one of two ways: government ordinances or laws and privately negotiated natural gas leases. First, ordinances or laws are passed (at the municipal, state, and federal level) that restrict activities at various stages of the drilling and production phases. However, many of the state-level regulations

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[2] Olmstead et al. (2013), Warner et al. (2013), Fontenot et al. (2013)

[3] Colborn et al. (2014), Caulton et al. (2014), Roy et al. (2014)

[4] Gilman et al. (2013), Muehlenbachs and Krupnick (2014)

are designed for rural drilling, as has been most common in the past, and the local ordinances are heterogeneous across municipalities and not comprehensive both in content and geographical coverage.[5]

Second, homeowners who are also the owners of mineral rights can sign lease agreements, which transfer those rights to operators who then develop the resource on behalf of the homeowner. Typically, the mineral rights holder receives a royalty payment based on a percentage of the value of the resource sold by the operator in addition to a one-time fixed bonus payment paid at the time the mineral rights owner signs the lease.[6] The lease agreement specifies other terms that restrict the operator's activities - e.g., noise limitations, restrictions on how surface disruptions must be restored after drilling, and restrictions on how long the operator can let the minerals go undeveloped before rights revert back to their owner. However, not all homeowners sign leases with the same terms, and in the data we observe that leases have more or less comprehensive addendums with added clauses that restrict firm behavior. Further, in some instances, the homeowners are not the mineral rights holders because the state of Texas allows the sub-surface minerals to be severed from the surface estate, or split estates properties. In the event of a split estate property, we do not expect the owner of the mineral rights to negotiate the terms of the lease with the interests of the surface estate owner in mind, which should be controlled for in an analysis of negotiated lease outcomes.[7]

We begin our analysis with a hedonic study of the types of leases signed between

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[5] There is a more detailed discussion about the state and local regulations governing the industry in Appendix B.1.

[6] Royalty payments in Texas are typically 18 to 25% of production pro-rationed by the acreage contribution to the producing well. Bonus payments can vary greatly depending upon operators' expectations about the profitability of a particular parcel of land.

[7] In the state of Texas, natural gas leases need only be negotiated with the owner of the mineral estate regardless of whether the estate is severed or not. There is no formal stipulation that firms negotiate a separate surface damage agreement with the surface estate owner as we find in other states with active oil and natural gas industries.

firms and landowners by quantifying the landowners' values for various clauses that are added to the leasing contracts. The natural gas leases are complicated, high-dimensional documents with many features, and in most states, the leasing phase is largely unregulated even though the leases play an important role in the *de facto* regulatory process. To condense the high-dimensional set of attributes that describe the types of leases we observe in Tarrant County, we create an index of lease quality using a property-value hedonic method. Using housing markets to value the individual lease attributes, we assess the value of the multidimensional lease by constructing our index using the utility weights determined by the hedonic estimates. However, using housing markets to value the lease attributes is not a straightforward exercise. We show how the values of the individual clauses are identified by the decisions of buyers in the market for split estate homes, but only using the split estate sample engenders an important censoring problem (i.e., we do not see the would-be split-estate price for most homes). We then describe how this problem can be mitigated by combining data from both the split and full-estate housing markets and extending the model to the "dual-gradient" framework suggested by Rosen (1979) and Roback (1982) and adapted to make the model appropriate for the shale gas setting. We use the duel-gradient model to recover the value for fourteen different lease clauses, using data on transactions of houses that already have leases associated with their minerals and drilling activity located within 2,000 meters of their property. These values are of independent interest and shine light on which sorts of restrictions are the most valuable.

In terms of environmental justice, we are interested in whether disadvantaged groups have equal protections from environmental risks expressed through added or redacted clauses that restrict firm behavior during the drilling and production phases of shale gas development. We explore our environmental justice questions by using the hedonic estimates to construct an index of lease quality, describing the aggregate value of the different clauses negotiated in each lease. Using the index values, we compare them to the attributes of the homeowner at the time the lease was signed. In particular, controlling for income, we measure whether race or ethnicity matters for the quality of the negotiated lease. In this piece of the analysis, we find that whether a household is of minority status, in particular, Black or Hispanic, is negatively correlated with our lease quality index, while these households are not necessarily disproportionately exposed to natural gas well development. A regression of lease quality on indicators for Black and Hispanic households results in negative and statistically significantly coefficients. Finally, we find that household composition is not related to the royalty rate paid, suggesting that minority households are not being monetarily compensated for low quality leases containing fewer landowner concessions.

Our results suggest environmental injustices whereby disadvantaged groups are facing a disproportionate exposure to environmental risks associated with shale gas activity. We conclude that shale gas is an environmental justice problem. If we assume that different racial groups have the same willingness to pay to avoid environmental damage from shale gas development, conditioning on income and other factors, then our results suggest that these disadvantaged groups are being inefficiently over-exposed to pollution risk. Among other causes, these households may be unable to express their true preferences during the lease negotiation, do not have full information about drilling consequences, or lack legal representation.

This paper proceeds as follows. Section 2.2 reviews the relevant literatures that we draw upon. Section 2.3 describes our data, which combine a novel source of information about the outcomes of lease negotiations with proprietary data on housing transactions, drilling activities, and mineral rights. Section 2.4 outlines the dual-gradient hedonic model, which explicitly incorporates leases and royalty payments into the homebuyer's optimization problem. Section 2.5 reports the results of several simple hedonic specifications followed by those from the dual-gradient model, and uses those results to measure the value placed on individual lease clauses by homeowners. Results suggest that the outcomes of lease negotiations have pecuniary repercussions, and that lease clauses are not distributed equitably across all types of households while controlling for observable factors like income and other households observables. Section 2.6 consists of our environmental justice analysis. We describe the lease negotiations in the context of Coasian bargaining outcome and report the estimates for our empirical specifications. Section 2.7 concludes with a discussion of our results and policy implications. Finally, we provide a series of appendices that describe the institutional and legal frameworks surrounding shale gas development in Texas (Appendix B.1), discuss the string matching, text scraping, and other procedures that are used to create our data (Appendix C.1), and detail the specific clauses that we extract from lease document (Appendix C.2).

2.2 Literature Review

The paper draws upon literature describing property value hedonic methods, Coasian bargaining, and environmental justice.

2.2.1 Hedonic Method

Hedonic models describe how homebuyers choose houses based on property and neighborhood characteristics. That choice process provides a theoretical construct with which to connect observed market outcomes to individual preferences, facilitating the measurement of welfare effects. Measuring the impacts of shale gas activity on property values is therefore one way to quantify its welfare effects. For a review of hedonic property value theory, see Freeman III et al. (2014), and Palmquist (2005) provides a review of the empirical literature. For a discussion of recent innovations in hedonic methods, see the discussion in Kuminoff et al. (2013).

There is a small (and growing) literature on the house price impacts of nearby shale gas development. No papers to date, however, have explored the effect of shale gas development on property values while controlling for leasing activity, nor have they measured the direct impact of shale gas leases on property values (either as sources of revenue to homeowners or as *de facto* regulations). In an early paper, Boxall et al. (2005) measured the house price effects of nearby (non-shale) sour gas wells in Alberta. More recently, Gopalakrishnan and Klaiber (2014) measure the temporal impact of shale gas wells in Washington County, Pennsylvania. Muehlenbachs et al. (2015) use data from all of Pennsylvania to conduct a triple-difference analysis of the effect of shale gas development on groundwater dependent homes, along with a double-difference analysis of the effect on all nearby homes regardless of water source. While that paper's results suggest small gains for houses dependent upon public water sources (likely from lease payments), it finds evidence of significant negative net effects on groundwater dependent houses. Other research has found similar evidence of concerns over risks to a household's water source (Throupe et al. (2013a)), or large negative effects on house values more generally (James and James (2014b)), although other researchers have found much smaller effects (Delgado et al. (2014)). Boslett et al. (2016) find a drop in house prices accompanying a moratorium on hydraulic fracturing in New York, suggesting that shale gas development is good for house values. Jacobsen (2015) finds evidence of increased house prices, rents and wages using a multi-county geography to define exposure to shale gas development. A related literature explores the impacts of shale gas development (and resource booms more generally) on employment and income.[8]

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[8] See Black et al. (2005), Allcott and Keniston (2014), Fetzer (2014), Maniloff and Mastromonaco (2014) and Jacobsen and Parker (2014).

2.2.2 Coasian Bargaining

The literature on the Coase Theorem is extensive; we do not attempt to summarize it here but rather refer the reader to one of several reviews (Schweizer (1988), Medema (1994), Zelder (1998), Medema (2014)). Coasian bargaining theory states that, in the absence of transaction costs and under well-defined property rights, parties will bargain to an efficient outcome in the presence of externalities. This will place the resource in question into its highest valued use, regardless of the initial allocation of property rights.

The size of the compensation paid by a polluter to a victim with property rights should depend upon both the victim's willingness to accept compensation in exchange for tolerating the externality and the magnitude of the externality. Bargaining power is also likely to have an effect - residents who are better able to organize themselves are better able to obtain outcomes favorable to their community. Jenkins et al. (2004) analyze the compensation offered by landfill operators to community leaders in exchange for being allowed to operate a nearby facility in the context of a Coasian bargaining process. Compensation packages of this sort became popular in negotiations between landfill developers and communities in the late 1980's. Using data on host fees paid by 104 largest privately owned solid waste landfills in 1996, the authors examine a number of characteristics that could potentially make bargaining payments larger. The primary factors that are found to affect the size of payments include citizen participation in negotiations, experience hosting a landfill, state mandates for minimum host compensation, and industry concentration (implying oligopoly rents and greater ability to pay). The authors find some indication of efficiency in the bargaining process, in that some measures of the severity of the externality (i.e., sludge and tires) do affect the size of the payment. However, they also find contradictory evidence in that lower host fees are paid the closer is the nearest subdivision to the facility.

Jenkins et al. (2004) take the size of the externality as given and model the determinants of the compensation payment, we model the results of the Coasian bargain over the size of the externality itself, and the subsequent division of the Coasian surplus. We argue in Section 2.6 that it is in the former where one should look for evidence of efficiency or inefficiency in the bargaining process.

In a study of the expansion plans of commercial hazardous waste facilities, Hamilton (1995) tests three theories for why exposure to environmental harms might vary with race: (i) pure discrimination, (ii) differences in willingness to accept payment for loss of environmental amenities linked to income or education, and (iii) propensity for collective action. The latter two explanations have connections to the theory of Coasian bargaining. In particular, firms will avoid locations where residents require a greater compensatory payment. They will also avoid locations where a tendency towards collective action will make payments more likely. It can be difficult to break the simultaneity between neighborhood characteristics and the presence of an environmental harm. Do nuisances locate in minority neighborhoods in an effort to avoid compensatory payments, or do neighborhoods become increasingly minority following siting decisions? Hamilton (1995) overcomes this problem and tests the hypotheses described above by using information on the planned capacity decisions of commercial hazardous waste facilities (i.e., looking to see how facilities' plans to expand vary with neighborhood attributes). Because those expansions have not yet taken place in the data, it is impossible for observed neighborhood demographics to have been determined by them. Hamilton (1995) finds that neighborhoods (zip codes) targeted for expansion in 1987-1992 had non-white population of 25% compared to 18% not targeted. Looking more specifically at the mechanism underlying this disparity, differences in the likelihood of raising firms' costs via collective action (measured by voter turnout) offer the best explanation, rather than pure discrimination or a simple Coasian bargaining story.

2.2.3 Environmental Justice

Analysts typically date the emergence of the environmental justice movement to a set of protests that followed the selection of a landfill site in the predominantly African-American community of Warren County, North Carolina in 1982 for the disposal of PCB's (Bullard (1994)). These protests were organized, in part, by the United Church of Christ Commission for Racial Justice, which went on to produce the first national-level analysis documenting the correlation between race and pollution (UCC 1987). These protests also prompted the U.S. General Accounting Office to carry out a study in 1983 showing that landfills were disproportionately located in Black communities, specifically in the U.S. South. US GAO (1983) and UCC (1987) were followed by a series of papers that demonstrated the correlation between race, poverty and exposure to environmental harm (Bryant and Mohai (1992), Brown (1995), Szasz and Meuser (1997), Boer et al. (1997), Ringquist (2005)). These studies found a significant disparity in proximity by race (even after controlling for income), local land use patterns, the percentage of employees in manufacturing, population density, and other relevant variables. Other analyses were more specifically focused on risk-based measures of pollution exposure, but found similar results (Morello-Frosch et al. (2002), Pastor et al. (2001), Bouwes et al. (2003), Ash and Fetter (2004), Morello-Frosch and Jesdale (2006)). In 2007, the UCC updated its 1987 analysis using information on hazardous waste facility locations and demographic data from the 2000 Census, finding that poor and minority groups were even more heavily concentrated around hazardous facilities than had been previously thought.

Analyses documenting the correlation between environmental harms and disadvantaged status (i.e., race and income) form the first strand of the environmental justice literature. A second strand seeks to explain the mechanism behind those correlations (Been (1994)). Understanding that mechanism is crucial for the design of effective policy. One story explains correlations as the result of the siting of nuisances, paying particular attention to the demographics at the time of siting (Hamilton (1995), Bullard (2000), Cole and Foster (2001), Saha and Mohai (2005)). A second story focuses instead on residential sorting, i.e., the tendency for disadvantaged groups to move into polluted areas where residences are less expensive ("coming to the nuisance").

We are not aware of any existing analyses of shale gas development from the perspective of environmental justice. Our paper seeks to document the existence of correlation between race, income, and lease terms that may be conducive to exposure to environmental harms.

2.3 Data

Our analysis employs a unique combination of lease, well activity, housing, and demographic data sets. This section details those sources of data and describes how certain variables are constructed. We have collected housing transaction and appraisal data from the Tarrant County Appraiser District office and Dataquick, a national real estate data aggregator. We link information about wells and leases to these data through a series of string-based address and name matches. Drilling data from the Texas Railroad Commission are used in conjunction with information from DrillingInfo. The Coasian analysis requires linking the housing data to data describing the demographics of each household (income, race, ethnicity, etc...), which is achieved by matching the property data to the Home Mortgage Disclosure Act Data (HMDA).[9] Finally, we generate a variable identifying leases where the mineral estate is likely split from the surface estate. Additional information about our data set and

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[9] The Home Mortgage Disclosure Act (HMDA) legislation passed in 1975 and amended in 1989 required lenders to collect demographic data to ensure fair and adequate lending and to limit discriminatory lending practices.

the procedures used to construct it is provided in Appendix C.1.

2.3.1 Housing Data

Information on housing transactions is the nexus for several connections between our data sources. In particular, leases are merged to the housing data by address and buyer/seller names using various string matching methods described in Appendix C.1, and well information is matched to the housing data using GIS software mapping tools.

We use appraiser data describing the household attributes compiled from the Tarrant County Appraiser District (TAD) office. TAD records document appraisals up to the present in addition to a file delineating all transactions in Tarrant County. We focus our analysis on appraised values because Texas is a non-disclosure state, meaning buyers and sellers are not required to report the transaction value of the house. We use a sample of houses with observed appraisals occurring between 2003 and 2013, and we construct a cross-section of those appraised values for each property. TAD also provides us with information on the houses' water sources (groundwater v. piped), and other geographic descriptions that can be merged to the data directly or spatially mapped to the houses using GIS software.

Table 2.1 summarizes housing attributes in our full sample of appraised houses and our estimation sample, and a detailed description of the composition of that sample follows at the end of this section. The appraisal value, age of the house, and drilling exposure (producing wells within a 2000-meter buffer at the appraisal date) are summarized using each of possibly many repeat appraisals for a given house. The house characteristics and groundwater use are summarized using unique property observations resulting in a smaller sample size for those variables. Comparing the house attributes of our estimation sample to the full sample, we see the estimation sample has more expensive and larger homes with less use of groundwater and more exposure to producing wells within a 2000-meter buffer at each appraisal date.

The Dataquick data provide us information about the financing used to purchase the houses transacted in our data, including lender name, loan amount, and whether or not the loan was a Federal Housing Administration (FHA) loan. This additional loan information allows us to connect our property value data to the HMDA data source using lender names, amounts, and a census tract identifier. The HMDA data adds to our data the home buyers' (loan applicants') income, race, ethnicity, and gender, along with whether the loan is a second lien, variable or fixed rate mortgages, or backed by Federal Housing Administration (FHA) or Veteran Administration (VA).

Table 2.2 summarizes the house and owner attributes for the sample used to conduct the Coasian analysis.[10] Similar to the summary statistics for the hedonic estimation sample, the appraisal values and drilling exposure are reported for the potentially repeat appraisals observed in the data that occur after the transaction action date. The race, ethnicity, and income variables from the HMDA data are reported for each observed transaction in the data.

2.3.2 Lease Data

The lease and lease contents are a primary and unique source of data used to describe the outcome of the bargaining process conducted between two parties – the lessee (i.e., who is typically an operator or third party "landman") and the lessor (i.e., the owner of the mineral rights, who is also the owner of the surface rights in the case of a full estate).[11] Signing the lease conveys the interests of the mineral estate from the lessor to the lessee.

Signing a comprehensive leasing document is important for households protect-

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[10] The hedonic and Coasian analyses use different samples of the dataset which will be described in greater detail below.

[11] Full estates are also referred to as fee-simple, or whole, estates.

ing their rights while they are royalty interest holders. In particular, lease terms can compensate for the absence of state or municipal regulations. Leasing agreements contain a set of primary clauses that are common to all leases drawn in the industry, and may also contain combinations of auxiliary clauses that are negotiable between lessors (mineral rights owners) and lessees (exploration and oil and natural gas production firms). Primary clauses include a careful description of the minerals leased to the lessee, information about the royalty payments owed to the lessor once the well begins to produce in paying quantities, the duration of the lease (i.e., primary term), and opportunities for extension once the primary term has expired. Auxiliary clauses are written into the agreement to protect one or both of the parties, but may not be included in all leases.

We have collected data describing the terms of these privately negotiated lease contracts. In particular, we have data describing the primary clauses (i.e., royalty rate and lease term) of all natural gas leases negotiated in Tarrant County, Texas between 2000 and 2013. In addition to the primary clauses contained in the leasing agreements, we have also collected auxiliary clauses for one third of the sample. The data period for auxiliary clauses with a large enough sample size begins in 2006 and ends in 2011. Our specific sample was collected from the "Drilling Down Series"[12] published by the *New York Times* from 2011 into 2012. We scraped these data and then mined the files for words and phrases indicating the existence of specific clauses using an algorithm written in Python. This process is described in Appendix C.1. We use six different auxiliary lease clause categories in our analysis. A list of these clauses and clause descriptions is included in Appendix C.2.

The full set of auxiliary lease clauses fall into several broad categories including strict legal requirements, clearer definitions of liability, additional environmental requirements, requirements for increased reporting by the lessee to the lessor regarding

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[12] `http://www.nytimes.com/interactive/us/DRILLING_DOWN_SERIES.html`

well activity, and restrictions on how a firm can access the mineral estate. A particularly important clause in Texas is the surface damage clause, which we capture by searching for phrases describing cleanup efforts and damage remediation. Mineral rights owners can negotiate a surface damage clause into the leasing agreement to protect the surface and use during production and ensure remediation after production ends. Surface owners are not owed any remuneration for the opportunity cost of the piece of their property lost during the drilling period or for reasonable damages to the land caused by drilling. If there is any perceived misuse of the land by mineral rights owners, surface owners are responsible for proving unreasonable conduct that does not include surface damage or inconvenience. Surface owners are somewhat protected by the Accommodation Doctrine, which protects existing surface owner use,[13] and surface owners can negotiate a separate addendum to the lease requiring surface protections.

Table 2.3 summarizes primary clauses (royalty rate, indicator for term length > 36 months) along with thirteen different auxiliary clauses that we use in our analysis. The table is split between the set of houses merged to leases with descriptions of auxiliary clauses and our hedonic estimation sample (i.e., the subset of those houses with active leases). Our hedonic estimation sample has a greater royalty rate and a longer term length, and among auxiliary clauses, the estimation sample has more environmental, noise restrictions, and indemnity clauses while the other clause occur with nearly the same frequency or are fewer. Table 2.4 describes the same lease variables for the Coase estimation sample.

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[13] If there exist alternative extraction methods, then reasonable usage might require a change on the part of the lessee under the Accommodation Doctrine (Vanham and Riley (2011)).

2.3.3 Well Exposure

Well permitting data are used to construct a variable describing well exposure from the perspective of the household at the time of the appraisal. Well permitting information comes from two sources: the Texas Railroad Commission and DrillingInfo, a proprietary aggregator of drilling activity information. Exposure is tabulated at different distance buffers surrounding the house, and if an operator has begun drilling a well by the appraisal date, the well is included in the exposure variable. We tabulate exposure based on 500, 750, 1000, and 2000-meter buffers, and the calculation differentiates between wells that are permitted, spudded, and producing. The primary exposure variable used in our analysis is the count of wells that are producing within a 2000-meter buffer. Table 2.5 summarizes well exposure over time for the full and estimation samples, revealing the dramatic growth in shale gas development in Tarrant County between 2003 and 2013. The exposure variable for wells located within 2000 meters of an appraised house in the estimation sample is large beginning in 2008.

2.3.4 Generation of Split Estate Identifier

Appendix B.1 provides legal background on the ability to sever mineral rights from the surface estate in Texas. We generate an indicator variable for each leased property describing whether the mineral rights are likely severed from the surface estate. This is an important variable to use as a control because owners of severed surface rights will not receive any royalty payments even if those payments are described in a lease. Unfortunately, split estates are not directly identified by the data. Rather, we determine what is a likely split estate based on a series of string matches that eventually compare the names of mineral rights owners signing leases with those of the individuals buying and selling properties in our housing data sets. After matching as many leases to properties as possible, we begin by merging all of the lease records and property identification numbers back to a list of all buyers and sellers associated with each house and each date of transaction to determine if and when names match between the housing and lease data.

We first look for perfect matches between names of individuals signing leases and buying or selling houses. We then proceed to identify close spellings using the Levenshtein string distance measure described in Appendix C.1. Using this function, we can find those names that are nearly the same (with differences likely arising from data entry errors) across data sets. After identifying the name matches, we can then use the transaction and lease date comparisons to finalize our split estate approximation. We consider two cases as evidence of a split estate: (i) the lease is matched to a property via address or another geographic identifier but the name of the signer does not match that of the person living on the property, and (ii) the lease is matched to the property via buyer or seller names, but the date the lease was signed is not consistent with when the house was sold. The inconsistency arises when, for example, the transaction date of the house precedes the date the lease was signed, but the name on the lease matches the seller of the house. In this case, mineral rights were likely severed at the time the house was sold.

Table 2.6 describes differences between houses and their leases depending upon the status of their mineral estate. Split estate homes tend to be smaller, older, and less expensive. They are on smaller plots of land and are exposed to fewer wells. Tables 2.10 and 2.11 report the percentage of leases that are split by city and by appraisal year in Tarrant County.

2.3.5 Sample Cuts

The paper comprises two analyses whereby the first is the property value hedonic analysis that uses the appraisal values of houses in the data that have signed leases for which we know the contents of the leasing documents and are located near to drilling activity. We chose to limit our sample to those houses located near to drilling activity because those households likely have active leases (i.e. firms are actively extracting natural gas from beneath their mineral estate) and the Tarrant County Appraisal District is likely aware of an active lease assigned to those properties because the state of Texas taxes the mineral estate once it is producing natural gas. As a consequence, the appraisal values are more reflective of an active natural gas well in terms of both added profitability from royalty payments and disamenities associated with drilling and production processes.

The second analysis evaluates the equitable distribution of leases with more landowner concessions using data that describe the households' demographic characteristics, which is built on the idea of Coasian bargaining outcome. This analysis uses properties that have been sold, matched to a lease for which we know the contents of the leasing documents, and the lease is signed after the transaction date, which is a different sample cut than that used in the hedonic analysis. Since the demographic data in HMDA is matched to properties based on lender names and amounts (along with the census tract identification), we only know the demographic data for loan applicants that have actually bought a house in Tarrant County within our data period spanning 2003 to 2013. Further, the lease must be signed after the transaction date for us to assign the demographic data to the landowner negotiating the lease. Below we describe how the samples are assembled in additional detail.

Considering how our hedonic analysis data are assembled, Table 2.12 summarizes the house attributes based on whether a house has been successfully merged to a lease, whether that lease has a full description of auxiliary terms, and whether the lease is considered active at the appraisal date (i.e., signed prior to the appraisal date). We begin with a sample of 215,638 house observations of which 95,525 houses are matched to leases as described in the first panel of Table 2.12. Of those 95,525 houses matched to leases, we have full descriptions of auxiliary clauses for 25,731 leases as described in the second pane of Table 2.12. Similarly, out of our sample of houses matched to leases, 69,794 of those leases are active at the time when the house is assessed as described in the first panel of Table 2.13. Finally, 14,764 houses have an active lease, a full description of auxiliary clauses, and drilling within 2,000 meters as described in the third panel of Table 2.13. We limit our analysis to only houses with drilling nearby, as the details of leases associated with these houses are more readily available to the assessor.

The second analysis begins with all properties that have transactions in our data period, 2003 to 2013, and landowners are observed signing leases after the transaction date. In particular, we are able to match 117,453 transactions in Dataquick properties to observations in the HMDA dataset using loan amounts, lender names, and census tract identifications. Of those Dataquick observations matched to HMDA, 91,067 observations have race and ethnicity data. Among those matched properties, 33,146 are matched to signed leases that are signed after the transaction date as described in the first panel of Table 2.14. Among those leases matched to properties, we have the clauses written into those leases for 9,140 observations as described in the second panel of Table 2.14, which is the data sample we use for the Coasian analysis.

2.4 A Dual Gradient Hedonic Model of Shale Gas Leases

In this section, we develop a model that uses information from the housing market to determine the values ascribed to each of the different lease clauses described in Appendix C.2. The goal is both to measure the value to homeowners of the *de facto* regulations carried out through leases, and to determine whether the outcomes of lease negotiations (including, but not limited to royalty rate) have pecuniary implications for homeowners. Importantly, mineral leases have the potential to affect utility in two ways; both directly, through the provision of royalty payments, and indirectly, through the restrictions imposed on the actions of operators. For full estates, we demonstrate that this requires two gradients to describe the total impact of lease clauses on utility, and go on to show how full- and split-estate households can be used together to recover willingness-to-pay estimates.

First, consider royalties, which provide direct payments to homeowners in the case of full estates, and payments to absentee mineral rights holders in the case of split estates. Royalty payments are determined along with other clauses as part of a lease negotiation process conducted between the drilling company or a third-party “landman” and the current owner or previous seller of the house. Bargaining over lease attributes at the time of signing may have included royalties, lease term, legal and environmental clauses, and a bonus payment. The bonus payment, however, is a one-time payment received by the mineral rights owner at the time of signing that is not capitalized into the value of the house. This negotiation process leads to a complicated relationship between royalty payments and the various lease clauses. That relationship reflects the tradeoffs that are required of subsequent homebuyers; we take those tradeoffs as exogenous constraints facing the buyers of homes with mineral leases.

The contents of leases determine the impacts of local shale gas development on homeowners and the compensation they receive. One or both of these factors will be attached to the housing unit (depending upon mineral rights), and their values will therefore be reflected in housing market outcomes. We adapt the Rosen-Roback dual gradient hedonic framework (Rosen (1979), Roback (1982)) to value lease attributes (including royalty payments, lease term and auxiliary clauses) from the point of view of homeowners, accounting for mineral rights status. We begin by modeling the decision of a homebuyer in a shale gas area. Different homes have different combinations of exposure to shale gas development, mineral rights, and lease clauses, although we restrict our analysis to the estimation sample.

$$max_{\{X,H,L\}} \quad U(X,H,L,P) \quad \text{s.t.} \quad X + P(L,H) = I + e^{\alpha} R(L,PP,T,H) \tag{2.1}$$

L	Vector of auxiliary lease clauses
T	Lease Term Dummy ($= 1$ if term > 36 months)
H	Vector of house (and neighborhood) attributes
$P(L,H)$	Annualized house value (5% of appraisal value)
$R(L,PP,T,H)$	Royalty rate x land area (if fee simple mineral rights; $= 0$ if split estate)
α	Scale parameter making royalty payments comparable to annualized house price in budget constraint
I	Exogenous income (i.e., not including royalty payments)
X	Numeraire commodity ($P_x = 1$)

H includes the traditional list of house attributes (square footage, number of bedrooms and bathrooms, lot-size, water source), a vector of municipal dummy variables (i.e., to proxy for local public goods), and a measure of well exposure (i.e., number of spudded wells within 2km). The appraisal value, $P(L,H)$, is a function of these house attributes as well as the vector of auxiliary clauses, L, contained in the house's lease. $R(L,PP,T,H)$ is a simple proxy for royalty payments; it is measured by the royalty rate (which typically varies between 0.18 and 0.25) multiplied by land area (measured in $\text{ft}^2/1000$). We allow this proxy to vary with the vector of auxiliary lease clauses (L), an added clause describing whether or not firms can deduct post production costs from the royalty owed to a landowner (PP),[14] lease term (T),[15]

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[14] Post production cost is a binary variable where a one indicates that firms cannot deduct post production costs from the royalty owed to the landowner thereby increasing the value of the royalty to the landowner.

[15] The lease term length is the number of months allowed for the firm to begin drilling a well

and the size of the landowners' property (H^{land}). We include measures describing the lease clauses and term length since they were jointly negotiated (along with any bonus payments)[16] by the mineral rights holder and lessee at the time when the lease was signed. In particular, our royalty equation is defined below.

$$R(L, PP, T, H) = H_i^{land} e^{\rho_0 + L_i'\rho_1 + PP_i'\rho_2 + T_i'\rho_3 + \omega_i}$$

Substituting the budget constraint in the place of X yields indirect utility:

$$\text{Full Estate: } V^F(I + R(L, PP, T, H) - P(L, H), L, H) \tag{2.2}$$

$$\text{Split Estate: } V^S(I - P(L, H), L, H) \tag{2.3}$$

Taking the derivative of full-estate indirect utility with respect to a particular lease clause l yields an expression for the willingness-to-pay for that clause:

$$\tfrac{\partial V^F}{\partial X}\{e^{\alpha}\tfrac{dR}{dl}\Big|_F - \tfrac{dP}{dl}\Big|_F\} + \tfrac{\partial V^F}{\partial l} = 0$$

$$WTP_l^F = \frac{\partial V^F/\partial l}{\partial V^F/\partial X} = \frac{dP}{dl}\Big|_F - e^{\alpha}\frac{dR}{dl}\Big|_F \tag{2.4}$$

The terms in this expression are easily observed except for the term that converts our royalty proxy into an income flow. For split-estate households:

$$\tfrac{\partial V^S}{\partial X}\{-\tfrac{dP}{dl}\Big|_S\} + \tfrac{\partial V^S}{\partial l}$$

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before the mineral rights revert back to the landowner. Presumably, after the initial lease expires, the landowner is able to sign a lease with another firm. In our analysis, the term length is represented as a dummy that is equal to one when the lease term is greater than 36 months long.

[16] The bonus payment is a one-time payment made to the lessor at the time of signing, and does not yield any future benefits. Its value is, therefore not capitalized into the transaction price of the home, and does not impact the budget constraint of any future buyers.

$$WTP_l^S = \frac{\partial V^S/\partial l}{\partial V^S/\partial X} = \frac{dP}{dl}\Big|_S \tag{2.5}$$

While it is therefore possible to recover willingness-to-pay for lease clause l from the split estate housing market price gradient alone, the strong statistical relationship between lease clauses and split estate status suggests a selection problem that will lead to biased estimates. Without a clear exclusion restriction (i.e., a variable that will predict split-estate status but is excluded from the price equation), the traditional Heckman correction (Heckman (1977)) cannot be implemented. Instead, we rely on a simple assumption – that the home buyer's willingness-to-pay for a lease attribute is the same regardless of which housing market the individual operates in. We can then combine information from all house assessments – split and full.

Begin by writing down a hedonic price function for each type of house:

$$\text{Full Estate: } P_i = \beta_0 + H_i'\beta_1 + L_i'\beta_2 + \epsilon_i \tag{2.6}$$

$$\text{Split Estate: } P_i = \theta_0 + H_i'\theta_1 + L_i'\theta_2 + \xi_i \tag{2.7}$$

The royalty equation only applies to full-estate homes, and reflects the fact that all lease clauses and royalties are negotiated simultaneously.

$$\text{Full Estate: } R_i = H_i^{land} e^{\rho_0 + L_i'\rho_1 + PP_i'\rho_2 + T_i'\rho_3 + \omega_i} \tag{2.8}$$

$$\text{Split Estate: } R_i = 0 \tag{2.9}$$

Assuming that the preferences of buyers of split and full estate houses are the same, we can impose the following restrictions:

$$\theta_1 = \beta_1 \tag{2.10}$$

$$\theta_2 = \beta_2 - \frac{dR}{dl}\Big|_F \tag{2.11}$$

$\forall\, l \in L$. Defining a dummy variable $s_i = 1$ if observation i is a split estate ($= 0$ if a full estate), we can combine the two price equations and estimate the following system of equations using non-linear least squares:

$$P_i = \beta_0(1 - s_i) + \theta_0 s_i + H_i'\beta_1 + L_i'\beta_2 - s_i L_i' \frac{dR}{dL}\Big|_F + \nu_i \tag{2.12}$$

$$R_i = H_i^{land} e^{\rho_0 + L_i'\rho_1 + PP_i'\rho_2 + T_i'\rho_3 + \omega_i}(1 - s_i) \tag{2.13}$$

In the results that follow, one can therefore read willingness-to-pay for auxiliary clauses from the split-estate parameters, which are estimated subject to the constraints described above.

2.5 Results

2.5.1 Simple Hedonic Model

We begin with a simple property value hedonic specification using the inflation-adjusted appraisal value (i.e., adjusted for inflation using the consumer price index and January 2000 as the base year), housing attributes, lease characteristics, and dummy variables to control for the city where the property is located, the appraisal year, and the firm identities signing the leases with the landowners. We restrict attention to houses with active drilling, as we do not expect housing assessors to necessarily be aware of lease characteristics for leased houses without active drilling. We focus our attention on column (3) of Tables 2.15 and 2.16, where we restrict our attention to houses from the split estate sample, as the model in the previous section demonstrates that we can indeed learn about homebuyers' preferences for lease clauses from the gradient recovered from this market. These results make no use of information from the full-estate housing market, nor do they control for selection into split-estate status.

A few variables in the split estate specification are statistically significant. We do find that households place a positive value on restrictions on *Saltwater Disposal* well and *Compression Station* placements, and *No Surface Access*. In the lower panel of the table, we also find that split estate households value the *Force Majeure* clause that requires firms to resume drilling within a specific period of time after a natural occurrence ceases well production.

Column (2) of Tables 2.15 and 2.16 report values for a simple hedonic using only full-estate houses. As the residents of these houses receive royalty payments, we include the royalty rate as a regressor. However, as the model in the previous section makes clear, there is no welfare-theoretical interpretation for this equation. We provide these results here simply for the sake of comparison. More coefficient estimates are significant and have sensible signs, although it is not clear how to interpret them in a welfare context.

Finally, in column (1) of Tables 2.15 and 2.16 we report a royalty equation that captures the suggested trade-offs between the negotiated royalty rate and the other clauses written into the leases. We report this regression as we move towards the dual-gradient model where this trade-off is modeled explicitly for full estate households.

2.5.2 Dual-Gradient Hedonic Model

Tables 2.17, 2.18, and 2.20 report the results from the dual-gradient hedonic model of shale leasing. Table 2.17 reports the coefficients shared by both full and split estate households in the hedonic equations, including house attributes, proximity to drilling activity, access to groundwater, and the mean values of being located in specific cities across Tarrant County Texas (city-level fixed effects). Coefficient values are consistent with priors, and most are statistically significant. Beginning with the top panel of Table 2.10, we find that our coefficients for house attributes make intuitive sense. Further, controlling for rural households, we find that accessing groundwater has a negative relationship with house appraisal values. All houses in the estimation sample are exposed to drilling at the time of the appraisal. Finally, we find that location near to drilling and producing activity has a negative and statistically significant effect on the annualized appraised values, echoing the results in Muehlenbachs et al. (2015).

The second panel reports the city-level fixed effects that describe the mean relationship between the location of a particular house and appraisal values. Most of these coefficients are statistically significant, and the largest range of values exists between houses located in Burleson (-2,348.81) and Grapevine (2,340.33). The two highest-valued communities correspond to casual evidence on school quality. The Grapevine-Colleyville School District contains eleven "National Blue Ribbon" schools, and has high-schools ranked among *U.S. News* and *Newsweek's* "Best High Schools" lists. The Burst-Euless-Bedford School District similarly was given a "What Parent's Want" Award each year from 1994-2012 from *SchoolMatch*, and the Education Resources Group named it a top school district in Texas in 2011 and in earlier years. Moreover, from 2007-2014, the American Music Conference recognized the district's Suzuki Strings program for creating one of the "Best Communities for Music

Education" in Texas.[17]

Table 2.18 reports the coefficients for each of the lease clauses across split- and full-estate hedonic and royalty equations. The interpretable column includes the hedonic coefficients for the split-estate households (first column), where constraints are imposed so that these estimates have a willingness-to-pay interpretation. In the reported specification, we find that the majority of more protective clauses are valued by households including: *Environmental* protection, *Surface Damage* (weakly significant), restrictions on *Saltwater Disposal* wells and *Compression Station* placements, *No Surface Access*, *Attorney Fees* (that are largely covered by the firms) and *Force Majeure*. Similarly, those clauses that increase the disamenities experienced by landowners have a negative coefficient, which includes *Injection Fluid* and *Subsurface Easements*. We find counterintuitive results for clauses that allow *Free water* access for drilling operations and added *Freshwater* protection; however, the latter of these is insignificant.

Compared to the simple hedonic model, we find that households value a larger fraction of the added protections (and do not value those clauses that increase their exposure to drilling disamenities) when using the dual gradient model that takes advantage of both the full and split estate observations.

2.6 Environmental Justice and Coasian Bargaining

We motivate our environmental justice empirical specification that explores the equitable distribution of leases containing more protective clauses with a brief discussion of the Coase Theorem and Coasian bargaining. The simplest version of the Coase Theorem states that, in the absence of prohibitive transaction costs and with

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[17] See http://info.tommypennington.com/blog/bid/387527/Which-Tarrant-County-School-District-is-Right-for-Your-Family.

well-defined property rights, parties will negotiate to an efficient equilibrium in the presence of an externality. Efficiency is defined either in marginal terms (i.e., the cost of the last unit of the externality borne by the victim is equal to the benefit of that unit of externality to the polluter) or in discrete terms (i.e., property rights will be allocated so that the resource in question is put into its highest value use).

In negotiations for the rights to shale resources, property rights are well-defined and lie with the mineral rights holder. In the case of a whole estate, the owner of the mineral rights is the same as the owner of the surface rights associated with the property. In the case of a split estate, the mineral rights and surface rights holders are different individuals. In terms of transaction costs, mineral leases are legally binding agreements between a lessor and a lessee that are enforced by U.S. courts. Many lease components are standardized. While lawyers may be involved in the negotiation process (helping to mitigate problems of asymmetric information), transaction costs are likely to be low. As such, this is an area where we might expect the Coase Theorem to apply.

In particular, we identify all of the disamenities associated with proximity to drilling activity, which includes (but is not limited to) air, light, noise, and water pollution (or the risk thereof), surface damage and alteration of the terrain. Some of these activities may be regulated by municipal ordinances and they may be privately "regulated" by clauses negotiated into leases. Because compliance with added restrictions is costly, the marginal value of producing disamenities through drilling a natural gas well is positive but decreasing for the operating firms. Added to the benefits are actual revenues that result from selling the natural gas extracted from the well.

In the lease setting, the landowner (who we assume for now is also the mineral rights holder) owns the property rights, and assuming the landowner has a marginal cost for drilling disamenities, zero negotiations imply that the well is never drilled. However, since the operating firms benefit from producing disamenities (via drilling a well), the firms are willing to compensate the landowners up to the point at which the marginal benefit to the firm is equal to the marginal cost experienced by the landowner. As a consequence of a negotiated level of produced disamenity, a Coasian surplus is generated and divided between the firm and landowner relative to their respective bargaining powers.

Analogously, in an equilibrium setting, firms derive a total benefit from drilling a well, extracting natural gas, and earning revenue from the sale of natural gas, and landowners experience a total cost to being located near to the drilling activity. However, landowners own the property rights and firms have a price they are willing to pay to compensate the landowners for their experienced disamenity. Under efficient Coasian bargaining, negotiators first maximize the bargaining surplus by choosing a level of disamenity that maximizes the difference between the total benefit of drilling (and generating disamenities) to firms and total costs to landowners. A separate negotiation subsequently divides the bargaining surplus between the negotiating parties. In our setting, the royalty split of future revenues from natural gas sales resembles the surplus split in the theoretical setting.

The equilibrium level of disamenity is determined by variables that affect the willingness-to-pay (WTP) to avoid exposure to the disamenity. Hamilton (1995) refers specifically to income and education. We also include the spatial controls[18] and a dummy variable indicating that the house relies upon groundwater. Variables like income, education, and family structure and water source might also influence bargaining power, which determines how the Coasian surplus is divided between the

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[18] We control for unobservable characteristics that maybe be similar for households located near to one another by including wellpad fixed effects. This should compensate for having fewer micro-level controls that describe the household size and prevalence of children and the elderly in the households for which we only have census tract-level controls.

driller and the lessor in the setting of the royalty rate. We might also expect variables such as race and linguistic isolation to have an effect on bargaining power and the royalty rate. It is, however, difficult to think of a reason why, after controlling for income, education and family structure, race and linguistic isolation should have an independent effect on the level of disamenity, and finding evidence that it does suggests we are not in an efficient Coasian outcome (i.e., the disamenity is being determined by factors aside from marginal costs and benefits). We test this hypothesis explicitly in our empirical specification presented in Table 2.21.

2.6.1 Coasian Results

The results in Table 2.21 report the estimates for a regression of the lease quality index on the observable characteristics of the household and wellpad and year fixed effects. In particular, we use the hedonic estimates and the variance/covariance matrix from the dual gradient model to draw 1,000 parameter estimates. Using the random parameter estimates, we construct an index measure of lease clause quality, and for each draw, we run a Coasian regression of index quality on the households' race, ethnicity, income, land size, a groundwater dummy, and wellpad and year fixed effects. We report only the results for full estate households because we know the landowner characteristics for those negotiated leases based on how the sample is constructed. We find a negative relationship between all non-white (excluded race dummy) households and lease index quality, while the effects for Asian and Black are smaller than those for Hispanic.[19]

These results suggest that, controlling for observable characteristics and mean-level unobservables (via fixed effects), race and ethnicity are correlated with the type of lease signed. In particular, we find that among full estates, those leases negotiated

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[19] We removed AIAN households from this analysis because they had too few observations.

between minority landowners and firms are potentially of lower quality.

In addition to the Coasian regressions using a lease quality index, we report similarly constructed regressions that use individual lease clauses as the dependent variables, which are reported in Tables 2.22 and 2.23. Table 2.22 reports the regression results for lease clauses that are more protective of landowners. We find that Hispanic households are negatively and significantly correlated with inclusion of these added restrictions, and the other minority households also have a negative relationship though the coefficients are not significant as often. Table 2.23 reports the results for additional clauses. Columns (11), (13), (14), and (15) report results for clauses that benefit the firm (or lessen their restrictions), and we find that the results tell a consistent story whereby Hispanic households are positively correlated with these lease "bads."

In Column (10), we report the results for a regression that uses the royalty rate on the left-hand side and find that there is not a significant relationship between race and ethnicity and the negotiated royalty rate. We use this regression to support the idea that minority households do not appear to be monetarily compensated for signing fewer landowner concessions. Table 2.26 further supports absent compensation as we find that there is a negative relationship between race and ethnicity and bonus values among the small sample of bonuses that we observe in our data.[20]

The final Table 2.27 reports the results of simple regressions relating well exposure to our race and ethnicity variables and other controls to capture whether minority households are disproportionately exposed to well development. We find that there is a positive relationship between race and ethnicity and being located to higher count of wells.

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[20] The first column reports regressions without firm fixed effects and the the second specification includes firm fixed effects.

2.7 Conclusions

The purpose of this analysis is two-fold: (1) measure consistent hedonic estimates that capture the value of the specific lease attributes to landowners signing natural gas leases in Tarrant County Texas and (2) use the hedonic estimates to explore whether there is environmental injustice among minority households in the shale gas leasing market. We find that accounting for the full and split estate households in our dual gradient hedonic model allows us to capture a willingness-to-pay for lease clauses that protect the landowner from drilling disamentities as the firms actually begin well operations located near to those properties. Using the hedonic estimates, we then find there is a negative correlation between the households' race and ethnicity and the quality of lease negotiated when controlling for other observable characteristics, some that may determine a landowner's willingness-to-accept proximity to drilling disamenities. This latter result suggests that there may be environmental injustice whereby minority households are offered lower quality leases and they are not negotiated further to include additional protective clauses.

Future work will investigate this question of environmental injustice in the natural gas lease setting further by exploring these relationships in the context of group negotiations and access to legal advice.

Table 2.1: House Attributes by Full and Hedonic Samples

	Full Sample			**Estimation Sample**[a]		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
Appraisal value[b]	132176.4	215638	92870.94	107457.7	14764	71769.65
Age (house)	23.61	215638	22.27	28.5	14764	20.07
Land (sqft)[c]	10229.8	136510	7828.19	9515.57	8242	5705.24
Living area (sqft)	2137.74	136510	878.47	1926.76	8242	731.23
Bedroom	3.38	136510	0.7	3.32	8242	0.63
Bathroom	2.12	136510	0.65	2.03	8242	0.54
Groundwater	0.64	136510	0.48	0.72	8242	0.45
Drilling (within 2000 m)[d]	3.58	215638	5.42	4.13	14764	3.67

[a] Properties with an active lease, observed auxiliary clauses, and a drilled well located within 2000 meters.

[b] Appraisal, age, and drilling are summarized for the full sample.

[c] Land, living, bedroom, bathroom, and groundwater are summarized for the unique set of properties observed in the data.

[d] Exposure to wells located within 2000 meters of any appraised house at the appraisal date.

Table 2.2: House Attributes by HMDA Samples[a]

	Mean	N	Std. Dev.
Appraisal value[b]	120939.9	9140	83142.5
Hispanic[c]	0.22	6212	0.41
Asian	0.05	6212	0.21
Black	0.11	6212	0.32
AIAN	0.01	6212	0.09
White	0.83	6212	0.38
Income (1e4)	78.02	6212	72.78
Groundwater	0.72	6212	0.45
Land (sqft)	9915.82	6212	6133.62
Living area (sqft)	2043.67	6212	809.53
Drilling (within 2000 m)	5.37	9140	5.53

[a] Properties with a lease signed after the transaction date and observed auxiliary clauses.

[b] Appraisal and drilling are summarized for the full HMDA sample.

[c] Hispanic, asian, black, white, income, groundwater, land, and living area are summarized for the unique set of properties and transactions observed in the data.

Table 2.3: Lease Attributes by Full and Hedonic Samples

	Full Sample		**Estimation Sample**	
	Mean	Std. Dev.	Mean	Std. Dev.
Primary:				
Royalty rate	0.23	0.04	0.23	0.04
Term length (> 36 months)	0.11	0.32	0.27	0.45
Auxiliary:				
Environmental	0.31	0.46	0.42	0.49
Surface Damage	0.53	0.5	0.49	0.5
Freshwater	0.03	0.16	0.04	0.19
Free Water	0.25	0.43	0.33	0.47
Injection Fluid	0.02	0.14	0.03	0.17
Salt Water Well	0.01	0.08	0.01	0.09
Compression Station	0.01	0.08	0.01	0.08
No Surface Access	0.56	0.5	0.76	0.43
Subsurface Easement	0.42	0.49	0.57	0.5
Legal Bundle	0.31	0.46	0.43	0.49
Attorney Fees	0.03	0.16	0.03	0.18
Force Majeure	0.25	0.43	0.33	0.47
Post Production Cost	0.01	0.12	0.01	0.12
Royalty Obs	57840		14788	
Term Obs	215962		14788	
Clause Obs	25782		14788	

Table 2.4: Lease Attributes HMDA Sample

	Mean	Std. Dev.
Primary:		
Royalty rate	0.23	0.05
Term length (months)	42.37	12.31
Auxiliary :		
Environmental	0.21	0.41
Surface Damage	0.53	0.5
Freshwater	0.02	0.14
Free Water	0.25	0.43
Injection Fluid	0.02	0.13
Salt Water Well	0	0.05
Compression Station	0	0.06
No Surface Access	0.53	0.5
Subsurface Easement	0.41	0.49
Legal Bundle	0.28	0.45
Attorney Fees	0.02	0.15
Force Majeure	0.23	0.42
Post Production Cost	0.01	0.1
Royalty Obs	11161	
Term Obs	11161	
Clause Obs	11161	

Table 2.5: Count of Producing Wells Within 2000 Meters

Panel (a): Count of producing wells within 2000 meters

	Full Sample			**Estimation Sample**		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
2003	0.04	1887	0.29	0.00	0.00	0.00
2004	0.21	4035	0.85	0.00	0.00	0.00
2005	0.64	4820	1.84	0.00	0.00	0.00
2006	1.21	11334	2.53	11	3	13.86
2007	1.52	16030	3.49	8.05	19	11.09
2008	4.81	24284	7.24	5.51	295	6.49
2009	4.14	16291	6.41	4.6	522	4.29
2010	3.29	38672	5.28	3.15	3447	3.05
2011	3.54	56568	4	4.08	6043	3.14
2012	4.98	23321	6.63	4.1	2502	3.65
2013	5.82	17975	6.14	5.71	1957	4.5

Panel (b): Minimum distance to producing wells

	Full Sample			**Estimation Sample**		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
2003	1233.38	403	430.06	0.00	0.00	0.00
2004	1171.26	1043	469.12	0.00	0.00	0.00
2005	1089.13	1959	498.57	0.00	0.00	0.00
2006	1071.01	6211	514.86	660.1	3	359.24
2007	1107.63	10107	508.55	1095.71	19	533.73
2008	894.69	21026	488.09	962.75	295	485.93
2009	894.53	14646	465.97	873.45	522	409.11
2010	909.45	35554	439.08	904.28	3447	377.04
2011	927.59	50064	426.98	921.81	6043	368.84
2012	904.03	21210	457.88	990.47	2502	406.79
2013	891.16	16902	449.11	885.81	1957	361.76

Table 2.6: Household Characteristics by Mineral Estate Status (Split vs. Full), Hedonic Sample

	Full Estates			**Split Estates**		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
Estimation Sample: Active lease and drilling						
Annualized appraisal value	107958.9	13527	71691.98	101853.4	1261	73306.79
Age (house)	28.23	13503	19.91	31.39	1261	21.46
Land (sqft)	9828.44	10302	6496.67	9528.89	948	5701.14
Living area (sqft)	1989.65	10302	769.32	1875.72	948	752.8
Bedroom	3.34	10302	0.65	3.26	948	0.62
Bathroom	2.05	10302	0.56	2.01	948	0.59
Groundwater	0.68	10302	0.47	0.66	948	0.48
Drilling (within 2000 m)	4.13	13527	3.65	4.19	1261	3.79

[a] Land, living, bedroom, bathroom, and groundwater are summarized for the unique set of properties observed in the data.

Table 2.7: Lease Attributes by Mineral Estate Status (Split vs. Full), Hedonic Sample

	Full Estates		**Split Estates**	
	Mean	Std. Dev.	Mean	Std. Dev.
Primary:				
Royalty rate	0.24	0.04	0.22	0.07
Term length (> 36 months)	0.28	0.45	0.26	0.44
Auxiliary:				
Environmental	0.43	0.49	0.36	0.48
Surface Damage	0.49	0.5	0.51	0.5
Freshwater	0.04	0.19	0.04	0.2
Free Water	0.33	0.47	0.37	0.48
Injection Fluid	0.03	0.17	0.02	0.15
Salt Water Well	0.01	0.09	0.01	0.09
Compression Station	0.01	0.08	0.01	0.08
No Surface Access	0.76	0.43	0.74	0.44
Subsurface Easement	0.57	0.5	0.59	0.49
Legal Bundle	0.43	0.5	0.38	0.48
Attorney Fees	0.03	0.18	0.04	0.2
Force Majeure	0.34	0.47	0.28	0.45
Post Production Cost	0.01	0.12	0.02	0.12
Royalty Obs	13527		1261	
Term Obs	13527		1261	
Clause Obs	13527		1261	

Table 2.8: Split Estate Probits, Hedonic Sample

	Split Estate Dummy	St. Dev.	Obs.
Term (>36 months)	-0.020	(0.044)	13,127
Environmental	-0.164***	(0.040)	14,833
Surface Damage	-0.051	(0.041)	14,849
Freshwater	0.055	(0.076)	13,764
Free Water	0.119***	(0.040)	14,882
Injection Fluid	-0.060	(0.083)	13,802
Salt Water Well	-0.066	(0.137)	5,192
Compression Station	-0.033	(0.152)	5,651
No Surface Access	-0.072*	(0.041)	14,844
Subsurface Easement	0.045	(0.040)	14,849
Legal Bundle	-0.125***	(0.041)	14,841
Attorney Fee	0.110	(0.072)	14,304
Force Majeure	-0.136***	(0.043)	14,816
Post Production Costs	0.111	(0.113)	12,248
City FE	yes		
Period FE	yes		
Firm FE	no		

Table 2.9: Split Estate Probits, Household Characteristics

	(1)	(2)
Hispanic	-0.017**	-0.019***
	(0.007)	(0.006)
Asian	-0.003	-0.001
	(0.011)	(0.011)
Black	-0.022***	-0.021***
	(0.007)	(0.007)
HH Income	0.067	0.145**
	(0.064)	(0.073)
HH Income squared	-0.072	-0.122*
	(0.052)	(0.064)
Land area (in sqft)	0.000	0.001
	(0.001)	(0.001)
Groundwater	0.012	0.009
	(0.021)	(0.021)
Rural	-0.010	-0.010
	(0.026)	(0.025)
Appraisal Value (log)		-0.028***
		(0.009)
Observations	8,470	8,470
R-squared	0.135	0.136
Period FE	Yes	Yes
Wellpad FE	Yes	Yes

Table 2.10: Percentage Split Estates by City (Hedonic Sample)

	Full Sample			**Estimation Sample**		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
Arlington	0.08	23613	0.27	0.08	4257	0.27
Azle	0.15	308	0.36	0.11	56	0.31
Bedford	0.14	1039	0.34	0.00	9	0.00
Benbrook	0.11	1227	0.31	0.11	324	0.31
Burleson	0.1	639	0.29	0.19	32	0.4
Colleyville	0.1	1586	0.31	0.00	7	0.00
Crowley	0.09	901	0.29	0.08	120	0.28
Dalworthington	0.1	164	0.3	0.18	34	0.39
Edgecliff Village	0.09	141	0.28	0.05	19	0.23
Euless	0.07	1970	0.25	0.1	248	0.3
Everman	0.1	298	0.31	0.11	97	0.32
Forest Hill	0.11	793	0.31	0.14	125	0.35
Fort Worth	0.11	32479	0.31	0.1	5014	0.3
Grand Prairie	0.06	3692	0.23	0.04	795	0.21
Grapevine	0.08	1836	0.28	0.1	60	0.3
Haltom City	0.1	2072	0.29	0.07	647	0.26
Hurst	0.09	2169	0.29	0.07	363	0.25
Keller	0.1	2281	0.3	0.15	78	0.36
Kennedale	0.1	481	0.31	0.07	107	0.25
Lakeworth	0.11	99	0.32	0.00	4	0.00
Mansfield	0.07	6360	0.25	0.07	1043	0.25
N. Richland Hills	0.08	4152	0.27	0.08	648	0.27
Richland Hills	0.09	999	0.29	0.04	181	0.19
River Oaks	0.12	430	0.33	0.1	42	0.3
Saginaw	0.13	551	0.34	0.21	38	0.41
South Lake	0.07	2597	0.26	0.4	5	0.55
Watauga	0.1	1315	0.3	0.1	192	0.31
White Settlement	0.11	583	0.32	0.16	126	0.37

Table 2.11: Percent Split Estate by Year (Hedonic Sample)

	Full Sample			**Estimation Sample**		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
2003	0.06	963	0.24	0.00	0.00	0.00
2004	0.07	2118	0.25	0.00	0.00	0.00
2005	0.06	2356	0.25	0.00	0.00	0.00
2006	0.07	4624	0.26	0.00	3	0.00
2007	0.09	7338	0.29	0.11	19	0.32
2008	0.11	8946	0.32	0.11	295	0.31
2009	0.12	6223	0.32	0.12	522	0.33
2010	0.09	19037	0.29	0.08	3447	0.28
2011	0.09	26139	0.29	0.09	6043	0.28
2012	0.09	10425	0.28	0.08	2502	0.27
2013	0.09	7053	0.29	0.07	1957	0.26

Table 2.12: House Attributes by Hedonic Sample Cuts

	Lease Match			**No Lease**		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
Appraisal value	128498.8	95525	94664.44	135101.2	120113	91314.19
Age (house)	28.91	95525	22.07	19.4	120113	21.52
Land (sqft)[a]	10463.47	61419	7479.16	10038.66	75091	8097.54
Living area (sqft)	2064.56	61419	865.03	2197.61	75091	884.82
Bedroom	3.34	61419	0.68	3.4	75091	0.72
Bathroom	2.09	61419	0.66	2.15	75091	0.64
Groundwater	0.69	61419	0.46	0.59	75091	0.49
Drilling (within 2000 m)	2.47	95525	3.62	4.47	120113	6.37

	Auxiliary Clauses			**No Auxiliary Clauses**		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
Appraisal value	119121.6	25731	85656.54	131955.9	69794	97549.65
Age (house)	28.85	25731	21.13	28.93	69794	22.4
Land (sqft)	10069.24	16622	6497.78	10609.76	44797	7807.01
Living area (sqft)	2020.43	16622	819.26	2080.93	44797	880.85
Bedroom	3.34	16622	0.66	3.35	44797	0.68
Bathroom	2.07	16622	0.62	2.1	44797	0.68
Groundwater	0.68	16622	0.47	0.7	44797	0.46
Drilling (within 2000 m)	2.68	25731	3.64	2.39	69794	3.61

[a] Land, living, bedroom, bathroom, and groundwater are summarized for the unique set of properties observed in the data.

Table 2.13: House Attributes by Hedonic Sample Cuts *(Continued)*

	Active lease			**Not active lease**		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
Appraisal value	124074.3	69271	92634.04	136010.9	146367	92736.71
Age (house)	30.3	69271	21.85	20.45	146367	21.76
Land (sqft)	10261.02	37948	7341.61	10217.77	98562	8007.65
Living area (sqft)	1991.58	37948	819.25	2194.02	98562	893.88
Bedroom	3.32	37948	0.65	3.4	98562	0.71
Bathroom	2.07	37948	0.63	2.14	98562	0.66
Groundwater	0.72	37948	0.45	0.61	98562	0.49
Drilling (within 2000 m)	2.99	69271	3.77	3.87	146367	6.03

	Active lease & drilling			**Active lease & no drilling**		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
Appraisal value	107457.7	14764	71769.65	147793.7	4194	111623.1
Age (house)	28.5	14764	20.07	33.26	4194	20.9
Land (sqft)	9515.57	8242	5705.24	10648.71	2096	6557.49
Living area (sqft)	1926.76	8242	731.23	2090.87	2096	891.43
Bedroom	3.32	8242	0.63	3.35	2096	0.65
Bathroom	2.03	8242	0.54	2.17	2096	0.71
Groundwater	0.72	8242	0.45	0.77	2096	0.42
Drilling (within 2000 m)	4.13	14764	3.67	0.00	4194	0.00

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[a] Land, living, bedroom, bathroom, and groundwater are summarized for the unique set of properties observed in the data.

Table 2.14: House Attributes by HMDA Sample Cuts

	Lease Match			**No Lease**		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
Appraisal value	135240.3	33146	95672.93	141340.1	57921	91436.3
Hispanic[a]	0.18	22752	0.39	0.14	39800	0.35
Asian	0.04	22752	0.21	0.06	39800	0.23
Black	0.1	22752	0.3	0.09	39800	0.29
AIAN	0.01	22752	0.08	0.01	39800	0.08
Income	83.91	22752	94.93	91.69	39800	111.72
White	0.85	22752	0.36	0.85	39800	0.36
Groundwater	0.73	22752	0.44	0.61	39800	0.49
Land (sqft)	10361.59	22752	6885.68	10122.06	39800	8089.99
Living area (sqft)	2129.77	22752	872.42	2269.91	39800	880.25
Drilling (within 2000 m)	4.77	33146	5.23	8.22	57921	9.01

	Auxiliary Clauses			**No Auxiliary Clauses**		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
Appraisal value	120939.9	9140	83142.5	140685.1	24006	99494.81
Hispanic	0.22	6212	0.41	0.17	16540	0.38
Asian	0.05	6212	0.21	0.04	16540	0.2
Black	0.11	6212	0.32	0.09	16540	0.29
AIAN	0.01	6212	0.09	0.01	16540	0.08
White	0.83	6212	0.38	0.86	16540	0.35
Income	78.02	6212	72.78	86.12	16540	101.93
Groundwater	0.72	6212	0.45	0.74	16540	0.44
Land (sqft)	9915.82	6212	6133.62	10529.01	16540	7140.72
Living area (sqft)	2043.67	6212	809.53	2162.11	16540	892.79
Drilling (within 2000 m)	5.37	9140	5.53	4.54	24006	5.09

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[a] Hispanic, asian, black, white, income, groundwater, land and living area are summarized for the unique set of properties and transactions observed in the data.

Table 2.15: Simple Hedonic Estimates With Lease Clauses

	(1) Royalty Full estate[a]	(2) Appraisal Value Full estate	(3) Split estate
Age (house)		-6.898***	17.427**
		(2.115)	(7.891)
Land (sqft)		997.033***	517.050
		(139.819)	(440.183)
Land (sqft)^2		-94.642***	-21.907
		(27.893)	(95.592)
Living area (sqft)		2,488.139***	1,220.594*
		(280.185)	(630.454)
Living area (sqft)^2		80.297	433.535***
		(58.883)	(133.238)
Bedroom		-792.998***	-611.799***
		(45.376)	(163.646)
Bathroom		933.098***	1,416.191***
		(75.521)	(223.874)
Rural		1,963.410***	1,373.033**
		(391.142)	(643.721)
Groundwater		-508.428***	132.677
		(190.470)	(321.371)
Drilling (within 2000 m)		-268.722***	-245.383**
		(34.345)	(99.496)
Environmental	0.006***	200.227***	-129.143
	(0.001)	(60.174)	(212.094)
Surface Damage	0.006***	79.810	124.077
	(0.000)	(62.845)	(217.940)
Freshwater	-0.008***	-147.303	-228.793
	(0.001)	(109.961)	(417.840)
Free water	0.006***	252.017***	6.833
	(0.001)	(61.360)	(230.267)
Injection Fluid	0.007***	-149.536*	-300.760
	(0.001)	(80.260)	(228.189)

[a] Sample includes those observations (properties) located within 2000 meters of drilling activity and with a signed, active lease that includes information about lease characteristics.

Table 2.16: Simple Hedonic Estimates With Lease Clauses *(Continued)*

	(1)	(2)	(3)
	Royalty	Appraisal Value	
	Full estate[a]	Full estate	Split estate
Saltwater Disposal	0.014***	4,628.167***	8,842.373**
	(0.001)	(564.979)	(3,482.442)
Compression Station	0.010***	769.776**	2,289.358**
	(0.001)	(387.600)	(991.443)
No Surface Access	0.003***	263.624***	470.930***
	(0.000)	(49.159)	(170.154)
Subsurface Easement	0.000	-145.930**	-70.991
	(0.001)	(63.257)	(201.036)
Legal Bundle	0.004***	119.632	6.873
	(0.001)	(76.927)	(219.164)
Attorney Fees	-0.007***	254.902**	73.800
	(0.001)	(110.568)	(199.731)
Force Majeure	-0.000	394.914***	445.985**
	(0.000)	(66.416)	(179.751)
Royalty rate		2,241.784**	
		(1,088.967)	
Term length	-0.006***		
	(0.000)		
Post production costs	0.001**		
	(0.001)		
Observations	13,208	13,188	1,151
R-squared	0.165	0.717	0.737
City, Period, Firm FE	yes	yes	yes

[a] Sample includes those observations (properties) located within 2000 meters of drilling activity and with a signed, active lease that includes information about lease characteristics.

Table 2.17: Non-Linear Hedonic Estimates: House Char. & City Fixed Effects

	Est.	Std. Err.	P-value
Constant	870.02	(533.91)	0.1
Age (house)	-4.68	(2.05)	0.02
Land (sqft)	979.3	(135.29)	0.00
Land $(\text{sqft})^2$	-92.49	(27.44)	0.00
Living area (sqft)	2440.56	(277.9)	0.00
Living area $(\text{sqft})^2$	95.72	(58.47)	0.1
Bedroom	-787.71	(43.92)	0.00
Bathroom	982.41	(72.02)	0.00
Rural	1902.61	(360.01)	0.00
Groundwater	-412.23	(160.19)	0.01
Drilling (within 2000 m)	-257.2	(32.5)	0.00
City-level Fixed Effects			
Arlington	-668.59	(109.74)	0.00
Azle	-827.41	(479.04)	0.08
Burleson	-2348.81	(480.5)	0.00
Crowley	-1000.57	(204.33)	0.00
Dalworthington	1594.42	(507.95)	0.00
Euless	722.31	(126.18)	0.00
Everman	-444.56	(186.31)	0.02
Foresthill	-1206.74	(152.12)	0.00
Fortworth	-536.98	(179.32)	0.00
Grandprairie	-796.36	(114.46)	0.00
Grapevine	2340.33	(242.82)	0.00
Haltomcity	-685.54	(125.66)	0.00
Hurst	111.13	(126.39)	0.38
Keller	1455.36	(290.63)	0.00
Kennedale	-125.58	(214.57)	0.56
Lakeworth	-1055.05	(171.67)	0.00
Mansfield	-350.97	(136.78)	0.01
Northrichlandhills	-304.96	(119.73)	0.01
Richlandhills	-519.53	(147.61)	0.00
Riveroaks	-1276.06	(310.62)	0.00
Saginaw	-500.25	(234.13)	0.03
Watauga	-870.36	(132.17)	0.00
Whitesettlement	-583.9	(138.06)	0.00

Table 2.18: Non-Linear Hedonic Estimates: Lease Clauses *(Continued)*

	Hedonic Split Est. Eq.			**Hedonic Full Est. Eq.**		
	Est.	Std. Err.	P-value	Est.	Std. Err.	P-value
Environmental	93.97	(29.59)	0.00	98.38	(29.59)	0.00
Surface Damage	44.69	(30.68)	0.15	39.2	(30.68)	0.2
Freshwater	-77.1	(55.4)	0.16	-77.22	(55.4)	0.16
Free water	112.03	(30.11)	0.00	119.49	(30.11)	0.00
Injection Fluid	-64.28	(39.33)	0.1	-77.95	(39.33)	0.05
Saltwater Disposal	2312.26	(278.81)	0.00	2376.13	(278.81)	0.00
Compression Station	378.9	(189.53)	0.05	401.13	(189.53)	0.03
No Surface Access	135.03	(24.22)	0.00	134.32	(24.22)	0.00
Subsurface Easement	-79.68	(31.01)	0.01	-73.28	(31.01)	0.02
Legal Bundle	40.3	(37.48)	0.28	49.26	(37.48)	0.19
Attorney Fees	139.52	(53.49)	0.01	123.05	(53.49)	0.02
Force Majeure	197.49	(32.09)	0.00	204.51	(32.09)	0.00

	Royalty Equation		
	Est.	Std. Err.	P-value
Environmental	0.00	(0.00)	0.28
Surface Damage	0.00	(0.00)	0.19
Freshwater	0.00	(0.00)	0.98
Free water	0.01	(0.00)	0.15
Injection Fluid	-0.01	(0.01)	0.05
Saltwater Disposal	0.05	(0.01)	0.00
Compression Station	0.02	(0.00)	0.00
No Surface Access	0.00	(0.00)	0.89
Subsurface Easement	0.01	(0.00)	0.11
Legal Bundle	0.01	(0.00)	0.09
Attorney Fees	-0.01	(0.00)	0.00
Force Majeure	0.01	(0.00)	0.00
Term months	-0.03	(0.00)	0.00
Post production cost	0.02	(0.01)	0.00

Table 2.19: Non-Linear Hedonic Estimates: Firm Fixed Effects *(Continued)*

	Hedonic Equation			**Royalty Equation**		
	Est.	Std. Err.	P-value	Est.	Std. Err.	P-value
Firm Fixed Effects						
Antero	-424.99	(336.61)	0.21	-2042.58	(397.02)	0.00
Chesapeake	-983.07	(329.62)	0.00	-1180.61	(373.31)	0.00
Cheyenne	-933.97	(358.42)	0.01	-0.47	(0.05)	0.00
Chief Operating	-1235.54	(603.11)	0.04	-0.02	(0.02)	0.37
Conglomerate	-1204.1	(418.97)	0.00	-0.04	(0.02)	0.01
Dale Property	-1266.86	(328.27)	0.00	-0.12	(0.01)	0.00
Ddjet	-628.68	(340.53)	0.07	-0.2	(0.01)	0.00
Devon	-3049.44	(623.61)	0.00	-0.2	(0.01)	0.00
Finley	-1568.43	(415.39)	0.00	0.02	(0.01)	0.23
Fleet	-990.32	(334.25)	0.00	0.01	(0.01)	0.38
Fort Worth	1997.42	(582.56)	0.00	-0.12	(0.02)	0.00
Four Seven	685.21	(347.09)	0.05	-0.08	(0.02)	0.00
Glencrest	-1565.78	(384.13)	0.00	-0.03	(0.03)	0.32
Grande	-144.78	(392.49)	0.71	-0.01	(0.01)	0.48
Harding	-471.23	(345.72)	0.17	0.03	(0.01)	0.03
Hillwood	221.78	(454.17)	0.63	0.01	(0.01)	0.45
Hollis Sullivan	-578.85	(338.88)	0.09	0.04	(0.01)	0.01
Htp	-1221.99	(591.21)	0.04	0.01	(0.01)	0.35
Llano Royalty	-613.89	(355.01)	0.08	-0.07	(0.02)	0.00
Paloma Barnett	-1320.82	(330.35)	0.00	-0.01	(0.02)	0.68
Poteta	-1404.8	(410.43)	0.00	-0.11	(0.01)	0.00
Quicksilver	23.92	(735.89)	0.97	0.01	(0.01)	0.57
Range	-541.67	(387.57)	0.16	0.00	(0.01)	0.8
Small Firm	388.86	(337.31)	0.25	0.01	(0.01)	0.32
Snow Operating	-677.73	(357.45)	0.06	0.03	(0.01)	0.02
Thunderbird	-1876.24	(375.93)	0.00	-0.17	(0.04)	0.00
Tierra	446.29	(471.41)	0.34	-0.09	(0.02)	0.00
Tip	-2042.58	(397.02)	0.00	0.01	(0.01)	0.68
Whitestone	-111.52	(347.41)	0.75	-0.19	(0.01)	0.00
Woodcrest	-1180.61	(373.31)	0.00	-0.11	(0.02)	0.00
Xto	-86.95	(417.13)	0.84	446.29	(471.41)	0.34

Table 2.20: Non-Linear Hedonic Estimates: Year Fixed Effects *(Continued)*

	Hedonic Equation			**Royalty Equation**		
	Est.	Std. Err.	P-value	Est.	Std. Err.	P-value
Year Fixed Effects						
2006	-1036.5	(985.68)	0.29	-0.28	(0.08)	0.00
2007	-1010.25	(758.24)	0.18	0.00	(0.01)	0.88
2009	352.99	(108.4)	0.00	0	(0.01)	0.83
2010	99.1	(118.13)	0.4	-0.01	(0.01)	0.61
2011	174.96	(96.8)	0.07	-0.01	(0.01)	0.63
2012	170.41	(95.7)	0.08	0.01	(0.01)	0.67
2013	349.55	(103.12)	0.00	0	(0.01)	0.85

Table 2.21: Coase Regressions with Index

	Full Estate (1)	
	Estimate	Std. Dev.
Hispanic	-128.837	(14.205)
Asian	-22.154	(3.259)
Black	-33.312	(2.998)
Income	481.961	(57.709)
Income^2	-416.845	(48.352)
Land (sqft)	3.005	(0.454)
Groundwater	47.56	(5.53)
Pct. College Edu. (tract)	21.816	(2.362)
Avg HH size (tract)	-82.432	(10.749)
Over 65 (tract)	404.42	(57.285)
Rural	-96.838	(14.563)
Observations	7,972	
Mean Index	940.756	
St. Dev Index	1248.533	
Period FE	Yes	
Wellpad FE	Yes	
Firm FE	Yes	

Table 2.22: Coase Regressions with Clauses

	(1) Environ-ment	(2) Noise	(3) Compress Station	(4) No Surface Access	(5) Attorney	(6) Reports	(7) Defend Title	(8) Vertical Pugh
Panel A: Full Estate								
Hispanic	-0.039***	-0.051***	-0.007***	-0.001	-0.016**	0.000	-0.052***	-0.037**
	(0.011)	(0.010)	(0.002)	(0.011)	(0.006)	(0.003)	(0.009)	(0.009)
Asian	-0.004	-0.009	-0.006**	0.029*	-0.017	0.007	-0.024	0.005
	(0.018)	(0.017)	(0.003)	(0.018)	(0.010)	(0.008)	(0.016)	(0.015)
Black	-0.026**	-0.010	0.001	-0.012	-0.010	-0.004	-0.015	-0.022**
	(0.013)	(0.011)	(0.002)	(0.013)	(0.008)	(0.004)	(0.010)	(0.010)
HH Income	0.120	0.205**	0.014	-0.018	0.012	-0.020	0.097	0.065
	(0.093)	(0.089)	(0.019)	(0.086)	(0.061)	(0.036)	(0.076)	(0.080)
HH Income^2	-0.135**	-0.173***	-0.008	0.037	-0.004	-0.005	-0.087	-0.093
	(0.061)	(0.058)	(0.012)	(0.056)	(0.039)	(0.040)	(0.054)	(0.060)
Land area (sqft)	0.000	0.001	0.000	-0.004***	0.004***	-0.000	0.003***	0.002*
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)
Groundwater	-0.013	0.020	0.002	-0.015	-0.008	0.010***	-0.004	0.031
	(0.035)	(0.033)	(0.002)	(0.034)	(0.029)	(0.004)	(0.033)	(0.028)
Pct. College Edu. (tract)	0.005***	0.008***	-0.000	0.000	0.004***	0.003***	0.008***	0.007**
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)
Avg HH size (tract)	-0.019	-0.033	-0.033***	-0.012	0.005	0.032***	-0.032	-0.029
	(0.025)	(0.023)	(0.008)	(0.024)	(0.015)	(0.007)	(0.022)	(0.023)
Over 65 (tract)	0.076	0.183	-0.108***	0.274***	-0.110	0.008	0.212**	0.232**
	(0.129)	(0.116)	(0.030)	(0.105)	(0.068)	(0.026)	(0.105)	(0.099)
Rural	-0.134***	-0.046	-0.003	0.054	0.051	-0.013	-0.062	-0.025
	(0.046)	(0.046)	(0.003)	(0.037)	(0.033)	(0.010)	(0.041)	(0.032)
Observations	7,973	7,973	7,973	7,973	7,973	7,973	7,973	7,973
R-squared	0.603	0.629	0.664	0.458	0.538	0.284	0.675	0.591
Period FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wellpad FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 2.23: Coase Regressions with Clauses

	(9) Surface Damage	(10) Royalty	(11) Term Len.	(12) Legal Bundle	(13) Free Water	(14) Injection Fluid	(15) Subsurface Easement
Panel A: Full Estate (Continued)							
Hispanic	0.034***	-0.096	0.913***	-0.051***	0.027**	0.008*	0.035***
	(0.010)	(0.115)	(0.310)	(0.009)	(0.012)	(0.005)	(0.010)
Asian	0.002	-0.018	0.276	-0.010	-0.011	0.006	-0.024
	(0.015)	(0.181)	(0.488)	(0.015)	(0.018)	(0.008)	(0.018)
Black	-0.010	0.105	0.830**	-0.015	-0.020	0.009	0.014
	(0.011)	(0.106)	(0.366)	(0.010)	(0.013)	(0.008)	(0.012)
HH Income	-0.211**	1.374	-6.436***	0.150**	-0.266***	0.099**	-0.216**
	(0.103)	(0.857)	(2.311)	(0.076)	(0.092)	(0.040)	(0.088)
HH Income^2	0.139	-0.890	3.811**	-0.119**	0.177***	-0.070**	0.233***
	(0.117)	(0.576)	(1.537)	(0.051)	(0.066)	(0.027)	(0.066)
Land area (sqft)	-0.005***	0.018	-0.021	0.003***	-0.001	0.001*	-0.002
	(0.001)	(0.012)	(0.031)	(0.001)	(0.001)	(0.000)	(0.001)
Groundwater	-0.026	-0.016	-2.605***	0.015	-0.000	-0.002	-0.025
	(0.028)	(0.359)	(0.993)	(0.033)	(0.038)	(0.005)	(0.034)
Pct. College Edu. (tract)	0.003***	0.009	-0.105***	0.008***	-0.003**	-0.001***	-0.005***
	(0.001)	(0.017)	(0.033)	(0.001)	(0.001)	(0.000)	(0.001)
Avg HH size (tract)	0.073***	-0.268	0.476	-0.032	0.013	-0.008	0.012
	(0.025)	(0.356)	(0.755)	(0.022)	(0.029)	(0.010)	(0.025)
Over 65 (tract)	-0.123	-0.448	-7.083**	0.326***	-0.499***	-0.018	-0.519***
	(0.110)	(1.207)	(3.323)	(0.106)	(0.137)	(0.032)	(0.115)
Rural	0.099***	0.212	1.235	-0.056	0.148***	-0.002	0.126***
	(0.035)	(0.454)	(1.236)	(0.042)	(0.044)	(0.009)	(0.041)
Observations	7,973	7,973	7,973	7,973	7,973	7,973	7,973
R-squared	0.570	0.362	0.457	0.684	0.560	0.236	0.660
Period FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wellpad FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 2.24: Coase Regressions with Clauses

	(1) Environment	(2) Noise	(3) Compress Station	(4) No Surface Access	(5) Attorney	(6) Reports	(7) Defend Title	(8) Vertical Pugh
Panel B: Split Estate								
Hispanic	-0.016	0.075	-0.020	-0.150	-0.048	-0.034	0.068	0.051
	(0.096)	(0.077)	(0.022)	(0.098)	(0.057)	(0.041)	(0.082)	(0.082)
Asian	0.026	0.156	0.128**	0.020	0.321**	-0.107	0.186	-0.034
	(0.161)	(0.166)	(0.063)	(0.163)	(0.148)	(0.091)	(0.158)	(0.115)
Black	0.040	0.258**	-0.028	0.039	-0.024	-0.030	0.171	0.256***
	(0.124)	(0.104)	(0.029)	(0.126)	(0.078)	(0.035)	(0.109)	(0.095)
HH Income	0.138	3.104*	-1.488**	-6.767***	-0.043	-0.097	2.217	0.560
	(2.008)	(1.645)	(0.686)	(1.919)	(1.338)	(0.792)	(1.663)	(1.741)
HH Income^2	-1.482	-7.984	3.277*	18.727***	2.807	-0.605	-6.117	-2.355
	(6.489)	(4.942)	(1.838)	(5.614)	(4.404)	(3.126)	(5.162)	(5.339)
Land area (sqft)	0.015*	0.006	-0.000	-0.005	0.008	0.001	0.013	0.017*
	(0.009)	(0.008)	(0.003)	(0.009)	(0.006)	(0.002)	(0.010)	(0.009)
Groundwater	-0.186	-0.198	0.159*	0.438**	-0.097	0.049	0.003	0.264
	(0.213)	(0.233)	(0.086)	(0.176)	(0.118)	(0.046)	(0.208)	(0.164)
Pct. College Edu.	-0.002	0.001	0.002	0.025**	-0.007	-0.001	0.001	-0.006
(tract)	(0.009)	(0.010)	(0.003)	(0.010)	(0.007)	(0.003)	(0.009)	(0.008)
Avg HH size	-0.245	-0.099	0.030	-0.111	-0.155	0.011	-0.173	-0.092
(tract)	(0.197)	(0.185)	(0.044)	(0.154)	(0.112)	(0.053)	(0.190)	(0.154)
Over 65 (tract)	-1.904***	-1.345*	-0.256	-0.876	-0.500	-0.294	-1.276*	-1.423**
	(0.731)	(0.751)	(0.177)	(0.764)	(0.435)	(0.235)	(0.750)	(0.707)
Rural	0.119	0.701	-0.069	0.044	0.884***	-0.010	0.366	-0.470**
	(0.286)	(0.578)	(0.084)	(0.236)	(0.180)	(0.064)	(0.568)	(0.231)
Observations	377	377	377	377	377	377	377	377
R-squared	0.817	0.795	0.629	0.825	0.814	0.616	0.787	0.766
Period FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wellpad FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 2.25: Coase Regressions with Clauses

	(9) Surface Damage	(10) Royalty	(11) Term Len.	(12) Legal Bundle	(13) Free Water	(14) Injection Fluid	(15) Subsurface Easement
Panel B: Split Estate (Continued)							
Hispanic	-0.222*	-1.944	-4.750	0.064	-0.343***	0.097	-0.180*
	(0.120)	(1.806)	(3.068)	(0.082)	(0.105)	(0.063)	(0.099)
Asian	-0.147	-0.015	1.912	0.171	-0.213*	-0.050	-0.238
	(0.148)	(2.639)	(3.727)	(0.160)	(0.111)	(0.090)	(0.149)
Black	-0.107	2.067	-0.883	0.165	-0.041	0.106	-0.195
	(0.149)	(2.461)	(4.239)	(0.112)	(0.145)	(0.084)	(0.130)
HH Income	-1.403	-33.090	-74.597*	1.424	-0.747	-1.645*	-3.499*
	(1.902)	(27.793)	(45.068)	(1.703)	(1.639)	(0.924)	(1.838)
HH Income^2	4.237	168.651*	205.205	-2.500	3.021	4.687*	11.405*
	(5.430)	(92.004)	(135.760)	(5.400)	(5.364)	(2.671)	(5.949)
Land area (sqft)	-0.016*	-0.303*	-0.334	0.015	-0.020**	0.007	-0.029**
	(0.009)	(0.178)	(0.296)	(0.010)	(0.009)	(0.005)	(0.011)
Groundwater	-0.014	5.096	5.443	0.038	0.149	-0.157*	0.123
	(0.205)	(4.264)	(8.090)	(0.202)	(0.229)	(0.088)	(0.194)
Pct. College Edu.	0.036***	0.290*	-0.012	0.001	0.021**	-0.013**	0.026**
(tract)	(0.010)	(0.147)	(0.311)	(0.009)	(0.009)	(0.006)	(0.011)
Avg HH size	-0.325*	-6.302**	-9.666*	-0.197	-0.402**	-0.024	-0.300
(tract)	(0.188)	(2.912)	(5.338)	(0.191)	(0.166)	(0.094)	(0.187)
Over 65 (tract)	0.304	-1.504	-0.175	-1.449*	-0.369	0.564	0.956
	(0.830)	(10.056)	(17.691)	(0.746)	(0.721)	(0.364)	(0.671)
Rural	0.549**	2.015	2.090	0.293	-0.055	-0.149	0.532*
	(0.257)	(5.571)	(9.585)	(0.568)	(0.551)	(0.138)	(0.314)
Observations	377	377	377	377	377	377	377
R-squared	0.801	0.837	0.829	0.790	0.824	0.620	0.813
Period FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wellpad FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 2.26: Race and Bonus Regressions

	(1)	(2)	(3)	(4)
Hispanic	-1,903.498***	-1,903.498***	328.733	328.733
	(639.211)	(639.211)	(5,113.638)	(5,113.638)
Asian	1,849.952	1,849.952	2,139.820*	2,139.820*
	(1,184.806)	(1,184.806)	(1,190.715)	(1,190.715)
Black	-769.004	-769.004	-602.042	-602.042
	(727.573)	(727.573)	(737.353)	(737.353)
Hispanic * Speaks English well			-28.697	-28.697
			(60.947)	(60.947)
HH Income	8,005.885	8,005.885	6,462.285	6,462.285
	(6,856.310)	(6,856.310)	(6,970.680)	(6,970.680)
HH Income squared	-7,926.191	-7,926.191	-6,500.608	-6,500.608
	(10,934.857)	(10,934.857)	(10,922.662)	(10,922.662)
Land area (in sqft)	90.546**	90.546**	90.859**	90.859**
	(41.416)	(41.416)	(43.386)	(43.386)
Groundwater	-2,669.341***	-2,669.341***	-2,219.225***	-2,219.225***
	(704.539)	(704.539)	(849.754)	(849.754)
Over 50% Eng. Speaking (tract)			-54.583	-54.583
			(59.482)	(59.482)
Pct. College Edu. (tract)	160.501***	160.501***	210.632***	210.632***
	(50.570)	(50.570)	(63.978)	(63.978)
Avg HH size (tract)	-3,988.875***	-3,988.875***	-4,385.389***	-4,385.389***
	(953.387)	(953.387)	(1,088.787)	(1,088.787)
Over 65 (tract)	16,366.248***	16,366.248***	17,013.010***	17,013.010***
	(4,180.207)	(4,180.207)	(4,744.981)	(4,744.981)
Observations	632	632	632	632
R-squared	0.604	0.604	0.607	0.607
Wellpad FE	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes
Firm FE	No	Yes	No	Yes

Table 2.27: Race and Well Exposure Regressions

	(1)	(2)	(3)	(4)	(5)	(6)
Hispanic	-0.0696	0.3911***	0.3039***	0.2970***	0.2129***	0.0061
	(0.0512)	(0.0511)	(0.0529)	(0.0523)	(0.0531)	(0.0429)
Asian	-0.2344***	0.1109	0.0872	0.1628**	0.1441*	0.2837***
	(0.0781)	(0.0822)	(0.0820)	(0.0827)	(0.0824)	(0.0628)
Black	0.7223***	0.9147***	0.8656***	0.9655***	0.9159***	0.6132***
	(0.0609)	(0.0627)	(0.0629)	(0.0627)	(0.0628)	(0.0508)
HH Income			-0.0020***		-0.0024***	-0.0004
			(0.0003)		(0.0003)	(0.0002)
HH Income squared			0.0000***		0.0000***	0.0000
			(0.0000)		(0.0000)	(0.0000)
Hispanic * Speaks English well				0.5394***	0.5306***	0.3369***
				(0.1153)	(0.1153)	(0.0877)
Pct. English Speaking (tract)				0.2734***	0.3274***	0.2921***
				(0.0384)	(0.0391)	(0.0346)
Groundwater						7.0014***
						(0.3766)
Rural						3.8100***
						(0.4587)
Land area (in sqft)						0.0001
						(0.0039)
Split Estate						-0.0996
						(0.0621)
Observations	90,430	32,913	32,913	32,913	32,913	32,874
R-squared	0.001	0.007	0.008	0.010	0.012	0.446
City FE	No	No	No	No	No	Yes
Period FE	No	No	No	No	No	Yes

3

Private contracts as regulation: A study of private lease negotiations using the Texas natural gas industry

3.1 Introduction

Within the last twenty years, operators increasingly used the combined technologies of large-scale hydraulic fracturing, horizontal drilling, and 3-D seismic surveying to access natural gas stored in tight-shale formations. This technological combination increases the amount of resources available for extraction while minimizing the "drilling footprint" as firms are able to reach a larger mineral acreage using a single bore hole and horizontal drilling technology. Before drilling such a well, firms must negotiate and sign individual leases with mineral rights owners, transferring the legal right to access the minerals beneath the parcel[1] when private parties own the surface and sub-surface minerals (as opposed to government owned sub-surface minerals, which is common in the Western part of the United States). The technological change results in firms drilling natural gas wells in increasingly urban areas, and as a consequence, we observe that firms are signing leases transferring the mineral rights underlying more densely populated areas and subdivisions. However, the oil and natural gas law enforced by the state was written before these technological changes. The rules were designed to regulate an industry that drilled in rural areas and that interacts less with people living in houses near to their well sites, rules that may or may not sufficiently protect urban households from the negative consequences of nearby drilling.

The leases signed between firms and mineral rights owners are the first line of defense protecting households from the negative consequences of nearby drilling. The leases can restrict how firms operate by stipulating surface access restrictions, surface restoration requirements once drilling is complete, the types of chemicals allowed to be used during any phase of drilling, and noise restrictions, among others. However, we observe lease quality heterogeneity across leases signed in the data, where we define better lease quality as those leases with terms more favorable to the

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[1] Parcels are the tracts of land demarking the boundaries between different property rights owners.

household (and in some cases, restricting firm activity), and worse lease quality as those allowing additional dis-amenities for the household.

Lease negotiation is largely an unregulated phase of the natural gas extraction industry as compared to other phases. The drilling, transporting, and selling of natural gas phases are governed by local, state, and federal authority. Private lease negotiation is only restricted in terms of when royalty payments are issued to mineral rights owners and the information firms are required to make known to those individuals. The state regulator also has jurisdiction over enforcing and undertaking remediation from undue negligence[2] on the part of firms and broadly enforcing the protection of ground and surface water from contamination caused by the industry. Aspects of drilling like truck traffic, noise, and air pollution are not regulated by state or federal agencies, and further, the dominant mineral estate allows firms to lay gathering pipelines, build roads, and use surface water to operate their wells without recourse for the mineral estate owner as long as none of these activities is deemed unnecessary.

More urban drilling increases the number of leases signed with individual mineral rights owners and subsequently exposes more households to the negative consequences resulting from living in close proximity to a natural gas well. In turn, the

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[2] Negligence is used several times throughout the text to describe operator activity; however, it is a legal definition subject to litigation and interpretation by the Texas Railroad Commission.

private negotiations between firms and mineral estate owners are more important because comprehensive leases protect mineral estate owners from some of the negative consequences of nearby drilling that would otherwise be permissible by existing state and federal oil and natural gas law.

We observe that not all leases are equal, and our paper explores some tract-level characteristics potentially driving the heterogeneous lease quality observed in our dataset. In particular, we explore whether heterogeneity across tracts in race and ethnic concentration is related to better or worse lease quality, and we find that tracts with higher concentrations of Black and Hispanic minority populations generally have worse lease quality. Ideally, race and ethnic concentration should not weigh on the quality of leases signed because there is not a discernible reason minority households should prefer worse leases, and subsequently, more exposure to the negative aspects of nearby drilling activity. However, we find that even when we control for measures of income, wealth, split estates, and timing, those tracts with higher concentrations of Black and Hispanic residents, on average, still have worse lease quality with Hispanic having worse quality across more categories.

First, we explore the relationship between tract-level characteristics and the quality of leases signed by firms and mineral rights owners, and we find that racial and ethnic composition of a tract has large and significant effects on the lease quality outcomes. We further explore the effects of added tract-level characteristics, including variables describing the concentration of split estates, the average time period when leases were signed, and measures of income and wealth, changes that do not alter the initial findings. Second, we estimate a model using the percent of English speaking individuals in a tract in lieu of the race and ethnic concentrations. We hypothesize that if the quality of the leases is a function of a household's negotiation ability, then speaking English well is likely a relevant attribute, and we find that in fact a higher concentration of individuals speaking English well is highly correlated with a greater lease quality. Third, we separate the favorable leases clauses into those commonly and uncommonly negotiated to generate our tract-level lease quality measures and estimate the relationship with our tract-level characteristics. We might think that certain clauses are easier to negotiate than others, or just more commonly known as potential auxiliary clauses to add to leases. We find that that Hispanics negotiate fewer common clauses while Whites and Non-Hispanics negotiate more uncommon clauses.

Given the findings of the paper, we conclude with a policy discussion of ideas to remedy the observed heterogeneity across tracts with varying characteristics ameliorating the potentially inequitable allocation of protective leases across demographic groups. The paper proceeds, first, with a literature review, followed by a brief description of the industry and property law relevant to our analysis. These sections are followed by a description of the data and results and a policy discussion to conclude.

3.2 Literature

In general, much of the leasing literature studying the oil and natural gas industry is focused on the negotiations between firms and federal government. For example, the auction literature estimates the valuations of operators bidding on parcels of on- and offshore mineral rights owned by the U.S. Department of the Interior (Porter (1995)). Fitzgerald (2010) estimates a model of the value of contracting by exploiting split versus whole estates in Wyoming where the federal government owns and auctions the mineral estates. He finds that bidders discount the split estates that can be attributed to the cost of bargaining between winners of the auction and the surface owners. Libecap and Smith (1999) and Libecap and Wiggins (1985) both study theoretical aspects of unitization contracts in the oil industry.

The ability of parties to extract quasi-rents from contracts between parties and exercise opportunistic behavior once the contract is established led theorists to consider the value of institutions, or regulations, when it comes to reducing the loss of quasi-rents and bargaining costs and measure the value of vertical integration (Klein et al. (1978), Williamson (1971)). These literatures are relevant for our environment analyzing the outcome resulting from the private negotiations between landowners and firms.

There are several existing property-value hedonics analyses designed to measure the impacts of shale gas activity on property values that are focused on the effects of nearby drilling. A few notable examples include Boxall et al. (2005), focused on sour gas wells in Alberta, and Gopalakrishnan and Klaiber (2014), measuring the temporal impact of shale gas wells in Washington County, Pennsylvania. Muehlenbachs et al. (2015) use data from all of Pennsylvania to conduct a triple-difference analysis of the effect of shale gas development on groundwater dependent homes, along with a double-difference analysis of the effect on all nearby homes regardless of water source. Other research finds evidence of concerns over risks to households' water sources including Throupe et al. (2013b). James and James (2014a) explores the Colorado housing market's response to increased hydraulic fracturing activity while controlling for the economic benefits of increased activity using a tract-level analysis.

Each of these papers implicitly focuses on the drilling phase, measuring effects of being located nearer to active wells. However, our paper is one the first to use lease clauses to evaluate the leasing phase, and unique to our analysis, we are exploring the relationships between tract-level racial and ethnic composition and lease quality. Our results suggest there is a measurable negative relationship between minority populations and greater lease quality.

3.3 Legal and Institutional Details

The following section describes the technological developments driving the natural gas industry's increased productivity and the institutional details behind the regulation of the industry focusing on the lease phase.

Over the past 20 years, horizontal drilling technology has evolved to allow access to natural gas contained in tight-shale formations spread over a large area while requiring a smaller "footprint" in terms of the number of wells drilled. Further, these technological developments have increased activity in urban plays, bringing drilling into suburban households' backyards. Regulation guiding industry practices, however, has been largely crafted for activity in less densely populated areas - the more common setting for oil and natural resource extraction. We describe the technological innovations and regulatory structure relevant to the leases negotiated between firms and mineral rights owners, the focus of our analysis.

The process of hydraulic fracturing enables firms to extract natural gas from tight shale formations by artificially stimulating the strata. This increases the flow of natural gas within the shale, resulting in its eventual release and collection at the wellhead. Horizontal drilling techniques allow firms to drill wells accessing minerals located within a large radius surrounding the wellhead. Fewer drill sites are therefore required to reach a larger subsurface area and better access is provided for broad resource deposits. Horizontal drilling therefore allows firms to extract large quantities of natural gas from a smaller surface footprint, facilitating extraction from areas of higher population density. Unlike the situation under conventional drilling, individuals in (sub)urban areas have subsequently found themselves to be parties to negotiations with operators over mineral rights leases.

The Texas Railroad Commission (TRC) oversees the majority of the oil and natural gas industry in the state of Texas, which encompasses approving and issuing the permits to drill wells and monitoring well activity once firms drill and begin producing natural gas for sale.[3,4] However, prior to permit approval, firms must first amass a large and contiguous mineral estate acreage that is spaced far enough away from existing well infrastructure that is achieved by firms signing leases with mineral estate owners temporarily transferring their rights to the firm. Households signing leases with natural gas firms or "landmen" are tasked with weighing the trade-offs between present and expected financial remuneration with that of the potential known and unknown risks to living near an active well.

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[3] The Texas Railroad Commission has jurisdiction over the "exploration, production, and transportation of oil and gas prior to refining or end use," and the TRC executes its jurisdiction by enforcing rules written in the Texas Administrative Code, Chapter 3.

[4] Texas Administrative Code, Chapter 3, Rules 37 & 38.

In general, the dis-amenities experienced by households from nearby shale gas activities are unregulated by state and federal entities and are folded either into the private leases signed between them and firms or captured by local ordinances passed to regulate firm activity through zoning restrictions. The TRC does not regulate noise, traffic, or well pad appearance, nor does it require air or water pollution testing. By law, operators have access to surface water to be used to treat the well, and chemical disclosure is restricted to only the non-proprietary chemicals used to fracture a well.

Higher-level regulation of the leases phase is limited to royalty payments (stipulating when they are to be paid), the required information that must be provided (and that which can be requested) by firms, notification upon re-assignment of leased rights, and determining the consequences of delinquent payments. In addition, the TRC has jurisdiction over enforcing and undertaking remediation from undue negligence on the part of firms and broadly enforcing the protection of ground and surface water from contamination caused by the industry. However, the TRC's jurisdiction over the leases signed between households and firms, and subsequently, the protection of households while a well is drilled and after production ends is limited, and a well-informed household may negotiate more comprehensive contracts with leasing firms to protect their interests beyond the minimal coverage of the law.

The rules passed at the municipal level are a tertiary layer of government potentially protecting surface owners from harmful drilling practices. Local regulation in Texas is an interesting feature of the legal structure whereby localities can exercise "home rule," passing ordinances that restrict activity within their jurisdiction. Local municipalities often employ land-use policy to restrict oil and gas development since they are able to enact local ordinances that stipulate types and locations of land use and permissible damage for the purposes of protecting public health and welfare. We do not focus on the effect of municipal laws in this analysis except to estimate models that loosely control for municipal laws by including city-level fixed effects; however, it is worthwhile to mention these laws as an important piece of the regulatory framework that can protect households from the negative effects of increased drilling activity.

Signing a comprehensive leasing document is important for households protecting their rights while they are royalty interest holders. Leasing agreements contain a set of primary clauses common to all leases drawn in the industry and sets of auxiliary clauses that are negotiable between lessors (mineral rights owners) and lessees (exploration and oil and natural gas production firms). Primary clauses include a careful description of the minerals leased to the lessee; information about the royalty payments owed to the lessor once the well begins to produce in paying quantities;

the duration of the lease, or primary term; and opportunities for extension once the primary term has expired.

Auxiliary clauses are written into the agreement to protect one or both of the parties, but may not be included in all leases. Negotiators may draft surface damage clauses ensuring that the operator restores the surface to a condition agreed upon by both negotiators once production is complete; environmental clauses requiring producers to perform regular environmental quality tests on the surface and ground water or soil samples; and restrictions on the noise level at the well and whether or not the firm can access the sub-surface minerals by drilling through the surface estate, to name a few. The online Appendix C lists the clauses and definitions used in our tract-level analysis.

The state of Texas allows the mineral estate to be split (or "severed") from the surface estate. It is therefore possible that the individual signing a lease with a natural gas firm is not the individual living in the house positioned on the surface estate. In the event of severance, the mineral estate dominates in terms of exploration and extraction, and the mineral lessee assumes the same rights owed to the mineral estate owner since the leasing document is perceived as a temporary transference of ownership.[5]

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[5] If the minerals are not reserved at the sale date, the mineral estate automatically goes to the buyer along with the surface conveyance (Fambrough 2015).

Texas has not passed a law protecting the surface estate, or a surface damage act, as has been passed in other states with prominent oil and natural gas industries (including New Mexico, Oklahoma, North and South Dakotas, and Montana). Surface owners are not owed any remuneration for the opportunity cost of the lost piece of their property during the drilling period nor must they be paid for reasonable damages to the land caused by drilling. If there is any perceived misuse of the land by mineral rights owners, surface owners are responsible for proving unreasonable conduct by suing the operating firm, which does not include surface damage or inconvenience. Surface owners are marginally protected by the *Accommodation Doctrine*[6] (Fambrough 1997), which protects existing surface owner uses.

In lieu of state regulation, and in some cases, relevant local ordinances, lessors can negotiate a surface damage clause into the leasing agreement to protect the surface estate during production and ensure remediation after production ends. Otherwise, the surface estate may only claim and prove unnecessary damage through litigation. However, since the state of Texas does not require operators to negotiate with the surface estate independent of the mineral estate, a severed estate with a lease may

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[6] Accommodation Doctrine: [W]here there is an existing use by the surface owner which would otherwise be precluded or impaired, and where under the established practices in the industry there are alternatives available to the [mineral owner] whereby the minerals can be recovered, the rules of reasonable usage of the surface may require the adoption of an alternative by the [mineral owner]. (Tarrant County Water Control & Improvement Dist. No. 1 v. Haupt, Inc., 854 S.W.2d 909, 911 (Tex. 1993)) (Merrill and Merrill (2013b)).

not naturally include a surface damage clause.[7]

3.4 Data

Our analysis is concerned with estimating the relationship between tract-level characteristics and the average quality of leases signed by individuals living in the tract. We use a combination of micro and tract-level data to calculate our dependent and independent variables of interest which are sourced from the US Census data, the Tarrant County Appraisal office, Drilling Info, the *New York Times* "Drilling Down" series, and the Tarrant County Clerk Office. The following describes our data sources in more detail, and we summarize our data in Table 3.1 reporting the tract-level racial, ethnic, and other control variable concentrations in the top panel and lease clause concentrations in the lower panel.

The lease terms and clauses are a primary and unique source of data used to describe tract-level average quality of leases signed by firms and mineral rights owners. We have attached a large fraction of the leases to specific households enabling us to identify each lease's tract for the present analysis. Table 3.2 reports the results of independent group t-tests comparing the means of house attributes across the samples merged to leases and not, and we find that older houses signing leases in our data

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[7] There is anecdotal evidence based on conversations with a Texas-based operator that a surface damage agreement is sometimes negotiated separate of the lease when the estate is severed, and the firm initiates the negotiation to protect them legally in the future.

have a slightly larger land area, smaller living area, and greater use of groundwater. Further, we use the lease locations and matches to households to identify the fraction of leases likely signed by split estates, an additional variable used in our analysis.

We have collected data describing the terms of the privately negotiated leases. In particular, we have data describing the primary clauses of all natural gas leases negotiated in Tarrant County, Texas between 2000 and 2013 from the Drilling Info database. In addition to the primary clauses, we have also collected auxiliary clauses for one third of the sample signed between 2006 and 2011.[8] We scraped these data and then mined the files for words and phrases indicating the existence of certain clauses using computer software. Table 3.3 reports another set of independent group t-tests comparing the mean values of the primary terms across leases with and without auxiliary clauses, and we find that our sample with auxiliary clauses have larger royalties, shorter term lengths, and smaller land area.

The auxiliary lease clauses are sub-divided across five lease bundle types: surface protection clauses, legal protection clauses, "bads," or clauses more favorable to the operating firm, externality clauses not directly related to the surface estate or legal proceedings, and water quality protection clauses. Table 3.4 delineates the classification of each clause used in the analysis and the online Appendix C includes

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[8] Our specific sample was collected from the "Drilling Down Series" published by the *New York Times* from 2011 into 2012. `http://www.nytimes.com/interactive/us/DRILLING_DOWN_SERIES.html`

more thorough definitions of each individual clause.

The lower panel of Table 3.1 summarizes these primary clauses including the average royalty, acreage, and term length in months, and it describes the frequency of auxiliary clauses that compose the lease quality bundles. The average royalty rate is around 23 percent and the average term length is 42 months. Surface clauses have the greatest tract-level frequency in our data followed by legal clauses and "bads." Visually, histograms in Figure 10 report the percent of tracts with sets of each lease clause type.

The final lease variable used in our analysis accounts for the average period in which leases are signed for each given tract. We take the signing year and subtract the baseline year, 2000, and we calculate the tract-level mean and use the variable to control for the average lease signing period. A positive coefficient on this variable indicates that leases signed later in the period, toward 2013, have a positive relationship with the dependent variable of interest.

The tract-level data consists of the questions and responses available through the American Community Survey, and our variables are taken from the 2012 5-year moving average outcomes. We extract the data using *Simply Map,*[9] and the variables most relevant to our analysis are the percent of Black, Asian, Hispanic, and White,

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[9] Simply Map is an online, data extraction tool that generates our tract-level census variables for Tarrant County Texas.

non-Hispanic households in a given tract controlling for the tract-level percent of households with individuals over 65 years of age and high school graduates, and the average tract population, household size, land area, and use of groundwater. We also test specifications including the median income and the percent of households speaking English well. These tract-level variables are summarized in the top panel of Table 3.1.

We use housing data provided by the Tarrant County Appraiser District (TAD) to calculate the median appraisal value of houses in a given tract and the frequency of split estates and households accessing groundwater by tract. The first variable, the median appraisal value, is our primary measure of wealth across tracts, testing the relationship between living in a wealthier tract and signing a higher quality lease. The tract-level split estate variable is formed by identifying observations in the lease data with mineral estate owners' living either out of state or using P.O. Box address, and adding to those cases, the split estate method described in Timmins and Vissing (2015). The tract-level groundwater frequency variable is formed using only those leases matched to specific houses, and the houses, in turn, are matched to district water regions using GIS software which we can use to calculate our independent variable of interest at the tract level.

3.5 Results

The analysis aggregates the mean frequency of each clause bundle by tract to capture the relationship between tract-level characteristics and the average, tract-level quality of leases signed. Figures 1 and 2 capture spatially Tarrant County tracts and population density, respectively, whereby darker shades represent greater concentrations. Figure 1 outlines tracts (the smaller outlined areas), cities, (the green shaded areas), and the water district, (the larger blue and transparent area in the middle of the map). In addition, the rural areas are colored rose and the permitted and producing wells are demarked by black dots.

Again, Table 3.1 summarizes the tract-level characteristics followed by Figures 3 to 6 depicting the tract-level wealth, racial, and ethnic concentrations spatially across Tarrant County with the darker shades representing greater concentrations. These maps also plot the well exposure, and we see a concentration of wells in the upper right hand corner of Tarrant County, a largely rural area. Figure 3 relays that a greater concentrations of Whites live on the periphery in more rural areas, and these tracts also have greater wealth as suggested by Figure 4, which is shaded to represent the heterogeneity in median appraised values across tracts. Figures 5 and 6 display the concentrations of Blacks and Hispanics, respectively. These figures show that the minority populations are concentrated in the Fort Worth (middle) region of the county. Figures 7 to 9 display the spatial heterogeneity in leases signed across space and time by coloring the map with the mean concentrations of lease clause counts in Figure 7, the royalty rate in Figure 8 (with on average greater royalty rates in darker regions), and the passage of time in Figure 9 (leases signed on average in later years have darker colors). We can see the greater concentrations of clauses and higher royalty rates do not necessarily correlate with more well exposure (black dots). In particular, the rural region in the upper right hand corner has low lease quality as evidenced by fewer clauses and lower royalty rates; however, those leases were signed in earlier years as shown in Figure 9. In other parts of the map, we see the better lease quality and higher royalties are signed on the periphery where there is a greater concentration of White population and wealth.

A simple correlation matrix[10] of all the variables reveals that Black and Hispanic concentrated tracts are negatively correlated with higher median incomes and appraisal values and with the concentration of White population. Independently, Hispanic is positively correlated with household size, and the negative correlations with positive lease clause types are all around or less than -0.2 (surface, legal, externality, full, and water). Further, there is a very strong and negative correlation between Hispanic and English speaking tracts, which is why we do a separate analysis

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[10] A full correlation matrix of all variables used in the analysis is reported in the online appendix.

using the English speaking independent variable.

The compilation of our figures and correlation matrix suggest that our minority populations are concentrated in areas with lower lease quality and less wealth, and the minority race variables are strongly correlated with non-English speaking tracts and lower average income and wealth levels motivating our regression analysis. Each model is a simple linear regression of lease quality on tract-level characteristics either taken from the US census or tabulated by tract using our micro-level data.[11]

The first set of specifications reported in Table 3.5 estimates a model measuring the effects of tract-level percentages describing race and ethnicity concentrations and controls on lease quality. Positive and significant coefficients for variables in the royalty, full set, surface, legal, and water bundles indicate that the presence of a particular race and ethnic concentration increases the quality of lease by including clauses that restrict firm activity. Conversely, positive and significant coefficients in the models for term length and "bads" indicates that the lease quality is decreased since term length is a measure of duration of the lease term and a longer lease term translates into a longer period for the firm to decide to permit and drill a well thereby foregoing any other option values for that period of time. Additionally, "bads" measure the average frequency of clauses that benefit the firm (as opposed

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[11] We also tested each specification using a negative binomial regression since the counts of lease clauses are somewhat discretized, and we find that the signs and significance of the estimates are relative consistent across specifications.

to the mineral estate owner).

The results largely suggest that tracts with a higher percentage of Black and Hispanic populations have a negative relationship with lease quality as evidenced by the negative and significant coefficients for the independent variables in the models of bundles describing greater lease quality. The converse is true for negative and significant coefficients in those models of costly bundles like term length and "bads" (from the perspective of the mineral rights owner). The presence of large Hispanic populations is correlated with worse lease quality across more categories than any other control variable reported.

Among the control variables, average area has intuitive signs in that larger average parcel sizes receive larger average royalty payments and shorter lease terms. The coefficients for household size in the royalty and "bads" regressions are both negative, the later suggesting that household size is negatively correlated with clauses favorable to firms. Groundwater households are located on the periphery of the maps where there is more wealth and a higher concentrations of White population. Controlling for these factors, groundwater is negatively correlated with lease quality except when estimated using the term length. Finally, high school educated households are consistently correlated with worse lease quality.

Table 3.6 estimates the same model while including a measure of tract-level wealth, median appraisal value.[12] Greater wealth is positively correlated with favorable lease terms when considering royalty, term length, and "bads" regressions, and otherwise, there is not a significant effect. Our race and ethnic variable effects are essentially unchanged, as are the effects for most of our controls. The exception is the effect of a high school education, which now enters fewer regressions with significant effects. Our remaining specifications will build on this specification including median appraised values.

This result is robust to including the tract-level median appraisal values from earlier years, as well, though the estimates are not reported. We have access to appraisal values spanning 2000 to 2013, and including the median appraisal value by tract for each year as a dependent variable still suggests that wealthier areas receive better lease terms including the earlier years before drilling really began in Tarrant County. Other property value hedonic analyses in Timmins and Vissing (2015) suggests that the lease quality is captured in the value of the house. Our analysis, focusing on the earlier appraisal values, does not contradict that conclusion but rather substantiates that lease quality is positively correlated with wealthier tracts.

The results including a measure of the concentration of split estates in a given

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[12] We ran a regression using median income at the tract level, as well, and the differences in estimated effects were not large among other variables; however, there was not a measurable effect of income, so we report the more intuitive results using median appraisal value.

tract are reported in Table 3.7. These models expand on Figure 6 results by adding an independent variable describing the concentration of split estates in a given tract.

Including the split estate measure removes the significance for Blacks in the "bads" regression and for Hispanics in the legal regression; otherwise, the estimates remain largely the same across specifications in Tables 3.6 and 3.7. However, split estate concentration is largely negatively correlated with the quality of leases as evidenced by the negative coefficients on split estate concentration in the specifications using the full set, surface, and legal clauses and the positive coefficient in the "bads" specification. These results are relatively intuitive since the clauses are largely designed to protect surface estate owner with a few exceptions thereby decreasing the incentive to include them in leases signed between parties where the mineral estate owner does not live on the premises.

We observe leases signed in Tarrant County from 2000 to 2013. In Table 3.8, we report a specification crudely controlling for whether the leases in a given tract were signed earlier or later in the leasing phase. Including a variable accounting for the average time period in which the lease was signed, we find that control for whether leases are signed earlier or later in the lease phase does not change the basic results. The relationship between the average time to sign the leases and lease quality are mixed. We find that leases signed later have better royalty rates and smaller term lengths, but these leases are negatively correlated with frequency of externality, legal, and water quality clauses.

Table 3.9 describes results using the percent of individual speaking English well as an independent variable along with other controls following from the analysis above. We chose to separate out this analysis because the Pct. English Speaking variable is highly and negatively correlated with Pct. Hispanic (-0.96); however, Pct. English Speaking is positively correlated with the lease quality across the surface, legal, water quality, and full bundle types and with a higher royalty rate. These results are intuitive if we believe there is asymmetry in negotiation ability based on how well a mineral estate owner speaks English. Similar to the race and ethnicity specifications, the control variables generally have reasonable coefficients and interpretations.

Finally, results differentiating between common and uncommon clauses are reported in Table 3.10. Common clauses primarily include those restricting surface access and damage and externalities borne by individuals living near the well except the Pugh and Force Majeure clauses. Mineral rights owners of split estates should intuitively be less likely to sign leases with clauses classified as common. We find that a high frequency of Hispanic population reduces the frequency of common lease clauses while a high frequency of White population increases the frequency of uncommon clauses in columns 1 and 2. However, when we include the median appraisal value, the effect for Whites is no longer significant (column 4).

3.6 Conclusion and Policy Discussion

Auxiliary clauses play an important de facto regulatory role in the US shale gas industry since they are the primary mechanism used by homeowners to protect themselves from the negative consequences associated with nearby shale gas development. In this paper, we determine whether the tract-level characteristics of homeowners play an important role in how leases for shale gas mineral rights are allocated. Focusing on fee-simple estates and using city fixed effects to control for variation in local ordinances, we find that race, ethnicity, and income (or wealth) have significant effects on the tract-level lease quality outcomes. Tracts with greater concentrations of Black and Hispanic households are correlated with worse lease quality, while wealth, as measured by median appraisal values, has the opposite relationship with lease quality in the tract, among other findings. These finding suggest that sub-populations are targeted for worse lease quality; and while we have not identified a mechanism, it could be because of information asymmetry, perceived lower opportunity costs, or mechanisms associated with environmental justice, among other potential factors.

As a consequence, we proceed with a discussion of policy ideas partially implemented, active in other states with an oil and natural industry, or purely hypothetical, that might reduce the heterogeneity in lease terms offered across sub-populations signing them and subsequently decrease the negative consequences experienced by those households exposed to nearby drilling.

As mentioned in the legal framework section, federal and state levels of government do not impose rules and restrictions that protect property owners (and their surface estates) signing leases. Nor are the rules they enforce broad enough to shield households and surface estates from the negative consequences of being located near to a natural gas well like traffic, noise, and air pollution, some of the byproducts of increased drilling activity experienced by nearby households. Rather, the primary mechanism protecting households and their surface estates from the negative consequences of drilling activity are the private leases negotiated between mineral estate owners and firms.

Further, the basic level of protection is likely thwarted for surface estate owners not owning the mineral estate, or split estates, and we find empirical evidence of this at the tract-level whereby tracts with a higher concentration of split estates receive worse lease terms as reported in Table 3.8. In states like Texas where the mineral estate dominates, this is particularly pertinent since firms are only required to sign leases with the mineral estate owner and they may make necessary use of the surface estate to access and extract from the mineral estate.[13] The former withholds the surface estates' bargaining power for any leases negotiated by the mineral estate owner of a severed estate. The latter requires the surface estate owner to prove unnecessary damage through litigation (or through a settlement negotiated with the firm out of court) in the event the surface estate is abused.

Potential second lines of defense for property owners located within a municipal jurisdiction are local ordinances. The state of Texas allows for "home rule," and several cities located in Tarrant County have written and enforce local ordinances within their jurisdictions. However, these rules do not protect rural property owners (unless they are located within a stipulated buffer around the municipality and have applied to be under that municipality's jurisdiction) and there is a large amount of heterogeneity across townships perhaps limiting the overall effectiveness by driving some firms to extract in more regulatory lax environments.

Other states have remedied the imbalance between surface and mineral estate owners of a severed estate by requiring that firms interested in accessing the minerals negotiate with both owners. In particular, other states with active natural gas industries have passed surface damage protection legislation including Wyoming, Col-

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[13] As described in the legal details, the mineral estate has a right to the surface water for hydraulic fracturing operations, they may access the drill site by building roads or laying pipelines traversing the surface estate, and they are not required to restore the property to the original condition as long as the well operations did not cause unnecessary damage.

orado, and New Mexico.[14] These laws, in some cases, build on the rules established for extracting minerals from federal lands and managed by the Department of the Interior, Bureau of Land Management (BLM).[15,16] States like Wyoming have passed more restrictive surface protection laws by increasing bond requirements and requiring surface owners be compensated for damage and loss of production and income (Watson 2008). Adoption of more comprehensive surface protection laws alleviates the burden of the surface owner roving negligence as the definitions of damage and lost production are clearly stated in a surface use agreement, stipulate remediation plans upfront, and require bonding to ensure the firm has set aside money to fulfill the terms of the contract.

Uniform leasing standards, whereby there is an established baseline set of clauses required for all leases relinquishing the mineral estate to firms for natural gas extraction, decrease the heterogeneity across leases signed by private properties and could be designed to protect the surface estate and households living near active well sites. As it stands, the lease term benchmark is written by the firm, which maintains some level of uniformity across the leases signed in a given region. However, a regulating

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[14] Wyoming Surface Owner Accommodation Act of 2005 [W.S. 30-5-401]; New Mexico Surface Owner's Protection Act of 2007 [N.M.S.A. 70-12]; Colorado Surface Owner Protection Act of 2007 [C.S. 34- 60-127].

[15] Onshore oil and gas order no. 1 (2007): `http://www.blm.gov/wo/st/en/prog/energy/oil_and_gas/Onshore_Order_no1.htm`

[16] "Split Estate: Rights, Responsibilities, and Opportunities" `http://www.blm.gov/wo/st/en/prog/energy/oil_and_gas/best_management_practices/split_estate.html`

body could use the experience of communities with active oil and natural gas industries to form a set of clauses most beneficial to both negotiating parties and use the list as a baseline from which firms and landowners could begin negotiation.

Regulators could stipulate a reverse pooling standard whereby a certain threshold of residents agree to allow natural gas development from beneath their mineral estates prior to allowing firms begin private negotiations. A reverse pooling rule staves off instances whereby property owners are "forced" to sign leases because their neighbors have already signed leases and they are certain to experience the negative consequences (or they are "force pooled," meaning the firm gains access to the mineral estate even when the mineral estate owner does not voluntarily sign a lease). Though we do not control for this situation in the current analysis, anecdotally we read about property owners losing access to their land under forced pooling rulings issued by the TRC.[17] Establishing a reverse pooling requirement in densely populated areas might increase the bargaining power of those landowners as such a policy would require some threshold of agreement across the set of mineral rights owners before any leases are signed to extract from the targeted area.

The final set of policy ideas are concerned with information provision as a mechanism for decreasing asymmetry across firms and households, and even between

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[17] `http://blogs.star-telegram.com/barnett_shale/leases_what_if_i_dont_sign/`

households. These include: increased information about risks and rewards of nearby drilling activity, subsidized access to legal expertise, and publicizing lease terms negotiated in nearby areas. Increasing access to information describing the risks and benefits of well development allows households to make more informed decisions by decreasing the information asymmetry between firms and landowners.[18] Facilitating the use of legal expertise prior to drawing up a highly legalized document with an experienced firm would also likely alleviate the imbalance. Finally, publicizing the existing lease terms in a particular region reduces the likelihood that firms could offer differential terms based on observable characteristics of the mineral estate owners.

This paper is primarily focused on more aggregate effects, estimating simple models that capture the effect tract-level variation in race, ethnicity, income, and wealth, among other variables, on lease quality outcomes observed in our data. We then use the analysis to motivate a policy discussion that explores alternatives reducing heterogeneity in lease quality across tracts, and subsequently, would reduce the heterogeneity in negative consequences experienced being located near drilling activity. Future analyses estimate the effects using household level data, and estimate the value of specific lease terms using property value hedonic modeling.

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[18] Leasing guides provide mineral rights owners with a checklist describing the potential clauses to use in negotiation facilitating a lease with clauses most valued by the negotiating parties. See McFarland, 2014.

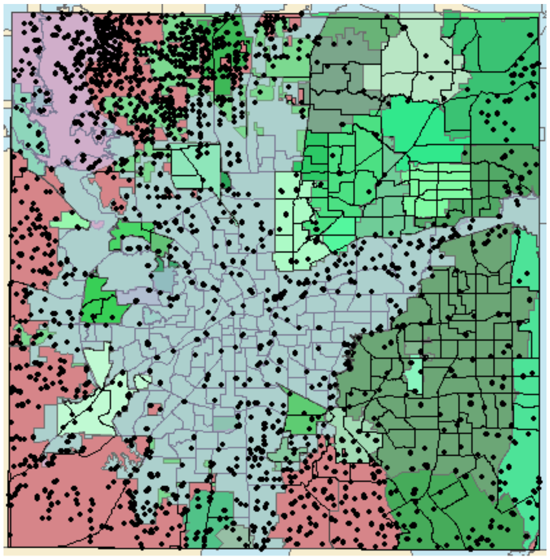

FIGURE 3.1: Tarrant Co. Tracts, Cities, and Water District

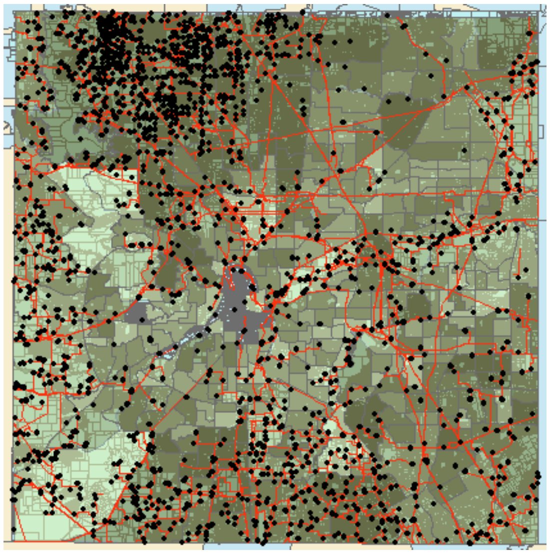

FIGURE 3.2: Population Density

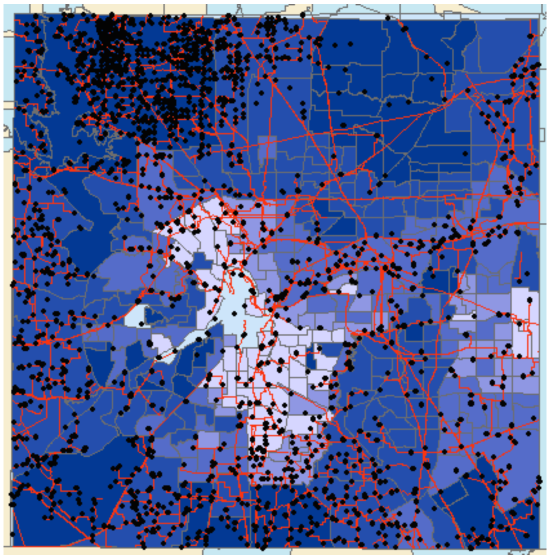

FIGURE 3.3: Pct. White, non-Hispanic

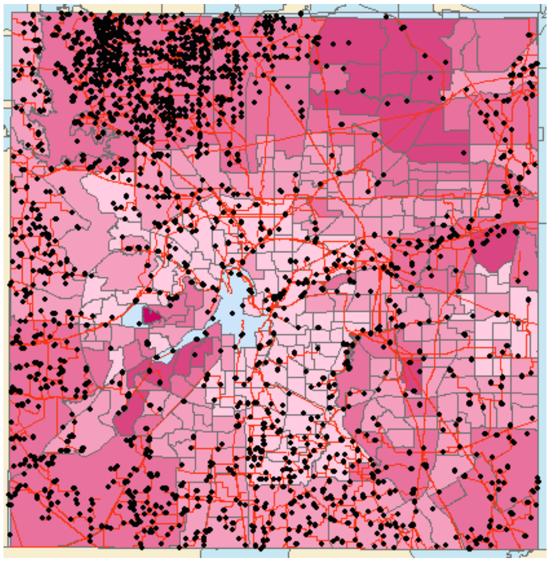

FIGURE 3.4: Median Appraisal Value

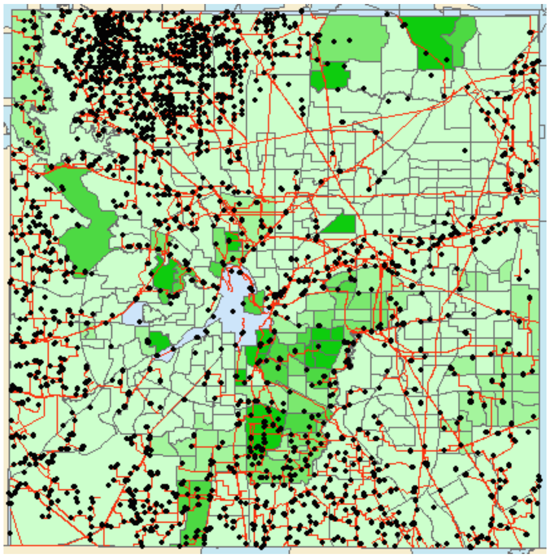

FIGURE 3.5: Pct. Black

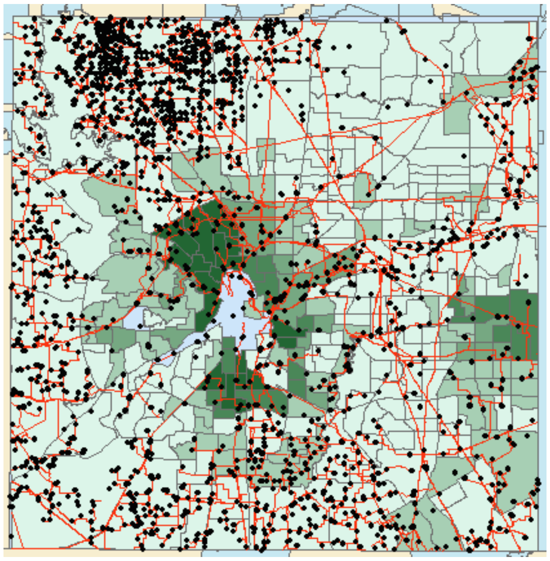

FIGURE 3.6: Pct. Hispanic

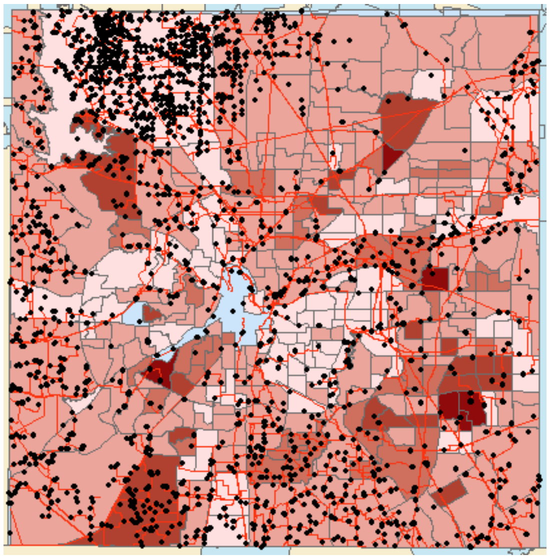

FIGURE 3.7: Full Set of Clauses Mean Count

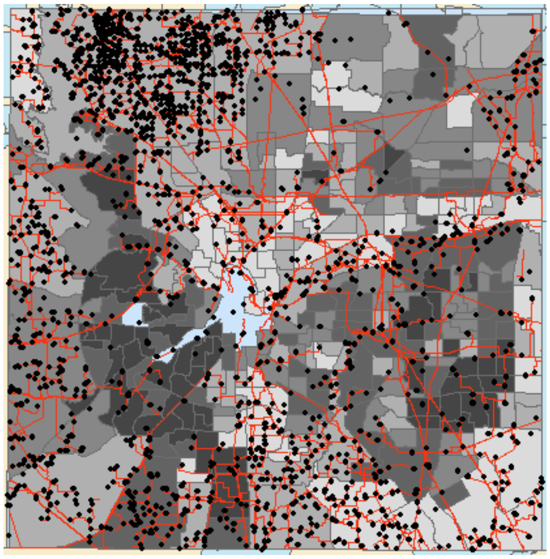

FIGURE 3.8: Mean Royalty Rate

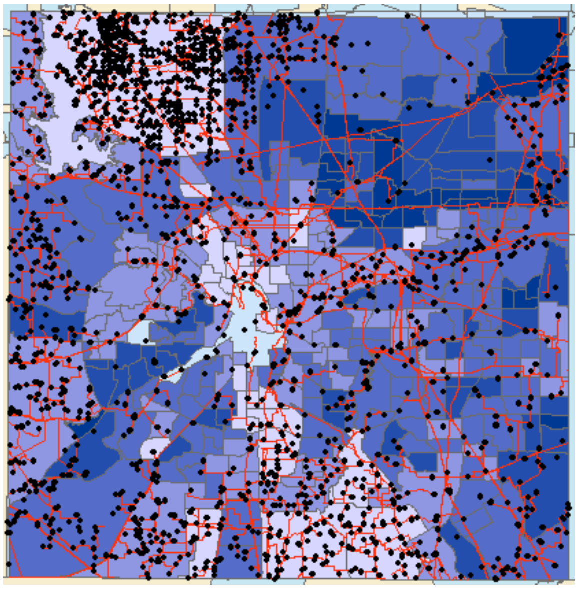

FIGURE 3.9: Mean Number of Years Since 2000

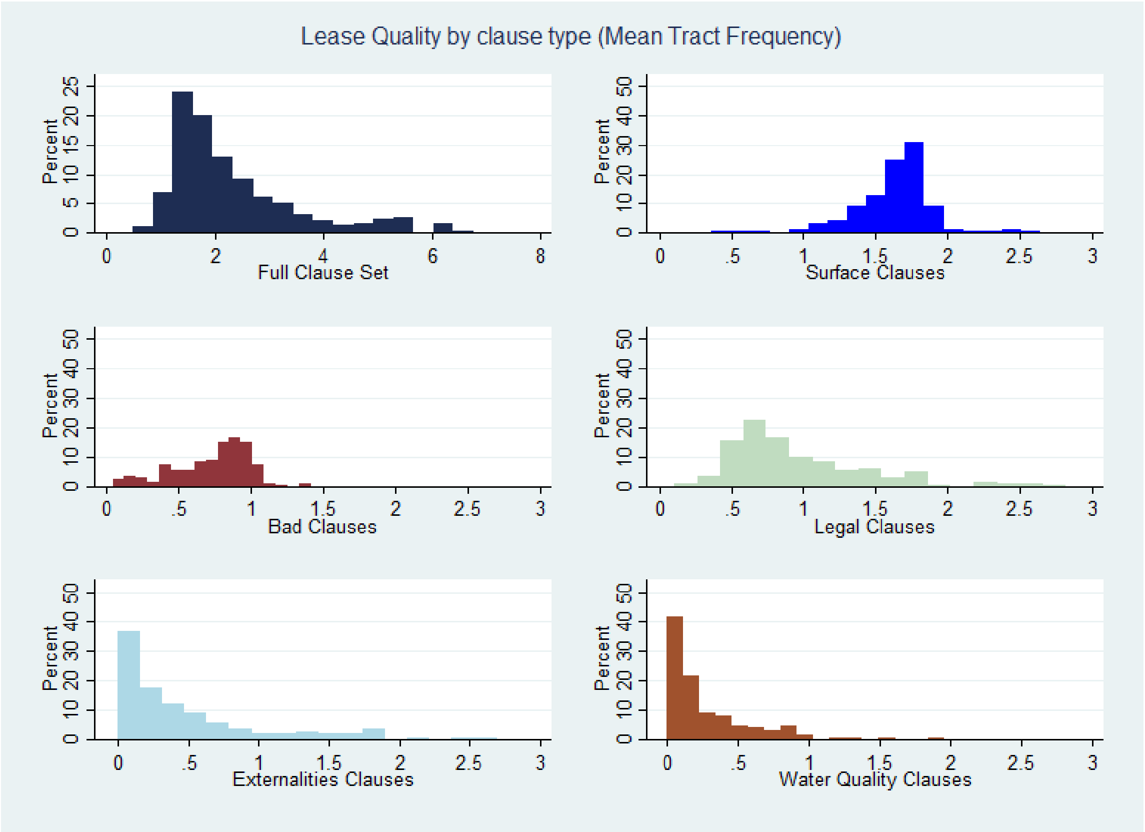

FIGURE 3.10: Histograms

Table 3.1: Summary statistics

	Mean	Std. Dev.
Tract Controls		
Pct. Black	0.18	0.23
Pct. Asian	0.14	0.23
Pct. Hispanic	0.26	0.23
Pct. White	0.55	0.25
Med. Income (in 10,000)	6.32	3.08
Med. App. Value (in 100,000)	1.21	0.97
Avg. Area (in 1,000)	4.31	5.98
Population (in 1,000)	4.97	1.79
Pct. Pop. under 65	0.09	0.06
Avg. HH size	2.82	0.45
Avg. Groundwater	0.57	0.48
Pct. High School	0.25	0.08
Avg. Split Estate	0.21	0.12
Avg. Years into signing	8.15	0.67
Pct. English Speaking	0.78	0.17
Lease Terms		
Avg. Royalty (pct.)	0.23	0.01
Avg. Term (months)	42.86	7.81
Legal Clauses	0.95	0.46
Surface Clauses	1.63	0.27
"Bad" Clauses	0.72	0.26
Externality Clauses	0.48	0.52
Full Set of Clauses	2.33	1.23
Water Quality Clauses	0.27	0.3
Common Clauses	2.76	0.9
Uncommon Clauses	0.3	0.33
Observations	296	

Table 3.2: Independent group t-test house merged and not merged to leases

	Mean	Std. Dev.
Sample without signed lease		
Groundwater	0.59	0.49
House age	29.22	22.45
Land (sqft)	12609.49	23752.65
Living area (sqft)	1984.61	970.29
Bathroom	1.97	0.7
Bedroom	3.17	0.8
Sample with signed leases		
Groundwater	0.63	0.48
House age	37.61	21.32
Land (sqft)	12931.23	25047.73
Living area (sqft)	1928.13	891.47
Bathroom	1.94	0.66
Bedroom	3.18	0.64

	T-stat
Groundwater	-29.21
House age	-141.91
Land (sqft)	-4.82
Living area (sqft)	22.43
Bathroom	16.67
Bedroom	-6.65

Table 3.3: Independent group t-test leases with and without auxiliary clauses

	Mean	Std. Dev.
No Auxiliary		
Land (acre)	4.49	73.8
Term length (months)	42.99	12.1
Royalty (pct)	0.22	0.02
Auxiliary		
Land (acre)	1.97	39.22
Term length (months)	42.6	11.73
Royalty (pct)	0.24	0.02
	T-stat	
Land (acre)	8.33	0
Term length (months)	7.2	0
Royalty (pct)	-201.44	0

Table 3.4: Bundle composition

Surface bundle	No surface access	Externality bundle	Environmental
	Surface restrictions		Noise restriction
	Surface damage		Freshwater protection
Legal bundle	Force majeure		Surface casing restriction
	Pugh		Compression station restriction
	Insurance, indemnity	Water bundle	Environmental
	Reporting		Freshwater protection
	Offset well		Surface casing restriction
“Bads” bundle	Subsurface easement	Royalty	
	Injection fluid	Term length (in months)	
	Free water access		

Table 3.5: Basic Results

	(1)		(2)		(3)		(4)	
	Royalty[a]		Term (months)		Full set		Surface	
Pct. Black[b]	-0.487	(0.384)	4.566**	(2.158)	-0.267	(0.264)	-0.048	(0.066)
Pct. Asian	0.041	(0.239)	-1.401	(1.7)	0.108	(0.265)	0.004	(0.067)
Pct. Hispanic	-1.178**	(0.465)	-0.847	(2.952)	-1.075**	(0.443)	-0.216**	(0.103)
Pct. White, non-Hispanic	-0.201	(0.474)	-5.015	(3.2)	0.556	(0.412)	0.101	(0.095)
Avg. Area	0.024**	(0.012)	-0.119**	(0.058)	0.001	(0.015)	-0.006	(0.005)
Population	0.005	(0.043)	0.07	(0.236)	0.047	(0.048)	-0.004	(0.01)
Pct. Pop. under 65	0.772	(1.297)	-9.11	(7.411)	0.494	(1.482)	0.43	(0.355)
Avg. HH size	-0.418**	(0.203)	0.332	(1.365)	0.218	(0.18)	-0.006	(0.045)
Avg. Groundwater	-1.039***	(0.375)	-7.214*	(3.687)	-1.254**	(0.545)	-0.910***	(0.194)
Pct. High School	-0.804	(0.958)	9.753*	(5.771)	-3.626***	(1.079)	-0.508*	(0.288)
R-squared	0.399		0.572		0.324		0.322	

	(5)		(6)		(7)		(8)	
	"Bads"		Externality		Legal		Water	
Pct. Black	0.120**	(0.061)	-0.16	(0.106)	0.062	(0.133)	-0.072	(0.064)
Pct. Asian	-0.007	(0.08)	0.075	(0.115)	0.021	(0.107)	0.059	(0.066)
Pct. Hispanic	0.118	(0.098)	-0.414**	(0.199)	-0.327*	(0.17)	-0.255**	(0.119)
Pct. White, non-Hispanic	-0.013	(0.089)	0.154	(0.164)	0.288	(0.182)	0.063	(0.095)
Avg. Area	-0.003	(0.004)	0.003	(0.007)	0	(0.005)	0	(0.003)
Population	-0.002	(0.01)	0.03	(0.021)	0.02	(0.02)	0.019	(0.013)
Pct. Pop. under 65	-0.35	(0.286)	0.095	(0.642)	-0.381	(0.592)	0.165	(0.397)
Avg. HH size	-0.128***	(0.043)	0.038	(0.077)	0.057	(0.072)	0.014	(0.044)
Avg. Groundwater	-0.03	(0.15)	-0.392*	(0.23)	0.018	(0.232)	-0.210*	(0.127)
Pct. High School	0.853***	(0.257)	-1.306***	(0.453)	-0.958**	(0.456)	-0.756***	(0.271)
Observations	296		296		296		296	
R-squared	0.309		0.316		0.299		0.317	
City FE	yes		yes		yes		yes	

[a] Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

[b] All variables are measured at the tract level.

Table 3.6: Basic results with a measure of wealth

	(1) Royalty[a]		(2) Term (months)		(3) Full set		(4) Surface	
Pct. Black[b,c]	-0.585	(0.365)	5.438**	(2.163)	-0.377	(0.279)	-0.062	(0.072)
Pct. Asian	0.088	(0.242)	-1.566	(1.691)	0.103	(0.256)	0	(0.069)
Pct. Hispanic	-1.007**	(0.475)	-0.813	(2.872)	-1.111**	(0.439)	-0.214*	(0.108)
Pct. White, non-Hispanic	-0.334	(0.465)	-2.87	(3.196)	0.142	(0.443)	0.052	(0.107)
Med. Appraisal value	0.220*	(0.121)	-1.635**	(0.719)	0.313	(0.203)	0.022	(0.053)
Pct. High School Edu.	0.681	(1.134)	1.818	(6.903)	-2.373*	(1.397)	-0.445	(0.396)
R-squared	0.417		0.592		0.336		0.319	

	(5) "Bads"		(6) Externality		(7) Legal		(8) Water	
Pct. Black	0.144**	(0.067)	-0.177	(0.117)	0.005	(0.133)	-0.08	(0.071)
Pct. Asian	-0.013	(0.081)	0.08	(0.111)	0.01	(0.104)	0.064	(0.065)
Pct. Hispanic	0.133	(0.099)	-0.423**	(0.207)	-0.341**	(0.169)	-0.262**	(0.127)
Pct. White, non-Hispanic	0.071	(0.096)	0.04	(0.18)	0.122	(0.198)	0.005	(0.105)
Med. Appraisal value	-0.070*	(0.038)	0.109	(0.081)	0.113	(0.071)	0.061	(0.043)
Pct. High School Edu.	0.574*	(0.321)	-0.926	(0.604)	-0.427	(0.507)	-0.555	(0.365)
Observations	271		271		271		271	
R-squared	0.331		0.327		0.309		0.332	
City FE	yes		yes		yes		yes	

[a] Robust standard errors in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$

[b] All variables are measured at the tract level.

[c] Other controls: Population, Pct. Pop. Under 65, Pct. High School Edu., Avg. HH size.

Table 3.7: Basic results with a measure of split estates

	(1) Royalty[a]		(2) Term (months)		(3) Full set		(4) Surface	
Pct. Black[b,c]	-0.421	(0.399)	4.269*	(2.26)	-0.267	(0.324)	-0.049	(0.082)
Pct. Asian	0.138	(0.255)	-1.211	(1.729)	0.099	(0.275)	0.012	(0.07)
Pct. Hispanic	-1.021*	(0.523)	-3.266	(3.228)	-1.070**	(0.503)	-0.257**	(0.116)
Pct. White, non-hispanic	-0.385	(0.563)	-6.297*	(3.602)	0.068	(0.544)	-0.032	(0.121)
Med. Appraisal	0.199*	(0.12)	-1.582**	(0.733)	0.295	(0.206)	0.024	(0.054)
Avg. Split Estate	-0.634	(0.632)	0.164	(3.272)	-1.817**	(0.825)	-0.409**	(0.163)
R-squared	0.407		0.592		0.324		0.324	

	(5) "Bads"		(6) Externality		(7) Legal		(8) Water	
Pct. Black	0.125	(0.078)	-0.155	(0.144)	0.063	(0.146)	-0.068	(0.091)
Pct. Asian	-0.006	(0.085)	0.068	(0.119)	0.013	(0.109)	0.054	(0.068)
Pct. Hispanic	0.098	(0.109)	-0.417*	(0.244)	-0.299	(0.194)	-0.259*	(0.152)
Pct. White, non-hispanic	0.088	(0.117)	0.03	(0.22)	0.158	(0.255)	0.01	(0.127)
Med. Appraisal	-0.067*	(0.04)	0.098	(0.081)	0.106	(0.073)	0.056	(0.043)
Avg. Split Estate	0.297*	(0.154)	-0.44	(0.528)	-0.670***	(0.258)	-0.124	(0.378)
Observations	252		252		252		252	
R-squared	0.304		0.311		0.315		0.296	
City FE	yes		yes		yes		yes	

[a] Robust standard errors in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$

[b] All variables are measured at the tract level.

[c] Other controls: Population, Pct. Pop. Under 65, Pct. High School Edu., Avg. HH size.

Table 3.8: Average number of years to sign the leases

	(1)		(2)		(3)		(4)	
	Royalty[a]		Term (months)		Full set		Surface	
Pct. Black[b,c]	-0.371	(0.37)	4.638**	(2.209)	-0.459	(0.282)	-0.059	(0.07)
Pct. Asian	0.056	(0.222)	-1.449	(1.691)	0.115	(0.249)	-0.001	(0.069)
Pct. Hispanic	-0.649	(0.471)	-2.146	(2.899)	-1.248***	(0.457)	-0.210*	(0.116)
Pct. White, non-Hispanic	-0.3	(0.443)	-2.998	(3.134)	0.129	(0.44)	0.052	(0.108)
Med. Appraisal Value	0.266**	(0.125)	-1.806**	(0.724)	0.296	(0.207)	0.022	(0.054)
Avg. Years into Signing	0.504***	(0.14)	-1.879**	(0.776)	-0.193	(0.119)	0.006	(0.028)
R-squared	0.458		0.603		0.341		0.319	

	(5)		(6)		(7)		(8)	
	"Bads"		Externality		Legal		Water	
Pct. Black	0.158**	(0.066)	-0.214*	(0.118)	-0.028	(0.136)	-0.104	(0.072)
Pct. Asian	-0.015	(0.079)	0.086	(0.108)	0.015	(0.102)	0.067	(0.063)
Pct. Hispanic	0.157	(0.098)	-0.486**	(0.217)	-0.395**	(0.174)	-0.302**	(0.135)
Pct. White, non-Hispanic	0.074	(0.095)	0.034	(0.178)	0.117	(0.197)	0.001	(0.103)
Med. Appraisal Value	-0.067*	(0.039)	0.101	(0.083)	0.106	(0.071)	0.056	(0.045)
Avg. Years into Signing	0.034	(0.029)	-0.088*	(0.052)	-0.077*	(0.045)	-0.056*	(0.033)
Observations	271		271		271		271	
R-squared	0.335		0.333		0.315		0.338	
City FE	yes		yes		yes		yes	

[a] Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

[b] All variables are measured at the tract level.

[c] Other controls: Population, Pct. Pop. Under 65, Pct. High School Edu., Avg. HH size.

Table 3.9: Speaks English well

	(1) Royalty[a]		(2) Term (months)		(3) Full set		(4) Surface	
Med. Appraisal Value[b,c]	0.191	(0.118)	-1.795**	(0.696)	0.349*	(0.196)	0.026	(0.051)
Avg. Area	0.025**	(0.011)	-0.157**	(0.061)	-0.001	(0.014)	-0.006	(0.005)
Population	0.02	(0.042)	-0.086	(0.245)	0.065	(0.048)	-0.002	(0.01)
Pct. Pop. under 65	1.09	(1.275)	-16.443**	(7.928)	0.445	(1.506)	0.445	(0.376)
Avg. HH size	-0.454**	(0.204)	0.352	(1.336)	0.153	(0.174)	-0.027	(0.045)
Avg. Groundwater	-1.007***	(0.344)	-9.319**	(4.2)	-1.027*	(0.575)	-0.888***	(0.196)
Pct. High School Edu.	0.049	(1.099)	9.072	(6.966)	-2.859*	(1.453)	-0.574	(0.387)
Pct. English Speaking	1.018**	(0.49)	0.778	(2.93)	1.036**	(0.459)	0.266**	(0.123)
R-squared	0.415		0.571		0.325		0.315	

	(5) "Bads"		(6) Externality		(7) Legal		(8) Water	
Med. Appraisal Value	-0.074*	(0.038)	0.122	(0.078)	0.127*	(0.066)	0.066	(0.041)
Avg. Area	-0.003	(0.004)	0.003	(0.006)	0.000	(0.005)	0.000	(0.003)
Population	-0.005	(0.011)	0.038*	(0.022)	0.024	(0.019)	0.023*	(0.013)
Pct. Pop. under 65	-0.366	(0.289)	-0.006	(0.676)	-0.36	(0.574)	0.102	(0.42)
Avg. HH size	-0.122***	(0.043)	0.011	(0.072)	0.047	(0.071)	0.003	(0.042)
Avg. Groundwater	-0.07	(0.158)	-0.286	(0.244)	0.078	(0.245)	-0.161	(0.135)
Pct. High School Edu.	0.646**	(0.318)	-1.122*	(0.646)	-0.518	(0.489)	-0.643*	(0.389)
Pct. English Speaking	0.000	(0.108)	0.354	(0.216)	0.416**	(0.161)	0.230*	(0.127)
Observations	271		271		271		271	
R-squared	0.324		0.317		0.302		0.323	
City FE	yes		yes		yes		yes	

[a] Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

[b] All variables are measured at the tract level.

Table 3.10: Common versus uncommon clauses

	(1) Common[a]	(2) Uncommon	(3) Common	(4) Uncommon
Pct. Black[b,c]	-0.149	0.003	-0.203	-0.03
	-0.183	-0.101	-0.196	-0.097
Pct. Asian	0.143	-0.042	0.135	-0.045
	-0.186	-0.086	-0.185	-0.085
Pct. Hispanic	-0.856***	-0.101	-0.854***	-0.124
	-0.311	-0.124	-0.311	-0.124
Pct. White, non-	0.331	0.212*	0.096	0.117
Hispanic	-0.306	-0.114	-0.329	-0.12
Med. Appraisal			0.171	0.072*
value			-0.143	-0.041
Observations	296	296	271	271
R-squared	0.331	0.284	0.328	0.29
City FE	yes	yes	yes	yes

[a] Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

[b] All variables are measured at the tract level.

[c] Other controls: Avg. Area, Pop., Pct. Pop. Under 65, Avg. HH size, Avg. Groundwater, Pct. High School Edu.

Appendix A

APPENDIX: One-to-Many Matching with Complementary Preferences: An Empirical Study of Natural Gas Lease Quality and Market Power

A.1 Estimation Details

A.1.1 Inference: Covariance Matrix

The following calculations for the variance/covariance matrices follow from Agarwal (2014) and Gourieroux and Monfort (1997). The following variance/covariance matrix, Σ, accounts for the correlation between moments calculated across markets.[1]

$$\Sigma = (\Gamma' W \Gamma)^{-1} \Gamma' W (\hat{V} + \frac{1}{S} \hat{V}^S) W' \Gamma (\Gamma' W \Gamma)^{-1} \tag{A.1}$$

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[1] It is likely there are still econometric issues to work out in approximating the variance/covariance matrix, and since the match presented in the paper occurs all at once for firms offerring leases across geographic markets, corrections for spatail correlation may be less relevant.

1. $\hat{\Gamma}$: *Gradient of moments with respect to* θ *evaluated at* $\hat{\theta}$.

   A two-sided numerical derivative of the simulated moment function $m(\hat{\theta})$ using the observed population of firms and landowners is used to calculate $\hat{\Gamma}$. The numerical derivative is calculated using 10,000 simulation draws and a step size of 10^{-2}.

$$m'(\hat{\theta}) \simeq \frac{m(\hat{\theta}+h) - m(\hat{\theta}-h)}{(\hat{\theta}+h) - (\hat{\theta}-h)} \tag{A.2}$$

2. The derivative is approximated by taking 10,000 simulation draws, perturbing the parameter by the step size ($h = 10^{-2}$), running the match algorithm, calculating the resulting moments, $m(\hat{\theta}+h)$ and $m(\hat{\theta}-h)$, and calculating the average over all the simulations. The two sets of moment quantities are calculated for each market.

3. $\hat{V}$: *Bootstrap estimate of the covariance of the moments at* $\hat{\theta}$.

   Based on the our estimated $\hat{\theta}$, we used the bootstrap samples to calculate the moments $m^b(\hat{\theta})$ for each b, and based on those calculated moments, $\tilde{V} = cov(m^b(\hat{\theta}))$

4. $\hat{V}^S$: *Estimate of the simulation error in the moments at* $\hat{\theta}$.

5. *W: Weight matrix.*

The reported estimates use an identity weight matrix that results in consistent but not efficient estimates. Increasing the efficiency of the estimator requires adopting the following weight matrix that uses the variance/covariance matrix from equation (A.3).

$$\begin{aligned} \tilde{V} &= var\{\sqrt{S}\, m(\hat{\theta}) - \frac{1}{S}\sum_s \sqrt{S}\, m_s(\hat{\theta})\} \\ W &= \tilde{V}^{-1} \end{aligned} \tag{A.3}$$

A.1.2 Bootstrap Sample

Calculating the numerical derivatives requires matches resulting from bootstrapped data evaluated at the estimated parameter value, and the following section describes how the bootstrap data is formed.

For each market, there are J^m observed participants, and for each of those participants, they offer a random count of leases c_j^m drawn from a distribution based on the observed firm-level activity in the data. The sum of leases signed in a given bootstrap market, $\sum c_j^m$, is equal to the sum of the observed leases signed in the data. The observables that are randomized between the two sides of the market (parcels and firms) are the count of leases signed by any single firm and the specific match between the firm and parcel.

Each parcel location and land size cannot be duplicated because there cannot be two parcels located at the same geographic point in space, so parcels are paired to firms uniquely. However, the date at which the parcel was signed and the lease quality can be independently drawn from the population with replacement for each observation (X_i, X_{ij}). The lease quality values are randomly assigned at the clause level based on the probability of being observed in the true data (in any market). The clauses are then re-bundled, and all time varying measures of lease quality are re-calculated. For example, a parcel observed matching to XTO could be randomly selected to match with Chesapeake signing a lease earlier in the period and that includes more environmental clauses and a lower royalty rate.

Based on the firms' new lease matches and signing dates, the existing well infrastructure (existing permits and producing wells) variables for that firm are re-merged to the data. Similar to lease quality and signing dates, firm competition varies based on the new bootstrap matches (and random variables c_j^m), so all of the competition variables are recalculated based on the new timing and market structure. Finally, I recalculate the distance measures and parcel contribution variables at the new signing dates.

After the new matches are assembled, the data is expanded to calculated the new utilities for each parcel and firm pair based on the bootstrapped market structure.

A.1.3 Computation Details

Each model is estimated, first, with a global search, the MATLAB genetic algorithm, and second, a local search, like Nelder Meade or fminsearch packages written in MATLAB. Each simulated outcome can be calculated in parallel.

The objective function is written in MATLAB while the pieces of the objective function, like the deferred acceptance algorithm, sorting functions, moment functions, and the like, are all written in C and compiled using matlab mex functions to expedite computation time. The entire set of MATLAB files were compiled as a linux executable for use on a supercomputer facilitated by Xsede of the NSF in addition to estimating specifications using the Duke University and Economics Department clusters.

The final model specification is estimated on twenty-five percent of the data because the computation time is intensive for the proposed algorithm.

A.2 Reduced Form Models

The following tables are added ordinary and two-staged lease squares regressions with additional control variables and one additional outcome variable, the count of active firms leasing in a wellpad, a measure of competition like that in Bresnahan and Reiss (1991).

Table A.1: OLS: Firm Cumulative Share

Panel A : Share concentration				
	(1) Royalty rate	(2) Term (month)	(3) Legal	(4) Surface
Land sqft (1e-6)	0.001***	-0.899***	-0.001	0.001
	(0.000)	(0.031)	(0.001)	(0.001)
Distance to wellpad (dummy)	0.001*	1.108***	-0.040***	-0.026***
	(0.000)	(0.159)	(0.005)	(0.005)
Rural (dummy)	-0.001	-0.644***	-0.035***	-0.030***
	(0.000)	(0.157)	(0.007)	(0.007)
Sign Order	0.000***	0.088***	-0.001***	0.000***
	(0.000)	(0.002)	(0.000)	(0.000)
Firm Cumulative Share (wellpad)	-0.004***	2.886***	-0.020***	-0.019***
	(0.000)	(0.079)	(0.003)	(0.003)
R-squared	0.391	0.378	0.314	0.309
	(5) Bads	(6) Externality	(7) Water	(8) Full set
Land sqft (1e-6)	0.005***	0.007***	0.007***	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Distance to wellpad (dummy)	0.062***	-0.063***	-0.034***	-0.080***
	(0.005)	(0.007)	(0.005)	(0.007)
Rural (dummy)	0.001	-0.068***	-0.052***	-0.060***
	(0.006)	(0.008)	(0.006)	(0.008)
Sign Order	0.002***	-0.002***	-0.001***	-0.002***
	(0.000)	(0.000)	(0.000)	(0.000)
Firm Cumulative Share (wellpad)	0.076***	-0.063***	-0.038***	-0.070***
	(0.002)	(0.003)	(0.003)	(0.004)
R-squared	0.307	0.301	0.313	0.341
Firm FE	yes	yes	yes	yes
Period FE	yes	yes	yes	yes

These regresions report the results when there is no time element. The shares represent the final share allocation for each firm across markets, and period fixed effects are removed from the specification. However, I use the same instrument,

A.3 Counterfactual

Table A.2: OLS: HHI

Panel B : HHI

	(1) Royalty rate	(2) Term (month)	(3) Legal	(4) Surface
Land sqft (1e-6)	0.001***	-0.929***	-0.001	0.001
	(0.000)	(0.031)	(0.001)	(0.001)
Distance to wellpad (dummy)	0.001	1.319***	-0.039***	-0.026***
	(0.000)	(0.158)	(0.005)	(0.005)
Rural (dummy)	-0.000	-0.589***	-0.030***	-0.027***
	(0.000)	(0.156)	(0.007)	(0.007)
Sign Order	0.000***	0.067***	-0.001***	0.000***
	(0.000)	(0.002)	(0.000)	(0.000)
HHI Cumulative (wellpad)	-0.003***	1.130***	-0.020***	-0.013***
	(0.000)	(0.038)	(0.002)	(0.002)
Observations	148,060	232,482	62,805	62,805
R-squared	0.394	0.376	0.315	0.310

	(5) Bads	(6) Externality	(7) Water	(8) Full set
Land sqft (1e-6)	0.005***	0.007***	0.007***	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Distance to wellpad (dummy)	0.062***	-0.062***	-0.034***	-0.078***
	(0.005)	(0.007)	(0.005)	(0.007)
Rural (dummy)	-0.004	-0.064***	-0.048***	-0.053***
	(0.005)	(0.008)	(0.006)	(0.008)
Sign Order	0.001***	-0.002***	-0.001***	-0.002***
	(0.000)	(0.000)	(0.000)	(0.000)
HHI Cumulative (wellpad)	0.035***	-0.031***	-0.020***	-0.041***
	(0.001)	(0.002)	(0.001)	(0.002)
Observations	62,805	62,805	62,805	62,805
R-squared	0.306	0.301	0.313	0.343
Firm FE	yes	yes	yes	yes
Period FE	yes	yes	yes	yes

Table A.3: OLS: Firm Count

Panel C : Firm Count

	(1) Royalty rate	(2) Term (month)	(3) Legal	(4) Surface
Land sqft (1e-6)	0.001***	-0.957***	-0.000	0.002
	(0.000)	(0.031)	(0.001)	(0.001)
Distance to wellpad (dummy)	0.000	1.176***	-0.040***	-0.024***
	(0.000)	(0.159)	(0.005)	(0.005)
Rural (dummy)	-0.002***	-0.637***	-0.029***	-0.019**
	(0.000)	(0.158)	(0.007)	(0.007)
Sign Order	0.000***	0.082***	-0.001***	-0.000***
	(0.000)	(0.003)	(0.000)	(0.000)
Firm Count (wellpad)	-0.000**	-0.446***	0.008***	0.012***
	(0.000)	(0.025)	(0.001)	(0.001)
Observations	148,060	232,482	62,805	62,805
R-squared	0.389	0.375	0.314	0.310

	(5) Bads	(6) Externality	(7) Water	(8) Full set
Land sqft (1e-6)	0.004***	0.008***	0.008***	0.002*
	(0.001)	(0.001)	(0.001)	(0.001)
Distance to wellpad (dummy)	0.063***	-0.062***	-0.033***	-0.079***
	(0.005)	(0.007)	(0.005)	(0.007)
Rural (dummy)	-0.006	-0.058***	-0.044***	-0.046***
	(0.005)	(0.008)	(0.006)	(0.008)
Sign Order	0.002***	-0.002***	-0.002***	-0.002***
	(0.000)	(0.000)	(0.000)	(0.000)
Firm Count (wellpad)	-0.013***	0.015***	0.011***	0.020***
	(0.001)	(0.001)	(0.001)	(0.001)
Observations	62,805	62,805	62,805	62,805
R-squared	0.299	0.299	0.312	0.340
Firm FE	yes	yes	yes	yes
Period FE	yes	yes	yes	yes

Table A.4: 2-SLS: Firm Cumulative Share

	(1) Royalty rate	(2) Term (month)	(3) Legal	(4) Surface
Panel A : stage 1				
Nearby producing wells	0.017***	0.010***	0.014***	
	(0.001)	(0.001)	(0.002)	
F-stat	1158.603	2347.391	548.798	
Panel B : stage 2				
Land sqft (1e-6)	0.002***	-0.926***	0.003**	0.007***
	(0.000)	(0.050)	(0.001)	(0.001)
Distance to wellpad (dummy)	-0.000	1.264***	0.007	0.040***
	(0.000)	(0.274)	(0.007)	(0.008)
Rural (dummy)	-0.003***	-0.302	0.031***	0.063***
	(0.001)	(0.515)	(0.010)	(0.010)
Sign Order	0.000***	0.064*	-0.009***	-0.011***
	(0.000)	(0.034)	(0.001)	(0.001)
Linear prediction	0.010**	0.505	-0.880***	-1.227***
	(0.005)	(3.404)	(0.086)	(0.098)
Observations	148,060	232,482	62,805	62,805
R-squared	0.389	0.374	0.314	0.311
	(5) Bads	(6) Externality	(7) Water	(8) Full set
Land sqft (1e-6)	0.001	0.014***	0.011***	0.010***
	(0.001)	(0.001)	(0.001)	(0.002)
Distance to wellpad (dummy)	0.021***	0.028***	0.009	0.022**
	(0.006)	(0.008)	(0.006)	(0.009)
Rural (dummy)	-0.057***	0.058***	0.008	0.083***
	(0.008)	(0.010)	(0.008)	(0.011)
Sign Order	0.009***	-0.017***	-0.008***	-0.019***
	(0.001)	(0.001)	(0.001)	(0.001)
Linear prediction	0.824***	-1.712***	-0.818***	-1.933***
	(0.069)	(0.088)	(0.071)	(0.099)
Observations	62,805	62,805	62,805	62,805
R-squared	0.298	0.300	0.312	0.340
Firm FE	yes	yes	yes	yes
Period FE	yes	yes	yes	yes

Table A.5: 2-SLS: HHI

	(1) Royalty rate	(2) Term (month)	(3) Legal	(4) Surface
Panel A : stage 1				
Nearby producing wells	0.047***	0.015***	0.042***	
	(0.003)	(0.002)	(0.004)	
F-stat	197.588	409.264	130.082	
Panel B : stage 2				
Land sqft (1e-6)	0.002***	-0.931***	0.001	0.004***
	(0.000)	(0.032)	(0.001)	(0.001)
Distance to wellpad (dummy)	0.000	1.304***	-0.005	0.023***
	(0.000)	(0.166)	(0.006)	(0.007)
Rural (dummy)	-0.002***	-0.343	0.055***	0.096***
	(0.001)	(0.782)	(0.011)	(0.012)
Sign Order	0.000***	0.061***	-0.002***	-0.002***
	(0.000)	(0.016)	(0.000)	(0.000)
Linear prediction	0.004**	0.356	-0.292***	-0.408***
	(0.002)	(2.400)	(0.029)	(0.033)
Observations	148,060	232,482	62,805	62,805
R-squared	0.389	0.374	0.314	0.311

	(5) Bads	(6) Externality	(7) Water	(8) Full set
Land sqft (1e-6)	0.003***	0.010***	0.009***	0.005***
	(0.001)	(0.001)	(0.001)	(0.001)
Distance to wellpad (dummy)	0.032***	0.004	-0.003	-0.004
	(0.006)	(0.008)	(0.006)	(0.008)
Rural (dummy)	-0.079***	0.104***	0.030***	0.135***
	(0.009)	(0.012)	(0.010)	(0.013)
Sign Order	0.003***	-0.004***	-0.002***	-0.005***
	(0.000)	(0.000)	(0.000)	(0.000)
Linear prediction	0.274***	-0.569***	-0.272***	-0.643***
	(0.023)	(0.029)	(0.024)	(0.033)
Observations	62,805	62,805	62,805	62,805
R-squared	0.298	0.300	0.312	0.340
Firm FE	yes	yes	yes	yes
Period FE	yes	yes	yes	yes

Table A.6: 2-SLS: Firm Count

	(1) Royalty rate	(2) Term (month)	(3) Legal	(4) Surface
Panel A : stage 1				
Nearby producing wells	-0.041***	-0.022***	-0.040***	
	(0.004)	(0.003)	(0.005)	
F-stat	2,869.14	5,887.791	1,702.973	
Panel B : stage 2				
Land sqft (1e-6)	0.001***	-0.945***	0.023***	0.034***
	(0.000)	(0.095)	(0.003)	(0.003)
Distance to wellpad (dummy)	-0.001	1.232***	0.035***	0.079***
	(0.001)	(0.467)	(0.009)	(0.010)
Rural (dummy)	-0.006***	-0.449	0.273***	0.401***
	(0.002)	(1.490)	(0.031)	(0.035)
Sign Order	0.000**	0.071	-0.017***	-0.023***
	(0.000)	(0.082)	(0.002)	(0.002)
Linear prediction	-0.004**	-0.241	0.308***	0.430***
	(0.002)	(1.621)	(0.030)	(0.034)
Observations	148,060	232,482	62,805	62,805
R-squared	0.389	0.374	0.314	0.311

	(5) Bads	(6) Externality	(7) Water	(8) Full set
Land sqft (1e-6)	-0.017***	0.052***	0.029***	0.053***
	(0.002)	(0.003)	(0.002)	(0.003)
Distance to wellpad (dummy)	-0.005	0.082***	0.035***	0.084***
	(0.008)	(0.010)	(0.008)	(0.011)
Rural (dummy)	-0.283***	0.529***	0.233***	0.615***
	(0.025)	(0.032)	(0.026)	(0.036)
Sign Order	0.017***	-0.034***	-0.016***	-0.038***
	(0.001)	(0.002)	(0.001)	(0.002)
Linear prediction	-0.289***	0.600***	0.287***	0.678***
	(0.024)	(0.031)	(0.025)	(0.035)
Observations	62,805	62,805	62,805	62,805
R-squared	0.298	0.300	0.312	0.340
Firm FE	yes	yes	yes	yes
Period FE	yes	yes	yes	yes

Table A.7: OLS: Firm Count

	(1) Royalty rate	(2) Term (month)	(3) Legal	(4) Surface
Panel A: OLS				
Firm Count (month)	0.000***	0.126***	-0.001	0.010***
	(0.000)	(0.021)	(0.001)	(0.001)
Parcel plot size	0.039***	-15.831***	-0.052*	-0.084***
(sqft/1e6)	(0.002)	(0.700)	(0.028)	(0.032)
Within 2000m	0.000	0.929***	-0.038***	-0.024***
of centroid	(0.000)	(0.158)	(0.005)	(0.005)
Rural Dummy	0.001*	-0.851***	-0.030***	-0.014*
	(0.000)	(0.156)	(0.007)	(0.007)
R-squared	0.409	0.390	0.312	0.310

	(5) Bads	(6) Externality	(7) Water	(8) Full set
Firm Count (month)	0.001**	-0.003***	-0.002***	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Parcel plot size	0.120***	-0.084***	-0.001	-0.134***
(sqft/1e6)	(0.023)	(0.030)	(0.026)	(0.031)
Within 2000m	0.060***	-0.059***	-0.031***	-0.075***
of centroid	(0.005)	(0.007)	(0.005)	(0.007)
Rural Dummy	-0.001	-0.052***	-0.039***	-0.044***
	(0.005)	(0.008)	(0.006)	(0.008)
R-squared	0.292	0.292	0.306	0.334

Table A.8: 2-SLS: Firm Count

	(1) Royalty rate	(2) Term (month)	(3) Legal	(4) Surface
Panel B: 2SLS (1^{st} Stage)				
Count Nearby Prod.	-0.322***	-0.404***	-0.270***	
Wells (2003,log)	(0.020)	(0.017)	(0.027)	
F-stat	1209	2635	783	

	(1) Royalty rate	(2) Term (month)	(3) Legal	(4) Surface
Panel C: 2SLS (2^{nd} Stage)				
Firm Count (month)	-0.011***	0.236	0.047**	0.035**
(Linear Prediction)	(0.001)	(0.373)	(0.020)	(0.016)
Parcel plot size	0.021***	-15.697***	0.036	-0.038
(sqft/1e6)	(0.003)	(0.836)	(0.047)	(0.044)
Within 2000m	-0.006***	0.994***	-0.010	-0.010
of centroid	(0.001)	(0.271)	(0.013)	(0.011)
Rural Dummy	-0.015***	-0.721	0.042	0.024
	(0.002)	(0.469)	(0.031)	(0.026)
Observations	148,056	232,482	62,769	62,769

	(5) Bads	(6) Externality	(7) Water	(8) Full set
Firm Count (month)	-0.048***	0.110***	0.071***	0.103***
(Linear Prediction)	(0.015)	(0.019)	(0.014)	(0.023)
Parcel plot size	0.030	0.123**	0.133***	0.052
(sqft/1e6)	(0.036)	(0.051)	(0.039)	(0.056)
Within 2000m	0.031***	0.006	0.011	-0.016
of centroid	(0.010)	(0.013)	(0.009)	(0.016)
Rural Dummy	-0.076***	0.119***	0.071***	0.110***
	(0.024)	(0.031)	(0.022)	(0.037)
Observations	62,769	62,769	62,769	62,769
Firm FE	yes	yes	yes	yes
Period FE	yes	yes	yes	yes

Table A.9: OLS: Firm Share *(no time)*

	(1) Royalty rate	(2) Term (month)	(3) Legal	(4) Surface
Panel A: OLS				
Firm Share	-0.011***	0.231***	0.086***	0.048***
	(0.000)	(0.075)	(0.003)	(0.003)
Parcel plot size	0.004	-16.854***	-0.119***	-0.248***
(sqft/1e6)	(0.002)	(0.693)	(0.031)	(0.037)
Within 2000m	-0.001***	1.043***	-0.050***	-0.039***
of centroid	(0.000)	(0.173)	(0.006)	(0.006)
Rural Dummy	-0.010***	-0.572***	-0.041***	-0.080***
	(0.001)	(0.145)	(0.008)	(0.009)
R-squared	0.215	0.343	0.170	0.268

	(5) Bads	(6) Externality	(7) Water	(8) Full set
Firm Share	-0.028***	0.070***	0.042***	0.104***
	(0.002)	(0.003)	(0.002)	(0.004)
Parcel plot size	0.067***	-0.166***	-0.069**	-0.245***
(sqft/1e6)	(0.023)	(0.030)	(0.027)	(0.034)
Within 2000m	0.064***	-0.071***	-0.040***	-0.094***
of centroid	(0.005)	(0.007)	(0.005)	(0.008)
Rural Dummy	-0.025***	-0.065***	-0.050***	-0.070***
	(0.006)	(0.008)	(0.006)	(0.009)
R-squared	0.264	0.194	0.220	0.204

Table A.10: 2-SLS: Firm Share *(no time)*

	(1) Royalty rate	(2) Term (month)	(3) Legal	(4) Surface
Panel B: 2SLS (1^{st} Stage)				
Count Nearby Prod.	0.034***	0.019***	0.084***	
Wells (2003,log)	(0.006)	(0.005)	(0.009)	
F-stat	2102	2890	1254	

	(1) Royalty rate	(2) Term (month)	(3) Legal	(4) Surface
Panel C: 2SLS (2^{nd} Stage)				
Firm Share	0.081***	-6.297	0.120*	-0.134**
(Linear Prediction)	(0.018)	(8.257)	(0.065)	(0.067)
Parcel plot size	0.054***	-20.204***	-0.101**	-0.345***
(sqft/1e6)	(0.010)	(4.300)	(0.046)	(0.053)
Within 2000m	-0.009***	1.626**	-0.053***	-0.024***
of centroid	(0.002)	(0.757)	(0.008)	(0.008)
Rural Dummy	-0.017***	-0.139	-0.041***	-0.081***
	(0.002)	(0.566)	(0.008)	(0.009)
Observations	148,056	232,482	62,769	62,769

	(5) Bads	(6) Externality	(7) Water	(8) Full set
Firm Share	0.019	-0.124**	-0.064*	-0.040
(Linear Prediction)	(0.047)	(0.054)	(0.039)	(0.069)
Parcel plot size	0.092***	-0.269***	-0.125***	-0.321***
(sqft/1e6)	(0.035)	(0.042)	(0.034)	(0.050)
Within 2000m	0.060***	-0.056***	-0.031***	-0.082***
of centroid	(0.006)	(0.009)	(0.006)	(0.010)
Rural Dummy	-0.024***	-0.066***	-0.051***	-0.071***
	(0.006)	(0.008)	(0.006)	(0.009)
Observations	62,769	62,769	62,769	62,769
Firm FE	yes	yes	yes	yes
Period FE	no	no	no	no

Table A.11: Counterfactual: No “Economies of Leasing”

Panel A : No “Economies of Leasing”

	(1)	(2)	(3)	(4)	(5)	(6)
		Est.^{a}			CF^b	
	Mean	Med.	95th	Mean	Med.	95th
Share	0.05 (0.12)	0.01	0.29	0.05 (0.1)	0.01	0.23
HHI	0.26 (0.17)	0.21	0.66	0.22 (0.13)	0.19	0.45
Firm Neg. Value	0.52 (5.43)	0.1	7.66	0.24 (6.57)	0.07	6.8
Parcel Neg. Value	-0.52 (1.70)	-0.40	-0.01	-0.60 (2.56)	-0.58	-0.01
Firm Neg. (Ind.)	4.3 (7.81)	3.78	13.65	-1.11 (6.71)	-0.96	2.09
Parcel Neg. (Ind.)	2.52 (5.36)	0.64	10.5	2.35 (5.58)	0.47	10.72

	(7)	(8)
	Mean^c Diff.(P-val.)	Median^a Diff.(P-val)
Share	0 (0.47)	0 (0.00)
HHI	-0.04 (0.57)	-0.02 (0.00)
Firm Neg. Value	-0.28 (0.53)	-0.03 (0.00)
Parcel Neg. Value	-0.08 (0.56)	-0.18 (0.00)
Firm Neg. (Ind.)	-5.4 (0.81)	-4.74 (0.00)
Parcel Neg. (Ind.)	-0.17 (0.52)	-0.17 (0.00)

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[a] Mean (standard deviation), median, and 95th percentiles of the estimated model.

[b] Mean (standard deviation), median, and 95th percentiles of the counterfactual model.

[c] Difference in the mean values between the counterfactual and estimated models, and in parentheses, the p-value of the Mann-Whitney two-sample statistic for non-normally distributed and unmatched data. The hypothesis is testing whether two independent samples are from the same distribution.

[d] Difference in the median values between the counterfactual and estimated models, and in parentheses, the p-value of the ‘k-sample test on the equality of medians’ statistic for non-normally distributed and unmatched data.

Table A.12: Counterfactual: Merger Simulation

Panel B : Merger

	(1)	(2)	(3)	(4)	(5)	(6)
		Est.[a]			CF[b]	
	Mean	Med.	95^{th}	Mean	Med.	95^{th}
Share	0.05 (0.12)	0.01	0.29	0.1 (0.2)	0.01	0.58
HHI	0.26 (0.17)	0.21	0.66	0.39 (0.17)	0.38	0.72
Firm Neg. Value	0.52 (5.43)	0.1	7.66	0.67 (6.36)	0.13	7.35
Parcel Neg. Value	-0.52 (1.70)	-0.4	-0.01	-0.68 (1.34)	-0.58	-0.02
Firm Neg. (Ind.)	4.3 (7.81)	3.78	13.65	3.59 (7.45)	3.65	10.45
Parcel Neg. (Ind.)	2.52 (5.36)	0.64	10.5	0.85 (4.85)	-0.43	6.85

	(7) Mean[c] Diff.(P-val.)	(8) Median[a] Diff.(P-val)
Share	0.05 (0.48)	0 (0.45)
HHI	0.13 (0.25)	0.17 (0.00)
Firm Neg. Value	0.16 (0.48)	0.04 (0.00)
Parcel Neg. Value	-0.16 (0.56)	-0.18 (0.00)
Firm Neg. (Ind.)	-0.7 (0.53)	-0.12 (0.00)
Parcel Neg. (Ind.)	-1.66 (0.74)	-1.07 (0.00)

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[a] Mean (standard deviation), median, and 95^{th} percentiles of the estimated model.

[b] Mean (standard deviation), median, and 95^{th} percentiles of the counterfactual model.

[c] Difference in the mean values between the counterfactual and estimated models, and in parentheses, the p-value of the Mann-Whitney two-sample statistic for non-normally distributed and unmatched data. The hypothesis is testing whether two independent samples are from the same distribution.

[d] Difference in the median values between the counterfactual and estimated models, and in parentheses, the p-value of the 'k-sample test on the equality of medians' statistic for non-normally distributed and unmatched data.

Table A.13: Counterfactual: Added Environmental Clause

Panel C : Added Env. Clause						
	(1)	(2)	(3)	(4)	(5)	(6)
		Est.^{a}			CF^b	
	Mean	Med.	95^{th}	Mean	Med.	95^{th}
Share	0.05 (0.12)	0.01	0.29	0.06 (0.16)	0.01	0.28
HHI	0.26 (0.17)	0.21	0.66	0.3 (0.25)	0.17	0.88
Firm Neg. Value	0.52 (5.43)	0.1	7.66	0.46 (5.25)	0.11	5.85
Parcel Neg. Value	-0.52 (1.7)	-0.4	-0.01	-0.26 (2.79)	-0.52	1.03
Firm Neg. (Ind.)	4.3 (7.81)	3.78	13.65	1.77 (7.68)	2.04	6.59
Parcel Neg. (Ind.)	2.52 (5.36)	0.64	10.5	9.25 (10)	3.48	29.23

	(7)	(8)
	Mean^c Diff.(P-val.)	Median^a Diff.(P-val)
Share	0.01 (0.48)	0 (0.00)
HHI	0.04 (0.55)	-0.04 (0.00)
Firm Neg. Value	-0.06 (0.49)	0.02 (0.04)
Parcel Neg. Value	0.27 (0.54)	-0.12 (0.00)
Firm Neg. (Ind.)	-2.52 (0.63)	-1.74 (0.00)
Parcel Neg. (Ind.)	6.74 (0.36)	2.84 (0.00)

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[a] Mean (standard deviation), median, and 95^{th} percentiles of the estimated model.

[b] Mean (standard deviation), median, and 95^{th} percentiles of the counterfactual model.

[c] Difference in the mean values between the counterfactual and estimated models, and in parentheses, the p-value of the Mann-Whitney two-sample statistic for non-normally distributed and unmatched data. The hypothesis is testing whether two independent samples are from the same distribution.

[d] Difference in the median values between the counterfactual and estimated models, and in parentheses, the p-value of the 'k-sample test on the equality of medians' statistic for non-normally distributed and unmatched data.

Table A.14: Counterfactual: Uniform Leasing of Medium Quality

Panel D : Half Set of Clauses + 0.25 Royalty

	(1)	(2) Est.[a]	(3)	(4)	(5) CF[b]	(6)
	Mean	Med.	95^{th}	Mean	Med.	95^{th}
Share	0.09 (0.21)	0.01	0.73	0.1 (0.23)	0.02	0.9
HHI	0.32 (0.28)	0.17	0.93	0.32 (0.33)	0.08	0.99
Firm Neg. Value	0.48 (5.72)	0.09	8.22	0.74 (6.64)	0.12	14.15
Parcel Neg. Value	0.06 (3.83)	-0.5	3.43	-0.13 (3.88)	-0.85	3.61
Firm Neg. (Ind.)	0.78 (6.62)	0.51	5.98	0.15 (6.36)	0	6.08
Parcel Neg. (Ind.)	11.88 (10.25)	12.24	24.05	12.85 (10.4)	11.73	28.88

	(7) Mean[c] Diff.(P-val.)	(8) Median[a] Diff.(P-val)
Share	0.01 (0.43)	0.01 (0.00)
HHI	0 (0.64)	-0.08 (0.00)
Firm Neg. Value	0.26 (0.5)	0.03 (0.02)
Parcel Neg. Value	-0.18 (0.58)	-0.35 (0.00)
Firm Neg. (Ind.)	-0.62 (0.54)	-0.51 (0.00)
Parcel Neg. (Ind.)	0.96 (0.49)	-0.51 (0.00)

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[a] Mean (standard deviation), median, and 95^{th} percentiles of the estimated model.

[b] Mean (standard deviation), median, and 95^{th} percentiles of the counterfactual model.

[c] Difference in the mean values between the counterfactual and estimated models, and in parentheses, the p-value of the Mann-Whitney two-sample statistic for non-normally distributed and unmatched data. The hypothesis is testing whether two independent samples are from the same distribution.

[d] Difference in the median values between the counterfactual and estimated models, and in parentheses, the p-value of the 'k-sample test on the equality of medians' statistic for non-normally distributed and unmatched data.

Table A.15: Counterfactual: Uniform Leasing of High Quality

Panel E : Full Set of Clauses + 0.25 Royalty

	(1)	(2)	(3)	(4)	(5)	(6)
	Est.[a]			CF[b]		
	Mean	Med.	95th	Mean	Med.	95th
Share	0.09 (0.21)	0.01	0.73	0.1 (0.24)	0.02	0.9
HHI	0.32 (0.28)	0.17	0.93	0.3 (0.33)	0.08	0.98
Firm Neg. Value	0.48 (5.72)	0.09	8.22	0.62 (6.72)	0.12	14.28
Parcel Neg. Value	0.06 (3.83)	-0.5	3.43	-0.11 (4)	-0.93	4.21
Firm Neg. (Ind.)	0.78 (6.62)	0.51	5.98	-0.08 (6.49)	0	5.87
Parcel Neg. (Ind.)	11.88 (10.25)	12.24	24.05	13.12 (10.13)	13.39	28.19

	(7)	(8)
	Mean[c]	Median[a]
	Diff.(P-val.)	Diff.(P-val)
Share	0.02 (0.41)	0.01 (0.00)
HHI	-0.02 (0.66)	-0.09 (0.00)
Firm Neg. Value	0.14 (0.5)	0.03 (0.02)
Parcel Neg. Value	-0.17 (0.6)	-0.43 (0.00)
Firm Neg. (Ind.)	-0.86 (0.55)	-0.51 (0.00)
Parcel Neg. (Ind.)	1.24 (0.5)	1.14 (0.00)

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[a] Mean (standard deviation), median, and 95th percentiles of the estimated model.

[b] Mean (standard deviation), median, and 95th percentiles of the counterfactual model.

[c] Difference in the mean values between the counterfactual and estimated models, and in parentheses, the p-value of the Mann-Whitney two-sample statistic for non-normally distributed and unmatched data. The hypothesis is testing whether two independent samples are from the same distribution.

[d] Difference in the median values between the counterfactual and estimated models, and in parentheses, the p-value of the 'k-sample test on the equality of medians' statistic for non-normally distributed and unmatched data.

Table A.16: Counterfactual: Participation Changes

Panel A : No "Economies of Leasing"

	Large Firm	Large Operator	Landman	Total Signed
Signed (Est)[a]	1950	855	1905	51456
Signed (CF)	1060	799	1016	50904
	Diff. (Pct. Δ)	Diff. (Pct. Δ)	Diff. (Pct. Δ)	Diff. (Pct. Δ)
Diff. Signed[b]	-890 (-0.456)	-56 (-0.065)	-889 (-0.467)	-552 (-0.011)

Panel B : Merger

	Large Firm	Large Operator	Landman	Total Signed
Signed (Est)	1950	855	1905	51456
Signed (CF)	2231	922	2253	54162
	Diff. (Pct. Δ)	Diff. (Pct. Δ)	Diff. (Pct. Δ)	Diff. (Pct. Δ)
Diff. Signed	281 (0.144)	67 (0.078)	348 (0.183)	2706 (0.053)

Panel C : Added Env. Clause

	Large Firm	Large Operator	Landman	Total Signed
Signed (Est)	1950	855	1905	51456
Signed (CF)	1578	702	1369	52545
	Diff. (Pct. Δ)	Diff. (Pct. Δ)	Diff. (Pct. Δ)	Diff. (Pct. Δ)
Diff. Signed	-372 (-0.191)	-153 (-0.179)	-536 (-0.281)	1089 (0.021)

Panel D : Half Set of Clauses + 0.25 Royalty

	Large Firm	Large Operator	Landman	Total Signed
Signed (Est)	1060	474	853	45351
Signed (CF)	1003	438	800	46752
	Diff. (Pct. Δ)	Diff. (Pct. Δ)	Diff. (Pct. Δ)	Diff. (Pct. Δ)
Diff. Signed	-57 (-0.054)	-36 (-0.076)	-53 (-0.062)	1401 (0.031)

Panel E : Full Set of Clauses + 0.25 Royalty

	Large Firm	Large Operator	Landman	Total Signed
Signed (Est)	1060	474	853	45351
Signed (CF)	963	420	751	46756
	Diff. (Pct. Δ)	Diff. (Pct. Δ)	Diff. (Pct. Δ)	Diff. (Pct. Δ)
Diff. Signed	-97 (-0.092)	-54 (-0.114)	-102 (-0.12)	1405 (0.031)

[a] Count of leases signed by each firm type in the estimated model.

[b] The differences in the count of leases signed between the counterfactual and estimated model by firm type, and in parentheses, the percent change between the counterfactual and estimated model.

Appendix B

APPENDIX: Valuing Leases for Shale Gas Development

B.1 Legal and Institutional Detail

Over the past 20 years, horizontal drilling technology has evolved to allow access to natural gas contained in tight-shale formations spread over a large area while requiring fewer well pads. This has allowed for increased activity in more densely settled areas, literally bringing drilling into suburban households backyards. Regulation guiding industry practices, however, has been largely crafted for activity in less densely populated areas the more common setting for natural resource extraction. In the following subsections, we describe these technological innovations and regulatory structures relevant to our analysis of property values.

B.1.1 Hydraulic Fracturing and Horizontal Drilling

The process of hydraulic fracturing enables firms to extract natural gas from tight shale formations by artificially stimulating the strata. This increases the flow of natural gas within the shale, resulting in its eventual release and collection at the wellhead. Horizontal drilling techniques allow firms to drill wells accessing minerals located within a large radius surrounding the wellhead. Fewer drill sites are therefore required to reach a larger subsurface area and better access is provided for broad resource deposits. Horizontal drilling therefore allows firms to extract large quantities of natural gas from a smaller surface footprint, facilitating extraction from areas of higher population density. Individuals in suburban (and even urban) areas have subsequently found themselves to be parties to negotiations with operators over mineral rights leases.

B.1.2 The Texas Railroad Commission and State-Level Regulation

The Texas Railroad Commission (TRC) oversees the majority of the oil and natural gas industry in the state of Texas, which includes the approval of permits to drill wells.[1] However, prior to permit approval, firms must first amass a large and sufficient mineral estate acreage that is spaced far enough away from existing well

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[1] The Texas Railroad Commission has jurisdiction over the "exploration, production, and transportation of oil and gas prior to refining or end use," and the TRC executes its jurisdiction by enforcing rules written in the Texas Administrative Code, Chapter 3.

infrastructure to be approved and permitted by the TRC.[2] Natural gas firms obtain mineral estate acreage by signing leases with sets of mineral rights owners or by purchasing signed leases from third party landmen. Households signing leases with natural gas firms or landmen are tasked with weighing the trade-offs between future income paid in the form of royalties and the potential risks of living near an active well. Once a well is permitted with the TRC, the operator typically has between two to three years to begin drilling the well before the permit expires.

The TRC's jurisdiction regulating the industry extends to the drilling and production phases; however, the TRC does not regulate noise, traffic, or well-pad appearance, nor does it require air pollution testing. By law, operators have some access to surface water to be used to treat the well, and chemical disclosure is restricted to only the non-proprietary chemicals used to fracture a well. In general, the dis-amenities experienced by households from nearby shale gas activities are unregulated by state and federal entities; in the absence of active municipal ordinances regulating these dis-amenities, they may be controlled by the terms of private leases signed between landowners and firms.

More specifically, federal and state regulators generally do not have direct jurisdiction over the private contracts drawn between landowners and parties interested

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[2] Texas Administrative Code, Chapter 3, Rules 37 & 38.

in leasing land for exploration and production of oil and natural gas. Higher-level regulation is limited to royalty payments (stipulating when they are to be paid), the required information that must be provided (and that which can be requested) by firms, notification upon re-assignment of leased rights, and determining the consequences of delinquent payments. In addition, the TRC has jurisdiction over enforcing and undertaking remediation from undue negligence on the part of firms and broadly enforcing the protection of ground and surface water from contamination caused by the industry. However, the TRCs jurisdiction over the leases signed between landowners and firms, and subsequently, the protection of households while a well is drilled and after production ends is limited, and well-informed landowners may negotiate more comprehensive contracts with leasing firms to protect their interests beyond the minimal coverage of the law.

B.1.3 Municipal Regulation

Local municipalities can employ land-use (zoning) policy to restrict oil and gas development within their jurisdictions. Municipal governments in Texas are also able to enact local ordinances that stipulate types and locations of land use and permissible damage for the purposes of protecting public health and welfare. Local regulation in Texas is an interesting feature of the legal structure whereby localities can exercise "home rule," passing ordinances that restrict activity within their jurisdiction. In the past, the oil and natural gas industry has focused most of its energy on drilling in rural areas; however, firms combining large scale hydraulic fracturing and horizontal drilling techniques have increased access to tight-shale formations lying beneath urban areas, like those overlying the Barnett Shale, with less surface interference. As firms have increasingly begun exploiting shale plays in urban areas, municipalities have passed local ordinances protecting properties within their jurisdictions. These local ordinances further restrict the activities of firms by requiring, for example, larger set-back distances, additional permits and fees, well construction restrictions, and additional environmental tests.

Local ordinances are rendered preempted (or essentially invalid) if state-level legislation limits local power directly (expressed preemption); the state rules already occupy the field even though the language is not specific to that expressed by the local ordinance[3] (implied preemption); or if those rules conflict with existing state laws. The last of these usually restricts local zoning ordinances that loosen state rules, but in the event that local ordinances are stricter that state laws, the local ordinances are upheld.

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[3] The state law is comprehensive enough that there is no room for local ordinances to be written in the field even though the language may not specifically address a local ordinance as it would be written.

B.1.4 Split Estate

Up to this point, we have assumed that the signer of the lease is the household, or surface-rights owner; however, the state of Texas allows the mineral estate to be split (or "severed") from the surface estate. The individual signing a lease with a natural gas firm may not, therefore, be the individual living in the house positioned on the surface estate. As early as 1953, Texas courts declared that landowners may reserve mineral rights and the oil and gas contained as in the case Benge v. Scharbauer [259 S.W.2d 166 (Tex. 1953)], thereby enabling the mineral estate to be severed from the surface estate (Merrill and Merrill (2013b)).[4] In the event of severance, the mineral estate dominates in terms of exploration and extraction, and the mineral lessee assumes the same rights owed to the mineral estate owner since the leasing document is perceived as a temporary transference of ownership.[5] Colloquially, the owner of the mineral estate may lease the minerals to third parties for exploration, but law only requires that the lessee (i) notify surface owners of the "intent to explore and drill;" (ii) have access to as much land as is necessary to explore and drill; (iii) remove trees and fences to make way for well and equipment; (iv) take up to one acre of land for the well pad; and (v) erect pipelines to transport the natural gas off

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[4] A grant or reservation of minerals by the fee owner affects a horizontal severance and the creation of two separate and distinct estates: an estate in the surface and an estate in the minerals [Acker v. Guinn, 464 S.W.2d 348, 352 (Tex. 1971)] (Fields (2006)).

[5] If the minerals are not reserved at the sale date, the mineral estate automatically goes to the buyer along with the surface conveyance (Fambrough (1987)).

the property (Rahm (2011)).[6]

As an independent entity, the mineral estate may exercise its rights without consulting the surface estate owners. Subsequently, a firm leasing the mineral rights for purposes of oil and gas exploration and extraction need only negotiate with the mineral estate owners, whether they also own the surface estate or not. The owners of the mineral estate are only required to inform the surface estate when drilling is imminent on their property due to legislation passed in 2007 (Maxwell (2008)).[7] Additionally, the mineral estate may use as much surface water from the leased land as is reasonably necessary to carry out operations, given that the use is not wasteful, and it may inject wastewater into sub-surface formations.[8,9] Moreover, the mineral estate does not accept responsibility for the full restoration of the property (Warren Petroleum Corp. v. Monzingo, 304 S.W.2d 362 (Tex. 1957)), nor is it required to pay surface damages as long as the damage is not unreasonable. Texas has not passed a surface damage act to protect the surface estate, as has been passed in

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[6] There are three exceptions to the dominant mineral estate including excessive use of land in exploration and operation activities to access the minerals, unnecessarily injuring the surface, and not accommodating the existing surface use, the latter more formally entitled the Accommodation Doctrine (Letter of the Law, 1997).

[7] Texas Natural Resource Code, 91.703(a): Not later than the 15th business day after the date the commission issues an oil or gas well operator a permit to drill a new oil or gas well or to reenter a plugged and abandoned oil or gas well, the operator shall give written notice of the issuance of the permit to the surface owner of the tract of land on which the well is located or is proposed to be located.

[8] Unless specified in the deed, the water rights fall to the surface owner but they are accessible with reasonable use by the mineral estate (Vanham (2011)).

[9] Warren Petroleum Corp. v. Martin, 271 S.W.2d 410 (Tex. 1954)

other states with prominent oil and natural gas industries (including New Mexico, Oklahoma, North and South Dakotas, and Montana). As mentioned above, surface owners are not owed any remuneration for the opportunity cost of the lost piece of their property during the drilling period nor must they be paid for reasonable damages to the land caused by drilling. If there is any perceived misuse of the land by mineral rights owners, surface owners are responsible for proving unreasonable conduct, which does not include surface damage or inconvenience. Surface owners are marginally protected by the Accommodation Doctrine, which protects existing surface owner uses.[10]

In lieu of state regulations or local ordinances, lessors can negotiate a surface damage clause into the leasing agreement to protect the surface during production, ensure remediation after production ends, and perhaps assign a surface damage fee. In a split estate, there may be little incentive for a mineral estate owner to negotiate a surface damage clause with a potential operator; a severed estate with a lease may therefore be less likely to include a surface damage clause. However, well operators may find it advantageous to negotiate separate agreements with surface estate owners to prevent conflicts could slow production.

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[10] Accommodation Doctrine: [W]here there is an existing use by the surface owner which would otherwise be precluded or impaired, and where under the established practices in the industry there are alternatives available to the [mineral owner] whereby the minerals can be recovered, the rules of reasonable usage of the surface may require the adoption of an alternative by the [mineral owner]. (Tarrant County Water Control & Improvement Dist. No. 1 v. Haupt, Inc., 854 S.W.2d 909, 911 (Tex. 1993)) (Merrill and Merrill (2013b)).

Appendix C

APPENDIX: Common

C.1 Data Description

C.1.1 Bonus Sample

Of the roughly 243,000 observations describing leases matched to parcels, only around 5,000 observations report bonus values. However, some of the specifications use predicted bonuses calculated from a simple linear regression model of the observed bonuses on firm and parcel characteristics. Table compares the sample of data with observed bonus payments to the sample without bonus payments by reporting the T-tests of the differences in variables across the two samples, which highlight potential selection issues in the small bonus sample.

Table C.1: Bonus sample T-tests

	Mean		Std. Dev.		tstat
	no Bonus	Bonus	no Bonus	Bonus	
Landman	0.411	0.458	0.492	0.498	-6.934
Large firm	0.757	0.758	0.429	0.428	-0.113
Large operator	0.321	0.434	0.467	0.496	-17.535
Auxiliary clauses	0.244	0.991	0.43	0.096	-127.158
Sign order (wp, firm)	44.257	43.115	58.445	49.773	1.421
Ordinance passed	0.576	0.779	0.494	0.415	-29.902
Median income	67,419.95	68,934.91	30,036.76	32,988.05	-3.441
Split estate	0.067	0.064	0.251	0.244	1.095
Groundwater	0.647	0.507	0.478	0.5	20.389
Subdivision	0.915	0.917	0.279	0.276	-0.615
Rural	0.018	0.007	0.132	0.083	6.046
Land size (sqft/1e6)	0.015	0.013	0.032	0.02	3.183

C.1.2 Scraping and Text-mining Lease Data

The auxiliary clauses are obtained by scraping the leasing documents from the "Drilling Down" series (Urbina (2011)) published by the *New York Times* or the Tarrant County Clerk office website. Each scraped document is converted from pdf image files to text documents and text-mined for specific language indicating the existence of different clauses negotiated into the contracts. The sample with auxiliary clauses in the analysis is roughly 90,000 observations.

The pdf image documents are converted to text documents using a combination of OCR (optical character recognition) software Tesseract.[1] Following conversion, I use a list of regular expression patterns indicating inclusion of each clause to search

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[1] Before employing the OCR software to convert to text, the pdfs must first be converted to jpeg files using Ghostscript software.

and identify leases containing those clauses with software written in Python. The use of regular expression functions allows one to search for fragments of words while also accounting for misspellings and superfluous punctuation that might prevent a perfect match between phrases. Perfect matches are particularly difficult to locate in converted text documents especially when the original copy is a pdf image, and often conversion results in misplaced spaces, characters, numbers, and letters. Below are examples of the regular expression patterns used to search for surface damage and restricted surface access clauses.

1. No Surface Use:
    (a) “No surface use”

    ```
    r‘[rmn][ao0][\s+]*su[rmn]f[ao0][\w+]*[\s+]*use’,
    ```

    (b) “No surface operations”:

    ```
    r‘[rmn][ao0][\s+]*[\w+]*[\s+]*[\\\~>/!\%\_,.-‘"\’()\$?@\#\d:;]*
     [\s+]*su[rmn]f[ao0][\w+]*[\s+]*[ao0]pe[rmn][ao0]t\w+’
    ```

    (c) “Lessee shall not conduct any surface operations”

    ```
    r‘[l1]es[s]*[\w+]*[\s+]*sh[ao0][l1][l1]*[\s+]*[rmn][ao0]t[\s+]*|
     c[ao0][rmn]d\\w+[\s+]*[\w+]*[\s+]*[\\\~>/!\%\_,.-‘"\’()\$?@
     \#\\d:;]*[\s+]*su[rmn]f[ao0][\w+]*[\s+]*[ao0]pe[rmn][ao0]t\w+’
    ```

    (d) “Lessee shall not enter upon w surface”

    ```
    r‘[l1]es[s]*[\\w$+$]*[\s+]*sh[ao0][l1][l1]*[\s+]*[rmn][ao0]t
     [\s+]*e[rmn]te[rmn][\s+]*up[ao0][rmn][\s+]*[\w+]*[\\s$+$]*
     [\\\~>/!\%\_,.-‘"\’()\$?@\#\\d:;]*[\s+]*su[rmn]f[ao0][\w+]*’
    ```

    (e) “Within (d) feet w w land (no surface use at all)”

```
r‘withi[rmn][\s+]*\w+[\s+]*[(\{\[)\}\]]*[\\\~>/!
 \%\_,.-‘"\’\$?@\#]*[\d+]*
 [\\~>/!\%\_,.-‘"\’()\$?@#]*[\s+]*[\d+]*[\\~>/!\%\_,.
 ‘"\’\$?@\#]*[\s+]*[\d+]*[(\{\[)\}\]]*[\s+]*fe[e]*t[\s+]*
 [\w+]*[\s+]*[\w+]*[\s+]*[l1][ao0][rmn]d’,
```

2. Surface Damage: “Lessee shall pay for damage”

```
r‘[l1]es[s]*[\w+]*[\s+]*sh[ao0][l1][l1]*[\s+]*p[ao0][v\\/y]
  [\s+]*[\w+]*[\s+]*d[ao0][rmn][ao0]g[\w+]*’
```

After extracting relevant text from the documents, the data were cleaned further using regular expression functions and quantified into a binary form[2] useful in the analysis using STATA. Finally, the auxiliary clauses were matched to the observational lease data[3] using a record number assigned by the county clerk office.

C.1.3 Leases Merged to Properties

Each lease observation in the data is matched to a specific parcel of property located in Tarrant County Texas, and this is achieved through string matches between the lease and housing data that are based on similar addresses, buyer, seller and owner names, and other location attributes. The lease data includes the addresses of the grantors and grantees along with their names. Similarly, the housing data provides addresses and buyer, seller, and owner names.

Each field, like address, is parsed into simpler categories like street name, city name, and state, for example. The data is cleaned for common miss-spellings and

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[2] For example, a lease has a surface damage clause $\{0, 1\}$.

[3] Observational data includes information about the grantors (landowners) and grantees (firms), royalty rates, and term length; the data available through Drilling Info.

superfluous characters. Miss-spellings are corrected by embedding a user defined function, *strgroup* ,[4] into a function designed for this project that groups similarly spelled words together and converges the spelling to the most common instances within some specified threshold. The number of allowed spelling changes is controlled by a standard measure of string differences, or Levenshtein distance, which counts the number of changes necessary to convert one word to a different word.[5] The project specific function assumes that the correct spelling is the spelling used most frequently across both data sets, it applies strgroup iteratively, and it assigns the correct spelling to all misspelled words before the data sets are merged. The function is used to clean each string component of the address, along with first, middle, and last names of buyers, seller, and owners.

Using the cleaned data sets, the merge code ranks the merges based on stringency of the match by matching using variable combinations that differ in restrictiveness. The first merge requires that the data sets match on all address fields and a first and last name. A less strict match would relax whether the street type matches (ex. road, street, boulevard, etc...). The code runs through a series of roughly fifty matches on the data, keeping the most strict merge feasible for each lease.

Split estates

Split estates are not directly identified in the data set, and a comparison of names and dates describing who and when the leases were signed relative to the transaction

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[4] In particular, *strgroup* , designed by Julian Reif at the University of Chicago, measures the levenshtein distance between each word in a data set and groups those word based on provided restrictions governing the maximum string distance. This function calculates the Levenshtein distance between all of the strings being fed to the function, and normalizes by the length, or edit distance, of the smallest string in the group. If the normalized distance is less than a specified threshold, the strings are grouped together and output into a new group variable.

[5] For example, “lessor” and “lessee” would have a Levenshtein distance of two as one needs to change the “or” to “ee” in order to make the two words identical.

dates allow for a variable that approximates whether the parcels' mineral estate rights are severed from the surface estate. As described above, each parcel is matched to a lease using a series of string matches between descriptions of addresses and the signers of the leases. Once matched, the names on the leases can be compared to the buyers and sellers of the house located on the parcel through time using the Tarrant County Appraiser data and DataQuick. The dates the house was sold and a lease was signed can be used as clues, as well.

Between the datasets, we first identify perfect matches between the names of the individuals signing the leases and the buyers and sellers listed in the housing databases. We then proceed to identify close spellings using the Levenshtein string distance measure. Using this function, we can find those names that are nearly the same and differ likely from data entry errors across data sets. After identifying the name matches, we can then compare the transaction and lease dates to approximate whether the transacted houses have split estates. The intuition of this final step is that sellers signing leases at a date after the transaction date are likely to have split the estate when they sold it to the new buyers, otherwise the name on the lease would match that of the buyers. A secondary split estate identifier tags those houses with owner names matching lease signers but not matching the buyer or seller of the house.

C.2 Lease Clause Description

Primary Clauses

1. Lease Term: The term of the lease often includes both primary and secondary terms in units of months or years. The primary term is the length of time allowed to drill a well and begin producing. Given that the well is producing in

paying quantities, or is capable of producing in paying quantities, the primary term rolls-over into the secondary term of the lease, which remains in effect as long as the well is producing. A typical lease term ranges between three and five years. A longer lease term is generally considered to be bad from the point of view of the lessor, as it allows the lessee to hold mineral rights for a longer period without paying royalties.

2. Royalty: The fraction of earnings from the producing well paid to the lessors owning royalty interest in the well based on the acreage contribution of an individual lease to the producing well.
3. Bonus: A signing bonus is often negotiated at a per acre increment and is exchanged between the lessor and lessee at the time when the lease is signed. Bonus payments are frequently not reported in recorded lease agreements.

Auxiliary Clauses

1. Environmental Clause: These lease clauses limit the types of substances allowed for exploration and extraction activities. They encourage the use of safeguards to prevent contamination of soil, water, and surface and subsurface strata. In particular, these clauses limit the use of hazardous substances as defined by the Comprehensive Environmental Response Compensation and Liability Act (CERCLA). There may be additional pollution restrictions and control mechanisms required of lessees.

2. Surface Damage: In general, the lessee is not required to compensate the lessor for reasonable and necessary use of the surface to access the mineral estate. Lessors can negotiate on a variety of dimensions; however, it is important to note that in large urban areas many of these dimensions are regulated through municipal ordinance.

3. No Surface Access: May stipulate that all acreage must be pooled, especially if the lessee owns a smaller tract of land. Other language may constrain where a well can be drilled in the context of a pooled agreement, for example, stating that the minerals may only be accessed through a well drilled on another pooled tract of land (might also be interpreted as a surface access clause).

4. Freshwater Protection: Lease may prohibit disposal, including discharge of oil field brines, geothermal resource waters, or other mineralized waters, or other drilling fluids, into any watercourse or drainage-way, including any drainage ditch, dry creek, flowing creek, river, or other body of surface water. Lease may prohibit use of pit for storage of oil or oil products, oil field fluids, or oil and gas wastes.

5. Free Surface Water Use: Lessees have a right to use the surface and subsurface water during drilling operations like hydraulic fracturing or secondary operations, and some leases more explicitly state the free use of water, oil, and gas produced on the land for operations.

6. Saltwater Disposal: Restricts that firms not locate a saltwater disposal well on the property.

7. Force Majeure: These clauses are often included to protect the lessee in the event of uncontrollable circumstances limiting or altogether halting operations on a well. To protect the lessor, additional clauses limiting the extent of delay or the definition of force majeure can be included.

8. Noise Restrictions: Most commonly, leases will limit the amount of noise by restricting production to certain times of day or requiring mufflers be used with loud equipment.

9. Post-Production Costs: Unless stipulated by the lease, post-production costs, like transportation and compression, might be deducted from the final royalty payment owed to lessors. Leases will often, to the benefit of lessees, contain language about royalty being calculated at the mouth of the well allowing courts leeway to rule in favor of deducting additional post-production costs. To protect property owners, lessors can add language constraining the post-production costs or stating that royalty be calculated at the point of sale.

10. Indemnity: An indemnity clause shifts the liability from the lessor to the lessee in the event that a third party claims negligence on the part of the lessor for lessee activities. The indemnity clause is strengthened by satisfying the express negligence rule; otherwise the court system is likely to not uphold the indemnity clause. This is achieved by including the phrase including claims alleging that the lessor is guilty of negligence of other misconduct.

11. Reporting Requirement: Lessors may stipulate what information is to be provided by lessees, including any reports on production or activity, geological or seismic surveys, assignments, description of the pooling unit, royalty calculations, and contracts for selling the oil and gas.

12. Offset Wells: Similar to top-leasing, provisions allowing lessors to insist firms drill off-set wells shortens the time to a producing (and profitable) well. These clauses are included to protect lessors concerned with their minerals being drained by nearby wells.

13. Minimize Residential Street Access: Lease clauses may restrict how the well is accessed in terms of roads built for well traffic and reducing traffic to the well-pad using residential streets.

14. Subsurface (Perpetual) Easement: Leases may state that the lessor gives the right to use the property to access wells (with pipelines) located on theirs and other property which may not be used to develop the lease, and that the easements can remain in place after the lease expires. This language is particularly relevant for gathering lines.
15. Insurance: Lessors may require lessees to acquire additional insurance coverage (e.g., general liability and worker compensation).
16. Legal bundle (*Hedonic Analysis*):
    (a) Indemnity: An indemnity clause shifts liability from the lessor to the lessee in the event that a third party claims negligence on the part of the lessor for lessee activities. The indemnity clause is strengthened by satisfying the "express negligence" rule; otherwise the court system is likely to not uphold the indemnity clause. This is achieved by including the phrase "including claims alleging that the lessor is guilty of negligence of other misconduct."
    (b) (Vertical) Pugh Clause: This clause relinquishes ownership of the mineral estate back to the lessor at the end of the primary term in the event the producing well is not drawing from that (sub-surface strata) portion of the lease.
    (c) Title Defense: Imposes that the grantee assumes all responsibility for checking the title prior to signing the lease and for resolving any issues that arise with respect to the title without penalizing future royalties (owed to the grantor) until resolution or any other similar penalties.[6]

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[6] There are several variants of "defend the title," and the one used in the analysis is the most protective of the landowner in the event that there are issues to resolve with respect to the title.

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