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

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Abstract

In a two-sided market with private contracting, what are the costs and benefits of spatial concentration? The oil and natural gas leasing market facilitates studying the net effect of two countervailing forces. First, firms benefit from signing contracts associated with large, contiguous acreage as it allows them to apply for a permit to drill a well and proceed to more profitable phases of well development. Second, firms with fewer competitors in a geographic market offer less desirable contracting terms to their negotiation partners, allowing them to exercise market power paralleling price markups in consumer product markets. Using unique data describing the location and contents of private leases, I model the private contracting behavior of firms signing natural gas leases with landowners as a one-to-many, non-transferable utility match. To estimate the effect of spatial complementarity, I extend the matching framework to allow for more complex preferences among firms valuing sets of geographically concentrated leases. I also present evidence that firms exercise market power in pecuniary and non-pecuniary contracting terms. I then use the model to explore the effects of counter-factual policies that restrict contracting behavior by requiring leases to include a more desirable menu of terms for landowners. I find that while the restrictions increase firms' contracting costs, firms respond by choosing negotiation partners with better drilling attributes (ex. proximity to well infrastructure) that are more spatially concentrated. Requiring a single, additional clause increases the average returns from contract quality across the two sides of the market by 3.6 times the returns under the status quo, while a uniform leasing policy increases average returns from leasing 10-fold, which suggests a welfare gain.

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1 Introduction

Markets comprised of private contract negotiations that are determined through bilateral agreement can exhibit market power similar to the monopolistic price mark-ups estimated in consumer product markets. If there are fewer firms negotiating contracts in a particular market, firms may offer a less preferred menu of clauses to their negotiation partners since their partners are receiving fewer offers for comparison, thereby reducing their negotiation partners' bargaining power. This setup results in final contracts that are more beneficial for the firms, as compared to their negotiation partners, on dimensions with pecuniary and non-pecuniary consequences, which parallels the price mark-ups. Further, these negotiated contracts may have more value together than independently as is common in markets in which firms hire several workers with complementary skills or across contiguous property rights, which are more valuable for building larger structures, resource extraction, or proximity to complementary businesses.[1,2] A firm profits from negotiating a set of contracts exhibiting complementarity more than it would from the individual contracts because of the consequent economies of scale or density. This paper combines these two sources of additional profit that result from market power and spatial complementarity into a single model of bilateral, private contract negotiations. I then restrict firms by removing their ability to exert market power and impose a contract floor, thereby increasing their contracting costs, and estimate a new market equilibrium in order to calculate the consequent welfare changes.

This paper examines three primary questions in the context of private lease negotiations that precede oil and natural gas development. First, is market power in private lease negotiations reducing the bargaining power of landowners signing away their mineral rights to firms? Second, to what extent do firms benefit from density economies in the private market for leasing mineral rights when there are complementarities from owning contiguous clusters of land? Third, how do the equilibrium market structure and total welfare change when firms are restricted to sign more contractually binding clauses? The first question is addressed by estimating simple models relating market structure to different dimensions describing the quality of leases signed. I find that greater market power for any given firm results in leases with lower pecuniary and non-pecuniary returns to the landowners, exposing landowners to lower payoffs and more risks once wells are drilled and producing natural gas. The second question requires estimating a structural model of lease negotiation that I execute using the one-to-many (a firm to many landowners) matching framework allowing for complementarity across mineral rights in close proximity and owned by a single firm. These two questions are related because they jointly explore the costs and benefits of firms' market power in the context of private contracting when there are economies of density. Estimating the joint preferences for types of lease clauses and economies of density allows me to measure the changes to costs and benefits as features of the private leasing market change. After estimating the model of spatial lease negotiation, I am able to ask how firms respond to lease market restrictions through their decisions of where and with whom to sign a lease, addressing the third question. A restriction imposing uniformity of lease clauses has not been implemented in the industry[3] and is a low cost mechanism[4] to increase protection of landowners

[1]There is an extensive economics literature describing the equilibrium outcomes when there is agglomeration and methods of dealing with endogeneity concerns driving agglomeration patterns.

[2]There are many examples of complementarity in markets; however, spatial complementarity is the specific focus of this paper.

[3]There are a few tangential policies. First, existing regulations stipulate that leases include surface damage clauses or have other surface protections as imposed in New Mexico, Oklahoma, North and South Dakotas, and Montana. The jurisdiction of leases mimics that of some local ordinances; however, since spring of 2014, Texas passed HB40 that limits the efficacy of ordinances passed under "home rule" significantly.

[4]This paper does not quantify the long term costs of firms abiding by more stringent regulations. However, a simple analysis estimating the firms' propensities to drill in areas with more local ordinances does not suggest deterrence. Local ordinances have

and property values during and following drilling activity.[5] Further, I find that uniformity increases firms' propensity to agglomerate their leasing decisions more, which allows them to more readily profit from their economies of density.

In the past decade, natural gas production capacity in the United States has increased as a consequence of technological innovations, freeing firms to extract natural gas from otherwise inaccessible reserves stored in tight shale formations and located beneath densely populated regions. The private market for oil and natural gas leases, preceding permitting, drilling, and producing gas from a well, is an ideal setting to study the costs and benefits of firm market power. The leasing market is largely unregulated,[6] firms value economies of density by virtue of state-wide mineral conservation and protection of correlative rights,[7] and landowners are increasingly exposed to the implications of the leasing market. First, states like Texas do not regulate excessive noise or mandate soil and water testing pre-drilling; however, restrictive leases address these unregulated features of the industry, ensuring less disruptive drilling and production practices. Second, before obtaining a permit to drill a well, firms must amass the mineral rights to a large contiguous acreage through individual landowner negotiations, leading firms to value economies of density in leasing activity.[8] Third, technological development in the industry has increased access to minerals stored beneath urban regions as firms can now drill horizontal laterals reaching up to three to five thousand feet in any direction.[9] While this technology decreases the number of individual wells drilled, it allows firms to drill adjacent to large subdivisions and extract oil and natural gas from beneath their homes.

The empirical analysis relies on a novel dataset that describes in detail the spatial distribution of a large number of private contracts and captures the implications of leasing behavior in urban settings. Each observation quantifies the specific clauses written into the individual leases signed between firms and landowners. Each of these contracts is associated with a specific parcel located across Tarrant County, Texas, a densely populated region containing the cities of Fort Worth and Arlington. These data are assembled and merged across three primary sources using web-scraping, text extraction, and string matching techniques, and to my knowledge, it is currently the most comprehensive database of these private contracting terms.

In the data, I find evidence that firms sign leases of varying quality[10] that is negatively correlated with firms' market shares and firms geographically concentrate their lease negotiations, which may lead to profitable well production sooner. In particular, simple summaries in Table 1 reveal that leases vary by the types of clauses whereby royalty ranges from 0.12 to 0.28 percent of the pro-rationed size of the

similar restrictions to those found in oil and natural gas leasing documents, which are applied to the entire city or township. While the non-deterrence result is coarse, it suggests that firms are not deterred by more regulatory compliance in this particular setting.

[5]There is a growing literature capturing the hedonic value of proximity to drilling activity in the environmental economics literature. Existing literature finds that households internalize perceived risks of nearby drilling activity through decreased property values (Muehlenbachs, Spiller, and Timmins (2015), Gopalakrishnan and Klaiber (2014), James and James (2014), Boxall, Chan, and McMillan (2005)), and a growing health literature finds that proximity to drilling is correlated with incidence of infant birth weight (Hill (2013)) and harm to drinking water (Hill and Ma (2017), Vengosh, Jackson, Warner, Darrah, and Kondash (2014)). Specific lease clauses can mitigate exposure to these factors in the absence of more comprehensive state or federal regulations.

[6]The exception, in Texas, is a minimum royalty rate of $\frac{1}{8}$ of the pro-rationed value of minerals extracted from the mineral estate. Other states have similar royalty thresholds and, in some cases, more extensive rules regarding other aspects of the leasing phase.

[7]Protected correlative rights ensure that mineral rights owners are able to profit from extracting those minerals even if the sub-surface mineral acreage is small (protection from the "rule of capture").

[8]Firms leasing in urban areas may need to sign hundreds of leases before applying to permit a well. The need to amass a large amount of contiguous, sub-surface mineral acreage has increased with the frequency of horizontal drilling that allow firms to extract from larger areas, as well.

[9]The law requires firms to own the sub-surface mineral acreage for any area in which they have drilled a lateral and the acreage lying within a buffer on both sides of the lateral (the buffer varies by state).

[10]Lease quality is measured by the number of included clauses positively benefiting landowners or by higher royalty rates and lower term lengths.

parcel, term length ranges between 12 and 60 months, and frequency of clauses in each bundle type range from 0.16 to 0.556 whereby the most popular types are surface protection clauses. Table 2 demonstrates the relationship between firms' market shares and average lease quality measures using a series of OLS regressions of quality on market structure, finding a negative relationship. The third panel in Table 3c summarizes the market structure in which the average firm share is roughly 0.13 (0.22), suggesting that firms geographically concentrate their spatial leasing decisions. In addition, Table 4 describes a negative relationship between firm share and the time to begin drilling and profiting from natural gas production, which suggests that firms have a monetary incentive to geographically concentrate their leasing efforts.[11]

Based on these empirical findings, I propose estimating a one-to-many matching model assuming non-transferable utility (NTU) whereby a single firm signs bundles of leases owned by individual landowners, amassing the legal rights to enough sub-surface mineral acreage to be eligible for a permit to drill a well. A matching framework allows me to estimate a model that captures the spatial distribution of firms signing leases across Tarrant County, estimate separate preference parameters for firms and landowners by assuming non-transferable utility, and mimic industry standards whereby firms extend offers to landowners and landowners have autonomy to reject undesirable offers. Finally, the institutional incentives for permitting wells allow me to extend the NTU, one-to-many matching framework by estimating the effect of economies of density that induces complex, complementary preferences for firms valuing bundles of leases.

The leasing market is composed of landowners and firms, two sides of the market that have different preferences for signing leases. While both sides stand to monetarily profit from a productive well, firms value attributes of the mineral estates that facilitate lower costs to transition from the leasing to the producing phase of well development. Conversely, landowners value minimizing the effects of increased noise, traffic, infrastructure deterioration, and other aesthetic and health risks that result from nearby drilling. A matching model that assumes non-transferable utility captures the divergent preferences of landowners and firms by parameterizing a model with separate landowner and firm utilities.[12,13] Second, lease agreements result from bilateral agreement of both firms and landowners whereby any specific match depends on the preferences across all players on both sides of the market.[14] Compared to the traditional discrete choice literature, matching models grant autonomy to both sides of the market mimicking bilateral agreement. Leases signed by any given firm and landowner pair depend on the preferences of all firms and landowners in the market, features that allow the matching model to more accurately mimic negotiations as they occur in the industry.

Allowing the firms to value economies of density requires estimating a matching model in which market structure is endogenous to other market-level unobservables. This paper contributes to the empirical matching literature by modeling the endogenously determined market structure as a match externality[15] that allows firms to have complex, complementary preferences. Market structure is modeled as the share of leases signed by a single firm in a geographic region of Tarrant County, and a large firm share increases the value of individual mineral rights in that region, which induces complementarity across the set of mineral rights.

[11] Each of these tables will be described in greater detail throughout the text.

[12] Models that assume transferable utility maximize the joint surplus. With non-transferable utility, the model is estimated using two exogenously given utility functions that describe firms' and landowners' preferences separately.

[13] Firms pay landowners a bonus when the lease is signed and royalty payments once the well begins producing oil or natural gas. These payments are incorporated into the model as the money metric used to interpret the coefficients for the non-pecuniary attributes. This assumption is addressed in greater detail in Section 4.4 and the data used to calculate the money metric is described in Section 5.5.

[14] A firm may sign a lease with their most preferred landowner, or they may sign a lease with a landowner lower in their preference ranking because their most preferred received a strictly better offer from their competitor. Matching models have endogenous choice sets whereby each matched pair depends on the preferences of all players on both sides of the market.

[15] A match externality refers to a characteristic of one or both sides of the markets' value functions that reflects the total assignment of the market.

To my knowledge, this is the first paper to estimate a large-scale, NTU model of one-to-many matching with a match externality that induces complex preferences like complementarity.[16]

Using the final match outcomes, the techniques used to estimate the matching model are predicated on the observed leasing market having low frictions and satisfying a pairwise stable equilibrium. Pairwise stability imposes that there is not a firm and landowner pair preferring to sign a lease with one another more than their current lease given the fixed market structure and lease terms. When there are complex preferences, the model may not have an equilibrium or there may be many equilibria. A myopic estimation function simplifies the firms' beliefs and allows for a tractable estimation strategy in the presence of complex preferences, and the equilibrium is verified post-estimation. Firms extending lease offers to landowners serves as an equilibrium selection mechanism when there is multiplicity, and the assumption mimics industry behavior where firms are actively approaching sets of landowners with contract offers. In general, this set-up can be useful to study other markets like labor markets where firms are searching for a diverse workforce, and the sets of worker types are complementary from the firm's perspective, for example.

Estimating the matching model reveals that firms value spatial concentration and, as a consequence, they value individual parcels more when they are located in geographic markets where firms have signed a large share of the leases. Second, the model estimates the marginal cost of contracting terms and finds that more legal clauses reduce the overall value of a parcel from the firms' perspectives. On the other side of the market, the model estimates that landowners positively value more contract clauses. Since the value of a lease increases with market concentration, one might conclude that firms offer more concessions to those landowners as additional compensation; however, that is the opposite relationship found in the data. Using several different measures of contract quality, ordinary and two-stagged least squares models are used to estimate the effects of firm concentration on each measure. Estimates from these models reveal negative relationships between firm concentration and lease quality suggesting that firms exercise market power in the leasing market for pecuniary and non-pecuniary contract terms.

The estimates from the matching and reduced form models suggest that firms benefit from spatial concentration in the leasing market along two dimensions. With greater spatial concentration, firms may proceed to oil and gas production faster and firms sign leases with fewer contract clauses, thereby reducing firms' costs and increasing landowners' risks. While the first consequence is beneficial for both firms and landowners, the second consequence may cause more harm to landowners in the long run.[17,18] The proposed policy experiment captures firms' responses when leases are restricted to be uniform and containing more clauses protecting landowners. Results suggest that firms sign thirty-four percent fewer leases; however market concentration increases thirty-nine percent. Further, back of the envelope calculations to approximate the change in welfare predict that requiring an additional clause increases the average returns from contracting terms by 3.6 times the value under the status quo, and the average returns increase to 10-fold under a uniform leasing policy.

The paper contributes to the empirical matching literature by estimating a one-to-many, non-transferable utility (NTU) match model with complex preferences, or complementarity across a set of matches. Models in which there is complementarity are common in settings where a firm hires workers with complementary

[16] Uetake and Watanabe (2013) estimates a one-to-one non-transferable utility match with a match externality and substitutable preferences; Fox and Bajari (2013) estimates a one-to-many, transferable utility match with complements.

[17] Quantifying the harm to landowners is beyond the current analysis, but it is a research area with growing evidence both in the economics and scientific literatures that nearby drilling can be harmful to residents through increased air pollution, traffic, aesthetics, and risks from leakage, among others.

[18] Joint with Christopher Timmins suggests that a lease with fewer landowner concessions is negatively correlated with the household's race/ethnicity controlling for other observable characteristics that may affect their marginal willingness to pay for lease terms (income and other tract-level characteristics).

skills and schools or classrooms are composed of students from diverse backgrounds or with varying skill levels, among other examples. In the lease market, complementarity is induced by firms' increasing values for single parcels based on having leased a higher share of those parcels' surrounding minerals. The empirical techniques build on the work of Uetake and Watanabe (2013) who estimate a one-to-one, NTU match with a match externality inducing substitutable preferences,[19] Agarwal (2015) who estimates a one-to-many, NTU model of hospitals matching to residents where hospitals have vertical preferences for residents,[20] and Boyd, Lankford, Loeb, and Wyckoff (2013) who estimates a one-to-many match between teachers and schools. This paper adds to the literature by proposing market structure moments that identify the effect of a match externality that induces complementarity. It also applies the matching methods to a new industry, the private oil and natural gas industry, in a way that conceptualizes a specific and measurable form of complementarity through firms' market shares.[21]

The empirical contribution rests on the growing theoretical literature focused on characterizing equilibrium when there are less restrictive preferences including complementarity. This literature has evolved from "matching with couples" with strong restrictions regarding the effect that couples can have on the total match.[22] Other studies have focused on markets in which agents are able to observe all interactions attributed to potential deviating pairs in order to sustain an equilibrium (Sasaki and Toda (1996) and Hafalir (2008)). Finally, a more recent approach to characterizing equilibrium under complex preferences is to study matching in large market settings as demonstrated by Kojima, Pathak, and Roth (2013), Azevedo and Hatfield (2012), and Che, Kim, and Kojima (2014). The large market setting best captures the urban leasing market where firms are signing hundreds of leases in a geographic region before permitting a single well.

The paper is broadly a study of market power and the value of density economies in the leasing market, which are oft studied incentives in the empirical industrial organization literature, and the leasing market is an ideal setting for jointly estimating the costs and benefits of firms' market power. More recently, industry-specific studies, such as Porter (1983), Bresnahan (1987), and Nevo (2001), among many others, have expanded the empirical methods used to study market power. Measuring market structure as a density of the firms' geographically concentrated leasing efforts[23] follows from the industrial organization literature studying chain store entry patterns as in Jia (2008), Holmes (2011), Ellickson, Houghton, and Timmins (2013), and Nishida (2014).

Topically, this paper studies the private natural gas leasing market and contributes to the growing literature in environmental and energy economics characterizing the industry and its implications. The contribution to the literature is twofold since it is, to my knowledge, the first paper to model the bilateral, private negotiations between firms and landowners using a method that allows for autonomy on both sides of the market, and to estimate the value of market concentration (economies of density) in the private leasing market. Prior work on leasing focuses on state and federally owned land whereby mineral rights

[19]They study entry in the banking industry with an option to merge with an existing institution. Their paper uses the theoretical work of Hatfield and Milgrom (2005) and substitutable preferences to partially identify a model with multiple equilibrium, allowing them to forgo assumptions regarding equilibrium selection mechanisms.

[20]Agarwal and Diamond (2014) demonstrate the value of using the "many" component of one-to-many matches to identify vertical preferences when matches are not perfectly assortative, and it informs the estimation strategy in Agarwal (2015).

[21]Traditional applications of the one-to-many, NTU matching framework include hospitals to residents (Agarwal (2015)), schools to students (Abdulkadiroğlu and Sonmez (2003), Abdulkadiroğlu, Pathak, Roth, and Sönmez (2005), and Abdulkadiroğlu, Pathak, and Roth (2005)), and schools to teachers (Boyd, Lankford, Loeb, and Wyckoff (2013)), among others.

[22]The number of couples may be small relative to the size of the market (Kojima, Pathak, and Roth (2013)) or the existence of couples cannot engender cycles (Ashlagi, Braverman, and Hassidim (2014)), and this literature is surveyed in Biró and Klijn (2013).

[23]The reduced form models of lease quality verify the market power effect using other, non-density measures of competition as robustness checks.

are auctioned, which includes Libecap and Wiggins (1985), Porter (1995), Fitzgerald (2010), and Lewis (2015). Other relevant literature emphasizes drilling decisions[24] and relates lease quality to demographic characteristics.[25]

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. Additional model, estimation, simulation, robustness check, counter-factual, and data details can be found in the Appendix.

2 Institutional Details

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, Gottlieb, Krupnick, and Wiseman (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,[26] 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[27] at high pressures into the drilled well such that the rock cracks and produces artificial fissures throughout the strata. 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.

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,

[24] Levitt (2009), Kellogg (2011), and Covert (2014) identify firms' learning behavior when deciding to drill new wells. Finally, Holmes, Seo, and Shapiro (2015) studies the sequence of firm decisions moving from leasing to production in a theoretical model.

[25] Timmins and Vissing (2015) study the heterogeneous distribution of protective leases across households using an environmental justice argument.

[26] 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)).

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

Texas.[28] 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,"[29] 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, Gottlieb, Krupnick, and Wiseman (2013)). The federal government protects air and surface water quality, and endangered species. Since 2012, the Environmental 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,[30] and they have more lax proximity restrictions.[31] 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 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[32] (given that the use is not wasteful) and inject waste water into sub-surface formations.[33,34]

Further, the mineral estate owner is not responsible for full restoration of the property,[35] 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

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

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

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

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

[32] 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)

[33] 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)).

[34] 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.

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

(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[36]). 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,[37] 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 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.[38] 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.[39]

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.[40] 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 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, Gottlieb, Krupnick, and Wiseman (2013) extensively explores the existing state of heterogeneous regulatory standards across states.

3 Model

3.1 Spatial Complementarity

The following section describes the leasing market in the context of one-to-many matching and assuming non-transferable utility. The presented framework is used to match a two-sided market comprised of landowners and firms where a single firm signs sets of leases with many landowners, and some of these leases are geographically concentrated. The matching framework is used to model the bilateral negotiations between firms and landowners and to identify the value of spatial complementarity for firms signing geographically clustered leases. The model and estimation differ from existing empirical matches by estimating the effect

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

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

[38] 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.

[39] 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.

[40] 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 (2013)).

of a match externality that induces spatial complementarity across sets of leases signed by a single firm, thereby compromising the existence of an equilibrium. The following describes the model characterizing the leasing market, the market structure modeled as a match externality, and an equilibrium assignment between landowners and firms active in the leasing market.

In the leasing market, pre-dating any drilling and production activity, firms amass the legal rights to the mineral estates from which they want to extract oil or natural gas. State and federally owned lands auction parcels to firms; however, when the mineral rights are privately owned, firms sign sets of privately negotiated leases with the landowners. Each firm decides where, across Tarrant County, Texas, they want to sign leases by ranking the parcels according to the observable parcel characteristics, the share of leases signed in that geographic region (or the market structure measure), and the costliness of the contract itself in terms of landowner concessions. Each signed lease represents a temporary transfer of the mineral estate from the landowner to the firm, thereby allowing the firm to drill for and extract oil or natural gas. Valuable parcel characteristics include the size of the parcel, proximities to pipelines or future drilling sites,[41] and the expected future profits from drilling a well. In urban settings like Tarrant County, firms need to amass hundreds of signed leases before applying for a permit to drill from the Texas Railroad Commission. As a consequence, firms value signing a large number of leases transferring densely spaced (and ideally contiguous) mineral rights, which is captured by a measure of firms' leasing shares in a geographic market of Tarrant County. Finally, each lease contains clauses, some that restrict firm behavior in costly ways. Each potential match between firms and landowners is ranked according to a value composed of these observable characteristics and an unobserved, match-level shock.

Leasing decisions are bilateral in the sense that firms extend offers to landowners and landowners, reciprocally, can accept or reject the offer depending on whether the landowner values a given firm's offer and if it is the most valuable among all offers received by that landowner. To decide whether to accept a match, landowners also have ranked preferences for each firm's offer based on the firm type, expected future profit from a well extracting their minerals, and the landowner concessions written into the firm's lease offer.

Firm and landowner preferences for matches are ranked using value functions comprised of observed and unobserved characteristics based on the pure characteristics model of Berry and Pakes (2007). Equations in (1) capture the firm j's and landowner i's values for matches in the data through v_{ij} and u_{ij}, respectively. The pecuniary and non-pecuniary characteristics enter firms' value function through $f(X_i, Z_j, \theta_{ij}; \beta)$ that measures the effects of parcel (X_i) and firm (Z_j) characteristics in addition to the lease contract value, θ_{ij}. Similarly, landowners' values are determined by the observables through $g(X_i, Z_j, \theta_{ij}; \alpha)$, and these values underly landowners' preference rankings across firms' lease offers.

Firms' and landowners' values also include unobservable, match-level shocks through the additively separable terms η_{ij} and ξ_{ij}, respectively. These measures are assumed to be uncorrelated with observables, unobserved to the econometrician, and observed by firms and landowners. The unobservables represent attributes of the lease or negotiation process known to firms and landowners that sign the lease rendering the particular negotiation more or less attractive to the two parties. These unobservable attributes might include bonus payments, a particularly effective sales pitch or strong negotiation skills, or a parcel unencumbered by trees, among other examples.

Firm values have an additional term reflecting the effect of market structure on their decision problem,

[41] Including proximity measure with respect to the future wellpad location might be problematic if it is assumed to be 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.

$\beta share_j^m$, which is defined for each firm j and geographic market m.

$$\begin{aligned} v_{ij} &= f(X_i, Z_j, \theta_{ij}; \beta) + \beta share_j^m + \eta_{ij} \\ u_{ij} &= g(X_i, Z_j, \theta_{ij}; \alpha) + \xi_{ij} \end{aligned} \tag{1}$$

Because the leasing market resembles a one-to-many match whereby a single firm signs leases with a set of landowners, firms have a cap on the total number of leases they are able to sign across Tarrant County, which is denoted $\bar{q}_j$.

Embedded in this characterization of the leasing market are several assumptions. First, the market structure observed in the data is assumed to be an equilibrium, which is to say that the set of leases signed between firms and landowners, and the resulting set of share values, observed in the data is in equilibrium. As a consequence, the observed equilibrium market structure is used to construct firm values in order to rank each firm's preference for potential landowner matches. Second, because the market structure is the result of all firm and landowner actions in the data, firms must have beliefs about other firms' actions before valuing and ranking the parcels. The model presented assumes that firms are boundedly rational about other firms' actions, and that all other firms will sign the number of leases they are observed signing in the data.[42] In practice, firms' lease constraints ($\bar{q}_j$) are exogenously given, and firms in the model sign the same number of leases as they are observed signing in the data.

3.1.1 Pairwise Stability

Based on the value functions described in (1) and firms' beliefs, firm j extends offers to landowners in sequence until they amass $\bar{q}_j$ leases or there are no remaining, profitable offers to extend. Reciprocally, landowners hold on to their most preferred and acceptable match and reject all others until they receive no more offers. Leases that are offered and accepted across the two sides of the market are modeled as a series of matches mapping from the sets of landowners to firms, where a match between firm j and landowner i is denoted $\mu_j(i) : \mathcal{N} \to \mathcal{J} \cup \{0\}$.[43] A particular match between j and i is predicated on the agreed upon contract value denoted θ_{ij}. The set of contract values and matches between the two sides of the leasing market are assumed to satisfy pairwise stability.

Pairwise Stability: Stability is defined in terms of firm j's value, v_{ij}, and landowner i's value, u_{ij}, the estimated measure of firm market concentration, $share_j^{m*}$, and the support of contract values available to firm j, $\mathcal{D}_j = \cup_{i \in \mathcal{N}} \{\theta_{ij}\} \cup \{0\}$.

1. *Individual rationality*:
   (a) Landowners: $u_{ij} \geq 0$.
   (b) Firms: $\nexists\, \tilde{\theta}_j \subset \mathcal{D}_j$ s.t. $V_j(\tilde{\theta}_j, share_j^{m*}) \geq V_j(\theta_j^*, share_j^{m*})$ and $\sum_{i \in \mu_j(i)} \mu_j(i) \leq q_j$.
2. *No blocking*: $\nexists\, j' \subset \mathcal{J}$ and $\nexists\, i' \subset \mathcal{N}$ such that
   (a) Landowners: $u_{i'j'} \geq u_{i'j}$
   (b) Firms: $V_{j'}(\theta_j^* \backslash \{i\} \cup \{i'\}, share_j^{m*}) \geq V_{j'}(\theta_j^*, share_j^{m*})$

[42] The myopic estimation function approach is described later in more detail in the Identification and Estimation section.
[43] $\{0\}$ denotes not signing a lease.

The first individual rationality condition requires firms and landowners to 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 estimated market structure $share_j^{m*}$. 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 match externality, the stability condition must hold for the estimated market assignment, $share_j^{m*}$.

In general, a pairwise stable equilibrium is not guaranteed to exist, and, if it does exist, it is not guaranteed to be unique. Existence is a particularly thorny issue in the presence of complex preferences like complementarity, which is induced in the current model by including a measure of firms' geographic market shares in their value functions. In particular, including firm share allows the preference for a single match to depend on the firms' matches to other, nearby parcels. Ignoring the unobserved, match-level attribute, a situation where $f(X_i, Z_j, \theta_{ij}; \beta) \leq 0$ and $\beta share_j^m > -f(X_i, Z_j, \theta_{ij}; \beta)$ results in $v_{ij} \geq 0$ and a potential instability among firms competing to sign these marginal leases.[44] Intuitively, there may be parcels of land with low acreage or that are located on the periphery, and when evaluated independently, acquiring the mineral rights is not valuable to the firm. However, if that firm signs a large concentration of leases in the geographic market, the values of the low attribute parcels increase. In the leasing market, firms with large concentrations in a single geographic market can move to the permitting and drilling phases more quickly and begin profiting from the natural gas sales.[45]

3.1.2 Heterogeneous Preferences

Heterogeneous preferences for landowner attributes are identified separately for firms that are landmen, or firms that do not drill wells and participate in the leasing market as appropriator of mineral rights, and large operators.[46,47] In particular, the firms' preferences for the size of the parcel and measures of proximity to drilling infrastructure vary for the two firm types.[48] These observable landowner attributes are excluded from the observable attributes characterizing landowner values on the other side of the market. Parcel size and proximity measures are valuable to firms with an expectation to drill a well because these measures affect the cost to drill either by lessening the time to permitting[49] or reducing infrastructure costs. Adding additional preference heterogeneity increases the computational dimensions significantly; however, identification is likely feasible, especially for the exogenous variables in the model. Future work will explore whether it is feasible to identify heterogeneous preferences for spatial concentration, which is modeled as a match externality and described in greater detail in Section 4.

3.2 Lease Quality

The model of lease negotiation suggests that firms value spatial complementarity across the sets of leases they negotiate with landowners located in the same geographic region. These leases are more valuable

[44] The appendix includes a description of a simple model with complements that adapts a model described in Che, Kim, and Kojima (2014) to the lease market setting.

[45] Empirical evidence supporting spatial complementarity is presented at the beginning of the estimation section.

[46] Large operators are defined as Chesapeake, Dale, XTO, and Carrizo.

[47] The model could estimate more complex preference heterogeneity; however, doing so would increase the computational complexity due to the large market. The model currently estimates matches between roughly 31 firms and 60,000 landowners.

[48] As described in the conclusion, future work will attempt to identify heterogeneous preferences for the match externality. More general settings would likely find that the levels of complementarity vary across market participants, including a variable effect of complementarity on firm preferences in the leasing market.

[49] A larger parcel may lessen the time to permitting by reducing the total number of negotiations comprising the remainder of the mineral rights that are required to permit a well.

to firms because owning the mineral rights to large contiguous acreage allows firms to proceed faster to drilling and production phases of well development. As a consequence of this added value, mineral rights are independently more valuable, in concert with the other observable characteristics of the parcel, when they are located in regions where firms own a large share of the mineral rights. This section presents a simple model capturing the relationship between spatial concentration, or market structure, and lease quality in order to understand whether there is a market power effect on the pecuniary and non-pecuniary attributes of the contracts.

There are potentially two countervailing forces as firms and landowners agree to a particular menu of lease clauses. The firm's value of a specific lease increases as that firm signs more nearby leases. However, as firms amass more leases in a geographic region, there are fewer competing firms since the property rights are rivalrous and competitor firms' values for individual parcels are not as large as if they had leased more in that region. As a consequence, the dominant firm may be able to offer terms that are less desirable to landowners knowing that landowners are receiving fewer offers from their competitors. A competitive equilibrium in the matching framework maximizes the total surplus, which suggests that lease offers result in high quality firms matching with high quality landowners. In the current setting, the landowner's quality to a given firm increases with a greater market share, among other observable characteristics. A firm exercising market power in contract terms allows the firm to extract additional rent from the landowner.

Based on this setup, lease quality is determined by the firm's and landowner's observable characteristics ($q(X_i, Z_j; \delta)$) and the market structure ($share_j^m$). Since a greater market share increases the value of the individual parcel, we might assume that firms valuing those parcels more would offer the landowners better contracting terms as proposed in 2 for $\gamma > 0$.

$$\begin{aligned} &\theta_{ij} = q(X_i, Z_j; \delta) + \gamma share_j^m \\ &\text{where } \ \theta_{ij}(share_j) \geq \theta_{ij}(share_j') \ \text{ if } \ share_j \geq share_j' \end{aligned} \tag{2}$$

However, when firms exercise market power, they extend worse contracting terms to landowners, $\gamma < 0$. The simple OLS and 2SLS models are designed to test for the prevalence of market power on leasing outcomes by estimating a series of models that describe the relationship between pecuniary and non-pecuniary contract terms and market shares, along with other firm and parcel characteristics.

The lease quality fits into the matching framework through equation 3. While the quality is not endogenously determined in the model of spatial competition, the correlation in the data between the endogenously determined market structure and the firms' lease quality is negative and is used to identify the parameters describing firms' preferences.

$$\begin{aligned} v_{ij} &= f(X_i, Z_j; \beta) + \beta share_j^m - \beta^{qual}\theta_{ij}(share_j) + \eta_{ij} \\ u_{ij} &= g(X_i, Z_j; \alpha) + \alpha^{qual}\theta_{ij}(share_j) + \xi_{ij} \end{aligned} \tag{3}$$

A rough test of whether the leasing market with spatial concentration most benefits firms or landowners is captured by relative effects of market share across firm and landowner values as in 4.[50]

[50]These two sides of the market are not directly comparable because they are normalized by different measures of expected profit for any given firm and landowner pair. Further, the coefficient capturing $\frac{\partial \theta}{\partial share}$ is not estimated with a money metric as is used in the matching models.

$$\begin{aligned} &\text{Firm Value:} && \frac{\partial v}{\partial share} + \frac{\partial v}{\partial \theta}\frac{\partial \theta}{\partial share} \\ &\text{Landowner Value:} && \frac{\partial u}{\partial \theta}\frac{\partial \theta}{\partial share} \end{aligned} \tag{4}$$

4 Identification and Estimation

This section describes the estimation strategy used to identify the two-sided model of one-to-many matching with a match externality and assuming non-transferable utility. The first subsection describes the myopic estimation function approach used to approximate the effect of the match externality. The subsequent sections describe the specific statistical moments used to identify the parameters of the structural model and the sequence of the estimation strategy. The identification strategy for the reduced form model of lease quality is described in the reduced form results section before presenting the estimates of those models.

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 market structure, $share_j^m$. In the model, $share_j^m$ is endogenously determined based on the outcome of the leasing market 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 market structure in firms' values, the model assumes that agents have boundedly rational beliefs about all other participants' actions and estimates the model using a myopic estimation function.[51,52] 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, which is denoted $\bar{q}_j$ in the model section. The estimator penalizes guesses of the parameter values that do not replicate the equilibrium market structure observed in the data.[53] Further description of how the model identifies the effect of firms' shares follows in the next section.

4.2 Identification

Point-identification of the model stems from the equilibrium selection mechanism that assumes firms extend offers to landowners and never the reverse. Assuming that firms extend offers is intuitive in the industry setting where it is not the norm for landowners to approach firms with lease offers.[54] In each

[51] Uetake and Watanabe (2013) and Baccara, İmrohoroğlu, Wilson, and Yariv (2012) estimate models using a myopic estimation function.

[52] 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).

[53] Among the moments used to estimate the model are the differences in observed and simulated market concentrations for each firm in each geographic region of Tarrant County.

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

simulated match, firms are only constrained by the total number of leases they are observed signing in the data. Otherwise, firms are free to sign leases (match) with landowners located anywhere across Tarrant County,[55] and the market structure for any given simulation is endogenously determined in the model through the matching algorithm. The flexibility of the model allows me to identify the parameters describing firms' preferences for signing leases in geographic clusters, an endogenous element of the firms' profit functions, by calculating moments that describe the simulated market structures and it's correlation with characteristics of those geographic regions.

Several types of moments are used to estimate the model including those that compare the statistical moments of the observed and simulated matches, moments that use within group variation, and those that use the endogenously determined market structure, $share_j^m$, and each of the moments used to estimate the model are described in greater detail in Table 5. For all moments, the objective function minimizes the distance between the observed moments from the data and the average moment values across all simulations for each draw of the unobserved match-level characteristics.

The first set of moments in Table 5 describe the assortative matching behavior across the two sides of the market, and they include the joint distribution and covariance across matched landowner and firm characteristics. Regressions that describe the correlations between the landowners' observed characteristics to that of their match partners demonstrate assortativity across observable attributes in the data, and they are discussed at the beginning of the match model results section.

The second set of moments, firm-level moments, utilize the econometric result of Agarwal and Diamond (2014) (and applied to the resident-to-hospital match in Agarwal (2015)), which find that one can use the one-to-many feature of the matching market to identify the parameters when there is not perfect assortativity across match partners. In the lease data, we find that small firms, for example, sign leases of larger than average land size that are located nearer to the future well site suggesting that small firms are more likely signing leases in rural areas.[56] The description of small firms' aggregate behavior can capture sorting on an unobservable factor not captured by a model that predicts smaller firms matching with low-quality properties (landowners)[57] due to capital constraints, for example. This is particularly relevant in an atypical drilling setting like Tarrant County where one might not be able to fully capture the observable attributes driving firms' sorting behavior across the geographic markets.

The third and fourth sets of moments identify the firms' preferences for signing leases across geographic sub-regions of Tarrant County and, in particular, firms' preference for their own market share, $share_j^m$. The third set of moments utilize the geographic clustering of landowners' parcels across Tarrant County by calculating within-market moments that identify parameters describing how firms sort across space. To estimate the model, each firm is constrained by the total number of leases they are observed signing in the data; however, the firms are free to match with landowners across Tarrant County, which is modeled as a single matching market.[58] The fourth set of moments utilize the simulated market structure resulting from the deferred acceptance algorithm, which is described in greater detail in the following section. The market structure moments compare the observed market structure to that of each simulated market, and they compare the joint distribution between the market structure and within-market moments across observed

[55]If XTO is observed signing 10,000 in the data, then XTO is limited to signing those 10,000 leases with landowners located anywhere across the county.

[56]A probit model describing the likelihood a rural lease is signed by a particular firm substantiate this observation.

[57]Rural property might be considered high-quality because the land masses are larger, resulting in fewer negotiations, and there are fewer spatial constraints like those that are prevalent to drill in urban settings.

[58]The market referenced here is secondary and that of the matching market where firms are able to match across landowners located anywhere in Tarrant County through the deferred acceptance algorithm. The primary use of market in the model and analysis is to describe the geographic sub-regions of Tarrant County.

and simulated markets. These moments are used to identify the parameter that describes firms' preference for signing leases in geographic clusters (firms' market shares, or $share_j^m$), the match externality in the model. Figure 1 describes the observed market structure across Tarrant County, and it captures some of the variation in the data that is used to identify the effect of the endogenous market share in firms' profits.

4.3 Estimation

This section describes the estimator used to identify the model and the simulation technique for a match with externalities. The appendix description includes added details about inference for the estimated parameter set and other computational details, including a Monte Carlo testing the efficacy of the market structure moments.

The model is estimated using a minimum distance estimator (McFadden (1989); Pakes and Pollard (1989); Gourieroux and Monfort (1997)) where the estimated parameter set $\hat{\Omega}$ minimizes the simulated objective function (5). The moments of the observed data are denoted $\hat{m}$ while the average moments from the set of simulated outcomes are denoted $\hat{m}(\Omega)$.[59]

$$||\hat{m} - \hat{m}^S(\Omega)||_W^2 = (\hat{m} - \hat{m}^S(\Omega))'W(\hat{m} - \hat{m}(\Omega)) \tag{5}$$

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.[60] The deferred acceptance algorithm[61] facilitates a pairwise stable matching for each draw.[62] The simulated draws are taken from a Halton sequence to reduce the computational magnitude of the problem.[63] 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.
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, $\widehat{share_j}^m$.

[59] The parameter estimates reported use an identity weight matrix which results in consistent estimates; however, efficiency is increased with a weight matrix noted in the estimation appendix.

[60] 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.

[61] Gale and Shapley (1962) first demonstrated that the deferred acceptance algorithm yields a stable equilibrium under representative or substitutable preferences.

[62] A modified 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 (1984), and Roth and Peranson (1999), among many others).

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

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 follows for each guess of the parameter space, $\hat{\Omega}$, and each draw of the error terms, η_{ij}^s and ξ_{ij}^s, and is proceeded by calculating the resulting joint distributions of the matched pairs' characteristics, along with the group-level moments and simulated market structure. The simulated draws are constant across each guess of the parameter set. After estimating the model, we verify whether the parameters describe an equilibrium by ensuring the market shares for firms across Tarrant County are stable.

4.4 Model and Estimation Assumptions

The model set-up and estimation rely on several assumptions or simplifications, and they are detailed in this sub-section. These assumptions describe the types of information firms and landowners have when they sign leases, the types of transfers observed in the market, the equilibrium imposed on the leasing market, and the potential for strategic behavior between firms.

Given the observable and unobservable elements of the firm and landowner values, the model assumes that firms rank all properties across Tarrant County and, reciprocally, that landowners rank offers from all firms. Embedded in this assumption is that firms and landowners have full information about the observable characteristics, which enables complete rankings, and this includes the expected future profitability of the well. In particular, to estimate the value of the non-pecuniary attributes of the firms' and landowners' values, the parameters for each side of the market are normalized using a money metric[64] describing the future productivity and profitability from leasing a parcel that is eventually used to drill a well. Using the money metric in the value function assumes that both firms and landowners know (or have some expectation about) the future profitability of the well extracting from each parcel. While this assumption is not very strong for knowledgeable firms, it is strong for landowners who may not know much about the industry. However, because the expected future profit is used to normalize, miss-specification of the profit can be added to the error term in the landowner values.

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.[65] 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

[64] The data section details how the money metric is constructed from the production and pricing data.

[65] 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.

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.

Equilibrium in the leasing market is defined by pairwise stability that imposes that there is not a firm and landowner pair preferring to sign a lease with each other over the observed leasing match in the data, which means that there would not be any post-leasing transfers. This is a strong assumption for the leasing market because there are likely unobserved lease transfers prior to permitting, drilling, and producing from a well. However, when the leasing firm is not an operator of the well, it is difficult to identify in the data whether a firm transfers the lease to another firm or maintains a royalty interest stake in any future well that is drilled. By estimating the model using pairwise stability, the model separates the leasing decisions from the permitting decisions and assumes that pre-permitting transfers occur at fair market value and all participating firms have perfect information. While these assumptions are strong, they are not unreasonable among knowledgeable oil and natural gas industry participants. In particular, firms have access to the same futures price data and monthly production values are publicly reported for all wells in Texas.

A related issue concerns whether operators and landmen are unobservably signing leases together even though the model treats them as separate entities with individual geographic market shares.[66] In the data, firms may sign leases under similar but differentiated names indicating a subsidiary that is designated as a property manager only, for example, and the their actions are modeled as a single entity. Further, there is anecdotal evidence that firms sign leases on each other's behalf even though one is not singularly contracted to the other. If two firms were competing as a single entity for a subset of the leases, then their value functions would include larger geographic market shares in that subset of regions. As a consequence, parcels in that region would, in reality, be ranked higher in those firms' preference rankings and holding the preferences for the other observable characteristics constant.

Suppose there are two markets, $m, m' \in \mathcal{M}$, and firms j and j' act as separate entities in market m and they act jointly in market m'. Using the model notation for firm j's values, equation (6) describe the value of a parcel located in m and equation (7) describes the value of the parcel located in m'.

$$v_{ij} = f(X_i, Z_j, \theta_{ij}; \beta) + \beta share_j^m + \eta_{ij} \tag{6}$$

$$v_{i'j} = f(X_{i'}, Z_j, \theta_{i'j}; \beta) + \beta(share_j^{m'} + share_{j'}^{m'}) + \eta_{i'j} \tag{7}$$

The firm's differing values of market structure will affect the firm j's preference ranking for all parcels across markets if $\beta share_{j'}^{m'} > f(X_{i'}, Z_j, \theta_{i'j}; \beta) - f(X_{i''}, Z_j, \theta_{i''j}; \beta) + \beta(share_j^{m'} - share_j^{m''})$ for $m' \neq m''$ and $\beta share_{j'}^{m'} > 0$. The data does not facilitate estimating a model in which we observe these between firm contractual arrangements. However, an additional counter-factual presented in the appendix attempts to answer what happens to the market when third party landmen are removed and each of the operating firms are left to sign leases across Tarrant County, which is used to approximate this potential outcome. Future work explores ways to deal with this heterogeneity more precisely.

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

[66] Thanks to Thomas Covert for identifying this potential issue during a presentation.

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 the appendix for more detailed descriptions of how the data were collected and assembled.

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.[67] 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 1a reports the primary terms summary statistics.

However, only two percent of the bonus payments are observed in the data sample, and most of those leases were signed in 2008 predominantly by nine firms.[68] Table 1a 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 sometime 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 summarizes the primary and auxiliary clauses in the data, and Table 1b summarizes specific clauses that are sub-categorized by lease clause bundles.[69]

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

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

[68] Firms and landowners are not required to report bonuses with the Tarrant County Clerk office.

[69] Figures in the appendix demonstrate the firm and year-level variation in the data by plotting the firm fixed effects estimates with confidence intervals by year.

Texas Railroad Commission (TRC)[70]. Each well observation includes important dates like the date the permit was issued 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.

Other measures of well activity are described in Table 3b, and they are used in the matching analysis to describe firm types. These include measures of drilling activity in Tarrant County and in the Barnett Shale more generally before 2004 and much of the leasing in Tarrant County began. Table 3b also describes the frequency of landmen and large operators signing leases in the data, and a measure of pre-2004 complaints filed with Texas Railroad Commission regarding firm drilling behavior.

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.[71] Further, they supplied appraisal and reported sale values[72] 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 the buyer or seller) and addresses. Table 3a 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.

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. The violation data is collected from the Texas Railroad Commission, which includes inspection dates and the type of violation incurred. The variable in the analysis is the sum of all violations cited for each firm.

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

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

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

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.[73] 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.

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 natural gas, p_t^{ng}.[74] 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:

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

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

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

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 the data sample. Table 3a summarizes the annualized revenues for parcels across Tarrant County.

6 Results: Instrumental Variable Models

6.1 Identification

The first piece of empirical analysis estimates a relationship between firm market structure and lease quality capturing whether firms exercise market power in leasing by signing contracts with fewer landowner concessions. Lease quality is multi-dimensional and composed of royalty rates,[75] primary term lengths,[76] bonus payments,[77] and specific clauses designed to restrict firm behavior in varying ways, and they are described in greater detail in the data section. Table 1 summarizes these characteristics for the data collected in Tarrant County, Texas. Table 1c describes the raw correlations across the dimensions of lease quality. Without controlling for any other observable characteristics, Table 1c describes a world in which features of the contracts are positively correlated. The positive correlations suggest that a good lease for landowners is good in all dimensions and landowners are not necessarily compensating fewer clauses with higher royalty rates, for example.

Lease quality is estimated as a function of market structure, or the share of leases signed by a single firm in a geographic region of Tarrant County, and other observable characteristics of the parcel like the surface area, proximity to the wellpad area, and an indicator for whether the parcel is located in a rural region. The instruments are used to mitigate potential omitted variable bias, and in particular, unobservable and potentially more valuable geographic market characteristics. The two proposed instruments are chosen to mitigate correlation with unobservable market and firm level characteristics:[78] (1) the inverse distance[79] between the firms' local office and the Tarrant County Clerk (TCC) office, where the mineral deeds are filed, and (2) the inverse distance between the signed lease and the TCC office. A relationship between market structure and the distance between the TCC office and the firms' local office can be attributed to the ease with which firms can access filed deeds that describe who are the mineral rights owners with whom they need to negotiate. Proximity between the leased land and firms' offices may decrease firms' costs to negotiate in measurable ways like time to drive to the landowner's household or in other unobservable ways.[80] These distance measures are likely exogenous to lease quality if it is assumed that lease quality depends on the parcel attributes that increase the profitability of the well. If these distances were somehow correlated with future productivity in an unobservable way, then the instruments would be invalidated since it likely that

[75]Royalties are paid on the fraction of land leased to the total leased mineral acreage from which the well is extracting.

[76]Firms have a specified number of months to drill a well and begin producing oil or gas (or to complete a well that is "capable of producing in paying quantities," as the law states in Texas). If they exceed the primary term, the mineral rights revert back to the landowner. Leases may also contain extension clauses that prolong the time till the lease expires, and usually the landowner is owed an additional fixed sum if the firm exercises the extension clause.

[77]Bonus payments are one-time, fixed payments paid to the landowner when they sign the lease.

[78]Tables in the appendix demonstrate the potential correlation with unobservables by estimating the lease quality models with market and firm-level fixed effects.

[79]The inverse distance is used for interpretive reasons so that nearness is valued while farther distances converge to zero and become less relevant.

[80]First stage results are not reported, however, the first stage F-statistics capturing the strength of the relationship between the instruments and the endogenous market share are reported in Table 6a.

lease quality is correlated with expected productivity.

We might be concerned that firms sign leases containing more landowner concessions in areas where the minerals are more valuable as evidenced by higher levels of production in earlier periods, or pre-2004 wells. However, using the set of wells drilled before 2004 in surrounding markets should not be correlated with the perceived productivity of the market in question, which supports its use as an instrument. The relationship with share may be derived from firms leasing less in rural and more in urban spaces post-2003 and signing more leases in areas not yet drilled resulting in a strong first stage relationship. The second instrument, the count of wells drilled by firms outside of Tarrant County as of 2003, may be correlated with lease quality if firms with historically greater capital or more industry experience sign different types of leases. However, one may argue that past drilling experience may not bear as strongly on lease types signed in Tarrant County, which is both urban and overlaying a tight-shale formation requiring unconventional drilling techniques that are more complex and expensive. Conversely, historically large operating firms are likely to lease a larger acreage of land as drilling expands to new regions like Tarrant County.

6.2 OLS and 2SLS Estimates

Table 6 reports the ordinary least squares estimates for each of the measures of lease quality when the geographic market is defined by wellpads, which is described in greater detail in the data section.[81] The measure of competition is the firms' cumulative share in a particular geographic market at the date in which the lease is signed.[82,83] In addition to competition, the models are estimated with controls that describe the parcel characteristics like the size of the parcel, whether it is located in a rural area of Tarrant, and proximity to the wellpad.[84] These are physical characteristics that might matter to a firm amassing mineral rights from which they want to extract.

Table 6a reports the estimates from the ordinary least squares specifications for the each definition of lease quality, and each column reports estimates for the seven different definitions. Without an instrument, Firm Cumulative Share does not have a measurable relationship with bonus payments among the small sample of bonuses. However, moving horizontally across the table estimates from Firm Cumulative Share, there is a consistently negative relationship with terms that benefit landowners and a positive relationship for the single term that is disadvantageous for landowners, Term Length (months). Focusing on the column estimating the effect of Firm Cumulative Share on the Dis-amenity bundle (-0.176***), a firm moving from a low market share of zero to 0.6 will offer approximately one-half fewer of the dis-amenity clauses, of which there are five.

Table 6b reports the estimates from the two-stagged lease squares model instrumenting for Firm Cumulative Share with two instruments:[85] (1) the inverse distance between the firms' local office and the TCC office, where the mineral deeds are filed, and (2) the inverse distance between the signed lease and the TCC

[81] Each of these results hold using a geographic market that exogenously defined by the Texas Appraisal Office, an abstract. Tables reporting the results for abstracts are included in the appendix.

[82] The cumulative share is defined as the firms' shares at the beginning of the month in which the lease is signed.

[83] Other measures of competition like the Herfindahl-Hirschman Index and the firm count by market are used to estimate similar models, and the patterns describing the relationships between quality and market structure are consistent across specifications. These results are reported in the appendix.

[84] The models were also estimated without these controls, and the relationships with firm concentration do not differ in interpretation.

[85] The results for instruments describing nearby production pre-2004 are presented in the Appendix. Both sets of instruments result in similar relationships between market structure and lease quality. The distance instruments are intuitively more exogenous if one were to think historic, nearby production may be correlated with future production causing firms sign leases that are correlated with expected profit. However, a nice feature in Tarrant County is that the urban area, and its nearby markets, are not as active pre-2004, which may mean these measures are less correlated with lease quality in this specific setting.

office. Across the top row, the patterns of relationships between concentration and the different lease quality measures is consistent with the OLS specification, and largely, the effects increase in magnitude in the 2SLS models. Contrary to OLS, the instrumental variable model estimates a significant and negative relationship between Firm Cumulative Share and Bonus payments (-26,875.91***). Using the small sample of bonuses, the model suggests that moving from zero to 0.5 market shares will decrease bonus payments by around $13,437. Returning to the effects for the dis-amenity bundle (-1.051***), a comparable move from zero to 0.5 market shares results in leases with two and a half fewer dis-amenity clauses.

The measure of lease quality bundles does not use differential weights across clause types, so one and half fewer dis-amenity clauses could mean leases that do no contain any of the following: environmental, noise, or compression station restrictions, freshwater protection, or surface casing. These results are robust to different definitions of competition and geographic market which are reported in the Appendix.

7 Results: Matching Model of Spatial Concentration

7.1 Empirical Motivation

Before presenting the results of the matching model, this subsection presents reduced form evidence motivating the modeling choices. In particular, the data are used to describe assortativity across the observed characteristics of firms and landowners matched in the data. Second, a simple model correlating market structure with other well timing decisions motivate firms' preferences for spatial concentration as a means to begin drilling and profiting from extraction faster.

Table 7 describes the level of assortativity between firm and landowner characteristics across the two sides of the market. Each column in each panel reports a separate OLS regression of an attribute on the set of attributes describing the other side of the market. Table 7a describes the assortativity of firms' characteristics with individual landowner characteristics (by column). Reciprocally, the assortativity of landowners' characteristics with each firm characteristics is reported in Table 7b.[86] Broadly, the observable characteristics used to model the leasing market have largely significant relationships. The most valuable parcel in term of expected profit are those with the largest land size (0.307***) and located nearest to infrastructure (0.132*** and 0.046*** associated with proximity to the well and pipeline, respectively), not with a higher property value (-0.040***), as suggested by the first column of Table 7a. The second column reports the relationships between firm characteristics and the lease quality, and it suggests a negative relationship between market structure and quality (-.808***), as discussed in the section describing the lease quality model.

In Table 7b, lease quality is positively related to profitability (0.025***) reported in the first column and the property value (0.116***) reported in the fourth column. Similar to the estimates in Table 7a, lease quality is negatively related to market structure (-0.231***) as reported in the last column of Table 7b.

Table 4 reports results of regressions that describe relationships between market structure and the timing of firms' permitting, production, and leasing decisions. In particular, the first two dependent variables in the first and second columns describe the time, in months, from the leasing decision until the well is permitted or the date of first production. The coefficient describing the relationship between market structure and time to first production (-5.575***) is negative and significant, suggesting that a larger market share of leases decreases the time until firms profit from a future well. Table 4a describes models that estimate firm fixed

[86]The matching model estimates heterogeneous firm preference by including interactions between observables and firm type, as reported in Table 7a; however, the lower panel omits the assortativity regressions for all firm interactions.

effects and Table 4b describes models that estimate the differential effects of signing a lease with a particular firm type like a landman or large operator. In the first two columns of Tables 4a and 4b, a larger market share reduces the time until firms move to more profitable stages of well development. The effects of firms' market share is several orders of magnitude larger for the relationship with the time to first production (the second columns).

The third column of Table 4 estimates models where the dependent variable describes the count, in days, between the last lease that was signed and the current leasing decision. As measured in the other specification, the effect of market concentration is negative and significant when estimated with and without firm fixed effects (-19.709*** and -19.796***). The estimated relationship indicates that a larger market structure decreases the incremental time between signing leases, which suggests that firms move more quickly through the leasing phase.

In all three settings, firms' market structure is negatively related to the timing of future, more profitable decisions, which gives credence to firms' preferences for spatial complementarity as estimated in the one-to-many matching model.

7.2 Estimates

The structural estimates from the one-to-many matching model are reported in Table 8 split between the parameters characterizing firm values as reported in Table 8a and those characterizing landowner values in Table 8b. The model captures heterogeneity in firm preferences for the observable attributes of any given parcel as defined by the second column of Table 8a. Each parameter estimate can be interpreted as the effect of a standard deviation change on firm or landowner values.[87] Each parameter value is monetized through the value of the future expected profit derived from signing a particular lease, or the money metric as described in the data section, which is set to one when estimating the matching model. In general, the estimates of the matching model fit the hypotheses proposed in the model section. Firms view more landowner concessions as costly while landowners value the added protection, and firms value spatial complementarity.

Beginning with firm preferences, the estimates suggest that firms view more landowner concessions as costly as indicated by the estimates for *Lease Quality* (-2.438) in Table 8a. Using the *Dis-amenity Bundle* summary statistics in Table 1b, an increase in clauses of 0.238, which is equivalent to one additional clause in the *Dis-amenity Bundle*, results in a decreased firm value of -2.438. Increasing lease quality for a particular parcels shifts that parcel lower in firms' rankings making it less likely the pair will match. The second variable of primary interest is estimate for the match externality, or *Firm Share*. Table 8a reports a positive relationship (4.743) suggesting that firms value spatial complementarity as hypothesized in the model section.

The estimates for the observable characteristics are also relatively intuitive. The model estimates suggest that landmen, in particular, value the land size (6.279) and proximity to pipeline infrastructure (10.077). Operators have an incrementally greater preference for landsize (1.288), though the primary driver of operators' preference rankings appears to be the effect of their market shares.

Landowner value estimates are reported in Table 8b, and the results suggest that landowners value more landowner concessions (2.968) in contrast to the firms' values. In addition to parameters for lease quality, the model estimates landowners' incremental values for firm types as characterized by firm size (*Firm Barnett Well Count*) and registered complaints (*Firm Complaints*) prior to 2004. The estimates suggest that landowners prefer signing leases with larger firm (11.274) and those with a complaint history (3.877). The positive preference for firm size and complaint history may be indicative of the positive relationships with

[87]The data is normalized to be the Z-score.

expected profit (0.262***) and lease quality (2.902***), respectively, reported in Table 7b, which captures assortativity between firm and landowner characteristics.

7.3 Model Fit

Table 9 describes how well the estimated match equilibrium from Table 8 captures the observed market structure in the data. Table 9a reports the observed and simulated equilibrium count of leases signed based on the match estimates, and the percent change reports that the simulated model mimics the observed data patterns by signing only 2.6% fewer leases. The mean HHI values across the observed and simulated leasing patterns are also very similar. Table 9b captures the model fit for different firms. The first two columns compare the firms' counts of leases signed in the data and simulated by the matching model while the last two columns compare the mean shares for those firms.

The first panel of Figure 2 plots the average market shares by firms and compares the observed market structure in the data to the market structure estimated by the matching model. The *Estimated* lines capture the average matching outcome when the simulation constrains the total count of leases signed by each firm to be the total count observed in the data. The second panel of Figure 2 plots the confidence sets for the observed and simulated market shares by firm. Largely, the estimated equilibrium captures the market structure by firm, as well.

7.4 Total Effects

As noted in Section 3.2, I can approximate which side of the market benefits most from the combined effects of spatial concentration through economies of density and market power in contracting terms. Using equation 4, I approximate the difference in values attributable to spatial concentration, firm value minus the landowner value as described in 8, using estimates from the matching and lease quality models.

$$\frac{\partial v}{\partial share} + \frac{\partial v}{\partial \theta}\frac{\partial \theta}{\partial share} - \frac{\partial u}{\partial \theta}\frac{\partial \theta}{\partial share} \tag{8}$$

Back of the envelope calculations suggest that firms benefit with a difference of 11.55 (= 4.743 + (-2.43)*(-1.259) - 2.97*(-1.259)). The combined parameter estimates are difficult to interpret since estimates from the lease quality models do not have a monetary interpretation. Further, the firm and landowner sides of the market are normalized by their respective expected profits from royalty payments. However, roughly, the matching model estimates represent the annualized royalty value attributable to increasing market concentration and lease quality.

8 Counter-factual Analysis

8.1 Uniform Leasing Standard

The data reveals that firms sign leases with varying sets of landowner concessions, and the estimates from the lease quality model suggest that firms exercise market power on this dimension by signing fewer landowner concessions when that firm is dominant in the region. The primary counter-factual limits firm competition in lease quality by requiring all firms to sign more uniform leases across all landowners, limiting the firms' abilities to exercise market power in private contracting. In the industry, leasing practices are largely unregulated by the state and federal governments. Pairs of firms and landowners are responsible for adding lease 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 damages occurring over the life of the well. Signing leases with more landowner concessions is particularly relevant in an urban region like Tarrant County where more households are exposed to nearby drilling behavior and the impacts are more widely experienced. Requiring firms to sign a standard lease that has a specific set of landowner concessions restricts firms from competing for cheap leases, but the restriction also increases firms' costs to lease. The counter-factual outcome under a uniform leasing standard allows one to measure whether, in response, firms decrease overall participation or employ a more or less spatially concentrated leasing strategy. In addition to the primary uniform leasing policy, I test how the market responds to requiring a specific, environmental clause and to the addition of a single, ambiguous clause to all leases signed.

The first uniform leasing counter-factual measures the change 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 landowner concessions. Instead of increasing the lease quality by a single clause for all firms not offering that clause, the bundles contain either all of the clauses such that any lease offered to a landowner is the same.[88] Under uniform leasing, firm j ranks their preferences for landowners based on the values for each parcel, $f(X_i, Z_j, \theta; \beta) + \beta share_j^m + \eta_{ij}$, where θ is now fixed for all firms and landowners. For firms signing fewer landowner concessions in the data, uniform leasing increases the costs to sign leases with those landowners, which may shift their spatial leasing behavior or cause them to signer fewer leases altogether. Further, the cost to sign specific lease terms is homogeneous for all firm and landowner pairs causes firms to value parcels' observable characteristics and market share. On the other side of the market, uniform leasing removes a significant amount of variation in landowner values that are used to rank firms' offers.[89] As a consequence, landowners' preferences become more vertical, and the resulting match depends more on the firms' rankings for landowners.

8.2 Results

The uniform leasing counter-factual removes firms' competition for cheap leases by requiring all firms to sign higher quality leases. To evaluate how the market for leases is altered by a uniform leasing requirement, Table 10 reports the change to the total count of leases signed by firms and to the mean-level market concentration for each scenario. Table 11 describes the changes to market structure by firm. It also reports the changes to the characteristics of leases signed by a firm given the primary counter-factual scenario.[90]

The first restriction to lease quality requires that all firms sign leases agreeing to a 25% royalty, whereas the majority of lease royalties observed in the data range from 18% to 25%. The third row of Table 10 reports that there is little change to the market structure when royalty is fixed at a higher rate, and the very small increase in the count of leases signed is likely attributable to an increase in the set of firm offers that are acceptable to landowners.

[88] Royalty rate is also fixed at 0.25 for the uniform leasing policy.

[89] Landowner preferences are represented by ranking firms' offers based on $g(X_i, Z_j, \theta; \alpha) + \xi_{ij}$. Restricting quality to be the same θ for all firms removes significant firm-level variation, whereas firm values have additional and remaining firm-level variation through the effect of market structure.

[90] For each counter-factual, preferences are ranked, firms are matched to landowners via the Deferred Acceptance Algorithm, and a new market structure, $share^{m,1}$, results. The counter-factual, equilibrium market structure results when the market structure stabilizes between t and $t-1$ iterations, or $share^{m,t} - share^{m,t-1} = 0$.

The fourth row of Table 10, *Added Environmental Clause*, increases the restrictiveness of lease quality by requiring all firms not formerly signing a lease including an environmental clauses to now include one. Requiring the environmental clause increases the costs for some, but not all firms active in the market since some firms were already signing leases containing the clause. In response, the change in concentration is positive (+4.9%) and the total number of leases signed decreases by a small amount, as well.[91] The fifth row of Table 10, *Added Clause*, adds a single clause to each potential lease negotiation. As the cost of leasing increases by a single clause, firms agglomerate more (+25%) and sign fewer total leases.

The sixth row of Table 10 increases the restrictiveness of lease quality significantly by requiring firms to sign a uniform bundle of landowner concessions that include restrictions to noise and additional environmental quality standards, among others.[92] Under uniform leasing restrictions, the market contracts by 34% and the market-level concentration increases (+40%). Among the leases signed, they have higher expected profits, greater land sizes, and are located nearer to drilling infrastructure as suggested by the positive changes to the mean lease characteristics reported beneath *Pct. Changes*. Rough calculations suggest that, on average, there is a net, monetized gain from restricting the market to higher quality leases. This results falls out of landowners valuing higher quality leases at a magnitude that is greater than the cost of those leases to firms.

Compared to a single added clause, uniform leasing alters firm behavior more significantly by contracting the total market for leases and causing firms to spatially concentrate their leasing efforts more. Based on this observation, a less costly option to uniform leasing may be requiring a set of particularly valuable clauses for landowners.[93] Further, back of the envelope calculations suggest that a single additional clause results in total welfare gain in contracting that is 3.6 times the benefit under the status quo, which is attributable to landowners valuing better contracts at a value (2.968) greater than the cost born by firms (-2.438).[94] Under uniform leasing, the gain is 10-fold.

The other lease quality counter-factuals allow the quality of leases signed to adjust with the market structure according to the relationships estimated in simple OLS models of lease quality. The three equations in 9 represent lease quality and firm and landowner values, respectively. Using parameter estimates from the reduced form models (reported beneath each separate counter-factual in Table 10) and the matching model, the model converges to a new equilibrium.

$$\begin{aligned} \hat{\theta}_{ij} &= \hat{\alpha}_0 + \hat{\alpha}_1 share_j^m + \hat{\alpha}_2 X_j \\ v_{ij} &= f(X_{i'}, Z_j, \hat{\theta}_{i'j}; \hat{\beta}) + \hat{\beta} share_j^m \\ u_{ij} &= g(X_{i'}, Z_j, \hat{\theta}_{i'j}; \hat{\beta}) \end{aligned} \tag{9}$$

The first, *Lease Quality Adj. (1)*, allows quality to adjust with market structure alone where 10% increase in firm's share results in a reduction to lease quality of -0.03. Allowing for a flexible function of lease quality

[91]The matching model does not differentiate between clause types in a given bundle, weighting the environmental clause the same as the noise clause. However, there would be differential effects across counter-factuals requiring different clauses because each clause is observed with differing frequencies in the data, which means that requiring a less common clause is going to change the market outcomes more than requiring one often already included among the contracting terms.

[92]The analysis treats individual clauses homogeneously, not allowing for differential effects from clauses that are potentially more valuable to landowners.

[93]This analysis does not differentiate preferences for types of clauses within a bundle; however, joint work with Christopher Timmins seeks to value clauses in a hedonic framework, which may reveal landowners preferences as measured through changes in property values.

[94]Coefficients are normalized by the coefficient for annualized expected royalty split between a contracting pair if a well is drilled. The welfare calculation takes the average lease quality from a counter-factual scenario and calculates the difference in costs to firms and gains to landowners using the estimates from the matching model.

results in fewer signed leases (-23%) than the baseline, though more than the number of leases signed under uniform leasing, and increases to market concentration (50%). Since firms view landowner concessions as costly, the negative relationship between lease quality and market structure together results in a decreased cost to lease parcel located in areas where firms have a large concentration of leases. The complete interaction results in a more profitable leases (from lower costs) and more firm concentration.

9 Conclusion

Using spatially identified private contracting terms, this paper estimates the effects of market power for the pecuniary and non-pecuniary terms of these contracts that facilitate the transfer of mineral rights to firms that drill and extract oil and natural gas. This paper models spatial private contracting behavior as a one-to-many match where firms sign bundles of leases with sets of landowners. The model is estimated as one-to-many matching with non-transferable utility, whereby firms value signing leases for contiguous mineral rights, which may induce complex preferences. As a result, I extend the one-to-many, NTU matching framework to allow for estimating a model with a specific type of complementarity by introducing a set of statistical moments that identify the complex preference. I am able to estimate the value of economies of density in this market, and I find that firms exercise market power in the contracting terms they offer landowners.

Post-estimation, the model is used to test the changes to market structure when firms are required to sign more favorable leases for landowners. Firms respond to the policy by signing fewer leases, but firms lease more efficiently by targeting parcels with a higher expected profit, better proximity to drilling infrastructure, and that are more spatially concentrated, which allows them to proceed to more profitable phases of well development faster. Further, back of the envelope approximations suggest a welfare gain in lease quality across the two sides of the market, whereby requiring a single, additional clause increases the returns from contracting by 3.6 times and uniform leasing increases returns 10 fold.

Future work will explore estimating a heterogeneous effect for spatial concentration across different types of firms. In the leasing market, there are broadly two types of firms signing bundles of leases, including operators with the capital to drill a well in the future and third party landmen focused on amassing the legal rights to mineral estates. The current model and counter-factuals begin to address the disparity in behavior across these firm types; however, the current estimation limits firm-level heterogeneity to exogenous characteristics of the model like a preference for land size and proximity to pipelines. Firms may also have heterogeneous preferences for spatial concentration, the endogenously determined match externality, as well, and future work will explore ways to estimate a richer model of firm preferences. Such work would also be relevant in more general studies of one-to-many matching when firms have heterogeneous preferences over complementarities across sets of workers perhaps due to varying firm sizes or vertical integration, among other potential reasons.

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Figure 1: Market Structure Variation

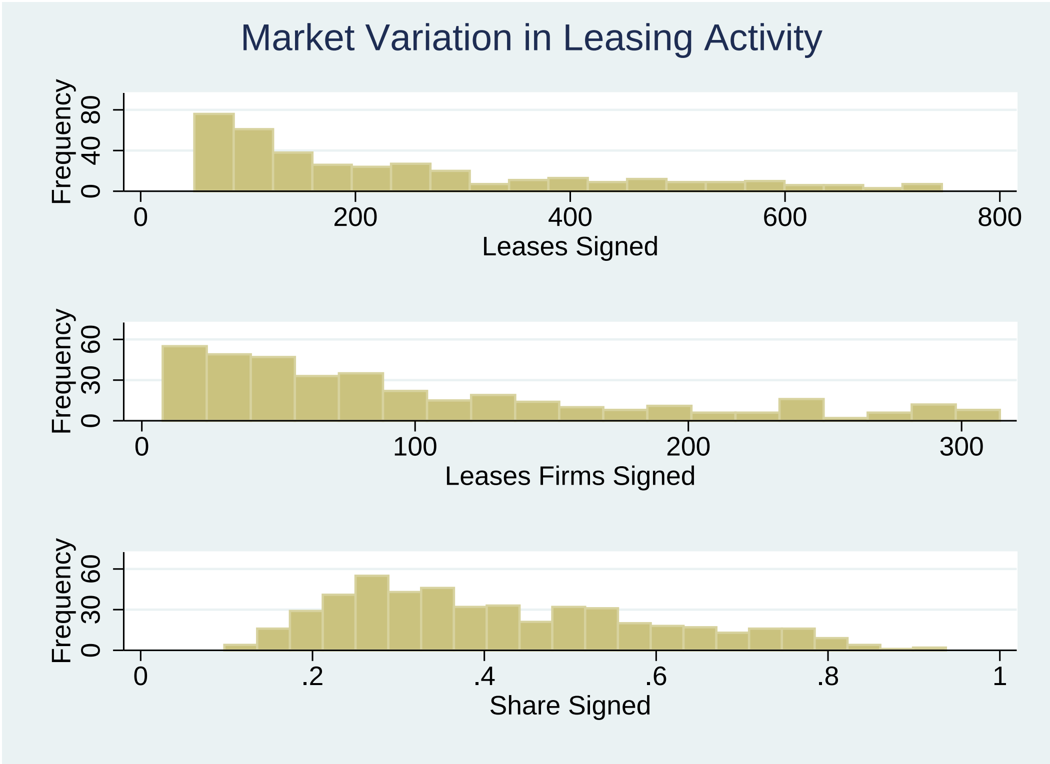

Table 1: Lease Clause and Bundle Summary Statistics

(a) Primary Terms

	Obs.	Mean	Std. Dev.	Min.	Max.
Royalty	176,380	0.231	0.024	0.125	0.284
Term Length (months)	284,797	42.467	11.887	12	60
Bonus	5,752	15,877.61	6,542.64	200	25,000

(b) Auxiliary Clauses

	Mean	Std. Dev.	Clause/Bundle	Mean	Std. Dev.
Dis-amenity Bundle	0.161	0.238	Legal Bundle	0.225	0.22
Environmental	0.316	0.465	Force Majuere	0.513	0.5
Noise	0.293	0.455	Pugh	0.399	0.49
Freshwater Protect	0.022	0.146	Offset Well	0.129	0.335
Surface Casing	0.008	0.091	Insurance/Indemnity	0.074	0.262
Compression Station	0.004	0.065	Reporting	0.012	0.109
Surface Bundle	0.556	0.231	"Bads" Bundle	0.217	0.182
No Surface Access	0.778	0.416	Sub-surface Easement	0.613	0.487
Surface Restriction	0.106	0.308	Injection Well	0.021	0.143
Surface Damage	0.785	0.411	Free Water Access	0.017	0.129
Observations	75,731				

(c) Correlation Matrix

	Royalty	Term (months)	Land Size	Clause
Term (months)	-0.2528	1.0000		
Land Size	-0.0138	-0.1032	1.0000	
Clause	0.2051	-0.3790	-0.0415	1.0000
Bonus	0.5969	-0.2617	0.0818	0.5158

Notes: (i) The first panel reports the summary statistics for the primary lease terms, royalty and primary term length, or the number of months until the lease expires and the mineral rights revert back to the landowner; (ii) the second panel reports the frequency of individual auxiliary clauses that are accounted for in each bundle types; (iii) all bundles except "bads" are clauses protecting landowners and a large term length is interpreted as worse for landowners; (iv) the primary lease quality analysis uses a sub-sample of 75,731 leases with auxiliary clauses; (v) the correlation matrix demonstrates the pecuniary and non-pecuniary terms of the lease are positively correlate suggesting landowners may not be trading off additional royalty for fewer clause concessions, for example (the negative correlations with the longer term length is consistent with no trade-offs, as well, as a longer term length restricts landowners from negotiating contracts with other firms).

Table 2: Lease Quality and Market Share Correlations

	(1) Royalty rate	(2) Term (month)	(3) Full	(4) Legal	(5) Surface	(6) Disamenity
Share leases signed by firm (market)	-0.011***	1.695***	-0.072***	-0.083***	-0.018	-0.056***
	(0.002)	(0.632)	(0.017)	(0.014)	(0.022)	(0.014)
Constant	0.226***	39.279***	0.242***	0.205***	0.450***	0.112***
	(0.000)	(0.137)	(0.005)	(0.004)	(0.006)	(0.004)
Observations	4,737	6,163	2,800	2,800	2,800	2,800
R-squared	0.011	0.001	0.006	0.011	0.000	0.005

Notes: (i) Each column represents a set of six OLS regressions; (ii) the first row estimates the relationship between firm share in a geographic region and average lease quality; (iii) the results are robust to a more exogenous definition of geographic market and other aggregate measures of market structure like firm count and Herfindahl-Hirschman Index.

Table 3: Parcel, Firm, and Market Summary Statistics

	Obs	Mean	Std. Dev.	Min	Max
(a) Parcel Characteristics					
Land Size (sqft)	174,162	10,811.62	9,005.925	1,000	87,556
Avg. Appraisal Value	163,519	112,811.9	86,421.23	0	2,810,455
Near Well (km)	174,162	1.072	0.517	0.211	3.999
Near Pipeline (km)	162,569	1.204	0.876	0.000	4.981
Expected Parcel Profit (annualized)	173,759	140.04	245.14	0.002	7,958.41
(b) Firm Characteristics					
Landmen	174,162	0.23	0.42	0	1
Large Operators	174,162	0.30	0.46	0	1
Complaint by Firm	14	1	3.46	0	13
Firm's Producing wells in Barnett (before 2004)	20	186	645	0	2,917
Firm's Producing wells in Tarrant (before 2004)	6	46	69	2	185
(c) Geographic Market Characteristics					
Leases in market	394	442.04	614.10	1	3,915
Firm Share	9,098	0.13	0.22	0	1

Notes: (i) The first panel reports the summary statistics parcel characteristics; (ii) the second panel summarizes the firm characteristics; (iii) the third panel summarizes the market characteristics; (iv) *Lease in market* describes the count of individuals parcels in geographic markets across Tarrant County and *Firm Share* summarizes the primary measure of market structure.

Table 4: Spatial Complements: Time to Permit & Produce

	Time to Permit	Time To Produce	Time Between
	(a) Firm Fixed Effects		
Firm Share	-1.319***	-5.575***	-19.709***
	(0.135)	(0.143)	(0.579)
Constant	46.515***	58.780***	18.688***
	(0.823)	(0.871)	(3.939)
Observations	217,781	215,515	288,089
Year FE	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
R-squared	0.251	0.369	0.048
	(b) Firm Type		
Firm Share	-0.607***	-3.531***	-19.796***
	(0.123)	(0.132)	(0.533)
Landman	-0.618***	-0.918***	-4.567***
	(0.087)	(0.093)	(0.384)
Large Operator	-2.854***	-4.541***	4.710***
	(0.084)	(0.088)	(0.359)
Constant	50.016***	62.211***	22.974***
	(0.722)	(0.766)	(3.358)
Observations	217,769	215,501	288,066
Year FE	Yes	Yes	Yes
Firm FE	No	No	No
R-squared	0.234	0.349	0.044

Notes: (i) Each column is a different model specification and the first and second dependent variables are the months until the eventual well is permitted and producing, respectively; (ii) the third column's dependent variable describes the days between the current lease and the last one signed; (iii) the first panel reports the parameter estimates from a regression of the time to permitting or producing from the date of leasing on market structure and firm fixed effects, which are not reported; (iv) the second panel substitutes firm fixed effects for dummy variables describing firm types, landman or large operator, and the omitted type are smaller firms.

Table 5: Moments and Identification

Joint Distribution	$\frac{1}{N}\sum_{\substack{i\in\mu(j)\\ \forall j\in J}} X_{ij}Z_{ij}$
Attribute Covariance	$\frac{1}{N-1}\sum_{\substack{i\in\mu(j)\\ \forall j\in J}} (X_{ij}-\bar{X})(Z_{ij}-\bar{Z})$
Firm-level Moments	
Within-Firm Joint Distribution	$\frac{1}{N_j}\sum_{i\in\mu(j)} X_{ij}Z_{ij}$
Within-Firm Variance	$\frac{1}{N_j}\sum_{i\in\mu(j)} (X_{ij}-\sum_{i'\in\mu(j)} X_{i'j})^2$
Within-Firm Covariance	$\frac{1}{N_j-1}\sum_{i\in\mu(j)} (X_{ij}-\frac{1}{N_j}\sum_{i'\in\mu(j)} X_{i'j})(Z_{ij}-\frac{1}{N_j}\sum_{i'\in\mu(j)} Z_{i'j})$
Market-level Moments	
Within-Market Joint Distribution	$\frac{1}{N^m}\sum_{\substack{i\in\mu(j)^m\\ \forall j\in J}} X_{ij}Z_{ij}$
Within-Market Variance	$\frac{1}{N^m}\sum_{\substack{i\in\mu(j)^m\\ \forall j\in J}}(X_{ij}-\frac{1}{N^m}\sum_{\substack{i'\in\mu(j)^m\\ \forall j\in J}} X_{i'j})^2$
Within-Market Covariance	$\frac{1}{N^m-1}\sum_{\substack{i\in\mu(j)^m\\ \forall j\in J}}(X_{ij}-\frac{1}{N^m}\sum_{\substack{i'\in\mu(j)^m\\ \forall j\in J}} X_{i'j})(Z_{ij}-\frac{1}{N^m}\sum_{\substack{i'\in\mu(j)^m\\ \forall j\in J}} Z_{i'j})$
Within-Firm & Market Variance	$\frac{1}{N_j^m}\sum_{\substack{i\in\mu(j)^m\\ \forall j\in J}}(X_{ij}-\frac{1}{N_j^m}\sum_{i'\in\mu(j)^m} X_{i'j})^2$
Market Structure Moments	
Market structure	$share_j^{0,m}-\widehat{share}_j^m$
Joint Distribution with Landowner Attributes	$\frac{1}{J}\sum_{\forall j\in J}\widehat{share}_j^m(\frac{1}{N_j^m}\sum_{i\in\mu(j)^m} X_{ij})$
Joint Distribution with Firm Attributes	$\frac{1}{J}\sum_{\forall j\in J}\widehat{share}_j^m(\frac{1}{N_j^m}\sum_{i\in\mu(j)^m} Z_{ij})$

Notes: (i) N is the count of matched landowners across all markets, N^m is the count of matched landowners located in market m, and N_j^m is the count of matched landowners to a firm j in market m; ii) $\mu(j)^m$ denotes the partition of landowners matched to firm j in market m, and $\mu(j)$ denotes the partition of landowners matched to firm j across all markets; iii) $\bar{X}$ and $\bar{Z}$ denote the mean attribute values for landowner and firm characteristics among pairs that match; iv) Each moment, except the market structure moments, is calculated for each k observable variable, and the notation is simplified by excluding a superscript k.

Table 6: Lease Quality Estimates

	(1) Bonus	(2) Royalty rate	(3) Term (month)	(4) Full	(5) Legal	(6) Surface	(7) Dis-amenity
			(a) OLS				
Firm Cumulative Share	-713.897	-0.017***	9.832***	-0.221***	-0.092***	-0.116***	-0.176***
	(658.465)	(0.000)	(0.128)	(0.005)	(0.005)	(0.005)	(0.004)
Land Size	57.216***	0.000***	-0.053***	-0.001***	-0.000***	-0.000***	-0.001***
	(9.509)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Wellpad Dist. (Inv)	-185.811	-0.000**	-0.075***	0.001***	0.000	0.000	0.001***
	(156.192)	(0.000)	(0.016)	(0.000)	(0.000)	(0.000)	(0.000)
Rural	-4,135.749***	-0.007***	-8.595***	-0.050***	-0.030**	-0.093***	-0.049***
	(1,507.570)	(0.001)	(0.259)	(0.017)	(0.014)	(0.021)	(0.015)
Rural*Land Size	-80.520***	-0.000***	0.026***	0.000	-0.000	-0.002***	0.001***
	(30.249)	(0.000)	(0.004)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	15,719.695***	0.234***	41.831***	0.381***	0.266***	0.589***	0.216***
	(243.988)	(0.000)	(0.043)	(0.002)	(0.001)	(0.002)	(0.002)
Observations	4,956	139,419	210,943	58,121	58,121	58,121	58,121
R-squared	0.020	0.036	0.046	0.030	0.010	0.025	0.024
			(b) 2SLS				
Firm Cumulative Share	-26,875.911***	-0.019***	113.778***	-1.259***	-1.014***	0.146***	-1.051***
	(2,338.057)	(0.001)	(1.705)	(0.039)	(0.032)	(0.026)	(0.033)
Land Size	67.233***	0.000***	0.049***	-0.001***	-0.001***	-0.000***	-0.001***
	(12.806)	(0.000)	(0.004)	(0.000)	(0.000)	(0.000)	(0.000)
Wellpad Dist. (Inv)	-44.085	-0.000*	-1.239***	0.010**	0.008**	-0.002	0.009**
	(42.859)	(0.000)	(0.288)	(0.004)	(0.004)	(0.001)	(0.004)
Rural	220.120	-0.007***	-28.561***	0.073**	0.077***	-0.118***	0.054**
	(1,972.522)	(0.001)	(1.046)	(0.031)	(0.026)	(0.023)	(0.027)
Rural*Land Size	-139.525***	-0.000***	-0.136***	0.003***	0.003***	-0.002***	0.003***
	(26.570)	(0.000)	(0.015)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	23,004.978***	0.234***	22.976***	0.558***	0.423***	0.547***	0.365***
	(665.480)	(0.000)	(0.357)	(0.008)	(0.007)	(0.005)	(0.007)
Observations	4,956	139,419	210,943	58,121	58,121	58,121	58,121
1st stage F-stat	60.9	1592.18	2404.77	671.31	671.31	671.31	671.31

Notes: (i) Each column represents a separate OLS or 2SLS specification with different lease quality dependent variables regressed on observable parcel attributes. (ii) 2SLS instruments Firm Cumulative Share with proximity measures between firms' local offices and the Tarrant County Clerk office and lease location and Tarrant County Clerk office; (iii) the final sample used to estimate the models eliminates leases associated with permits issued prior to the leasing date; (iv) these results are robust to an exogenous definition of geographic market, the subset of leases primarily signed before the year 2008, other definitions of market structure or competition, and a fixed effects analysis controlling for unobserved spatial variation, and the robustness checks are reported in the appendix; (v) the appendix also reports the results for a different set of instruments that use drilling behavior in nearby regions pre-2004.

Table 7: Assortativity

(a) Firm Assortativity

		Exp. profit	Lease Qual.	Firm Compl.	Firm Well Ct.
Parcels in Market		-0.090***	-0.023***	-0.009***	-0.008***
		(0.001)	(0.001)	(0.001)	(0.001)
Appraisal Value		-0.040***	0.106***	-0.013***	-0.015***
		(0.002)	(0.002)	(0.002)	(0.002)
Land size (sqft)		0.307***	-0.071***	0.084***	0.100***
		(0.003)	(0.003)	(0.002)	(0.003)
Within 1km of Well		0.132***	-0.147***	0.194***	0.299***
		(0.005)	(0.005)	(0.004)	(0.005)
Dist. To Pipeline (Inv.)		0.046***	-0.005	-0.025***	-0.044***
		(0.003)	(0.003)	(0.002)	(0.003)
Land size (sqft)	Landman	-0.014**	-0.020***	-0.103***	-0.113***
		(0.006)	(0.006)	(0.004)	(0.005)
Within 1km of Well	Landman	-0.005	0.041***	-0.046***	-0.251***
		(0.008)	(0.007)	(0.006)	(0.007)
Dist. To Pipeline (Inv.)	Landman	0.005	-0.021***	0.034***	0.043***
		(0.006)	(0.005)	(0.004)	(0.005)
Land size (sqft)	Large Operator	-0.052***	0.039***	-0.111***	-0.116***
		(0.005)	(0.004)	(0.004)	(0.004)
Within 1km of Well	Large Operator	0.236***	-0.247***	-0.247***	-0.310***
		(0.007)	(0.007)	(0.005)	(0.006)
Dist. To Pipeline (Inv.)	Large Operator	0.066***	-0.024***	0.031***	0.047***
		(0.005)	(0.005)	(0.004)	(0.005)
Firm Share		0.141***	-0.808***	-0.301***	-0.290***
		(0.006)	(0.005)	(0.004)	(0.005)
Lease Quality		0.091***		0.011***	-0.006***
		(0.003)		(0.002)	(0.002)
Expected future profit			0.065***	0.024***	0.026***
			(0.002)	(0.002)	(0.002)
Observations		174,162	174,162	174,162	174,162
R-squared		0.139	0.326	0.062	0.047

(b) Landowner Assortativity

	Exp. profit	Lease Qual.	Parcels Ct.	App. Value	Land size	Within 1km of Well	Firm Share
Firm Complaints	-0.238***	2.902***	-2.586***	0.000	-0.263***	-1.229***	-1.180***
(Pre-2004)	(0.021)	(0.019)	(0.040)	(0.020)	(0.020)	(0.013)	(0.009)
Firm Barnett Well Count	0.262***	-2.364***	2.013***	-0.025	0.280***	1.044***	0.927***
(Pre-2004)	(0.018)	(0.016)	(0.033)	(0.017)	(0.017)	(0.011)	(0.007)
Lease Quality	0.025***		-0.518***	0.116***	0.010***	-0.264***	-0.231***
	(0.003)		(0.005)	(0.002)	(0.002)	(0.002)	(0.001)
Expected future profit		0.045***	-0.249***	0.027***	0.303***	0.067***	0.016***
		(0.002)	(0.005)	(0.002)	(0.002)	(0.002)	(0.001)
Observations	174,162	174,162	174,162	174,162	174,162	174,162	174,162
R-squared	0.004	0.125	0.139	0.016	0.090	0.242	0.362

Notes: (i) Each column for both panels is an OLS regression describing assortativity; (i) the dependent variables for each column are the firm or landowner characteristics; (ii) the first panel reports estimates of firms' assortativity across landowner characteristics (columns); (iii) the second panel reports estimates of landowners' assortativity across firm characteristics; (iv) the data use to run the OLS regressions are normalized Z-scores to mimic the scaling used to estimate the matching model.

Table 8: Matching Model Estimates

	Firm Type Pref.	Estimate	Std. Errors
	(a) Firm Values		
Parcels in Market		0.66	(0.117)
Land size (sqft)		-3.849	(0.118)
Dist. To Pipeline (Inv.)		1.119	(0.128)
Within 1km of Well		0.013	(0.122)
Lease Quality		-2.438	(0.112)
Land size (sqft)	Landman	6.279	(0.114)
Dist. To Pipeline (Inv.)	Landman	10.077	(0.096)
Within 1km of Well	Landman	0.28	(0.117)
Land size (sqft)	Large Operator	1.288	(0.109)
Dist. To Pipeline (Inv.)	Large Operator	-13.504	(0.095)
Within 1km of Well	Large Operator	-0.038	(0.105)
Firm Share		4.743	(0.101)
	(b) Parcel Values		
Firm Barnett Well Count (Pre-2004)		11.274	(0.109)
Firm Complaints (Pre-2004)		3.877	(0.105)
Lease Quality		2.968	(0.101)
J-Statistic	0.0012		

Notes: (i) The first panel reports the parameter estimates from the one-to-many matching model associated with the values underlying firms' preferences; (ii) the second panel reports the parameter estimates from one-to-many matching model associated with the values underlying landowners' preferences; (iii) the *Lease Quality* terms measures the effect of additional landowner concessions in leases for firms and landowner; (iv) the *Firm Share* term measures the effect of market structure on firms' values, or the effect of the match externality; (v) the data is scaled to be Z-scores, so the estimates are interpreted as the effect resulting from a change of standard deviation in the data.

Table 9: Model Fit

	Lease Count	Pct. Change	HHI	Pct. Change
		(a) Lease Count & HHI (Mean)		
Observed	52979		0.421	
Simulated	51620	-0.026	0.404 (0.2)	-0.039

	Obs. Count	Sim. Count	Obs. Share	Sim. Share
		(b) Lease Count & Share (Mean)		
Smallfirm	1980	1965	0.0743	0.0899
Axia Land	1321	947	0.0168	0.0096
Caffey	2252	2252	0.0244	0.0459
Carrizo	6121	5195	0.0655	0.1096
Chesapeake	13994	13988	0.2295	0.1774
Collins Young	637	611	0.0046	0.017
Dale	12731	12761	0.2721	0.266
Ddjet	1226	1152	0.0182	0.0322
Fortworth	290	264	0.0091	0.0015
Foursevens	1642	1605	0.0393	0.0223
Grande	832	865	0.0057	0.0047
Harding	321	322	0.0064	0.003
Hollis Sullivan	1370	1529	0.0181	0.0149
Paloma Barnett	3812	3895	0.0389	0.0772
Potestas	170	169	0.0017	0.0034
Titan Operating	241	240	0.0045	0.0014
Western	568	456	0.0102	0.0047
Xto	2232	2196	0.0916	0.0517

Notes: (i) The top panel compares the count of leases observed in the data to the count simulated using the matching equilibrium estimated and reported in Table 8, and it compares the mean HHI; (ii) the bottom panel evaluates the model fit by firm comparing the observed to simulated lease counts and firm shares.

Figure 2: Market Structure Model Fit

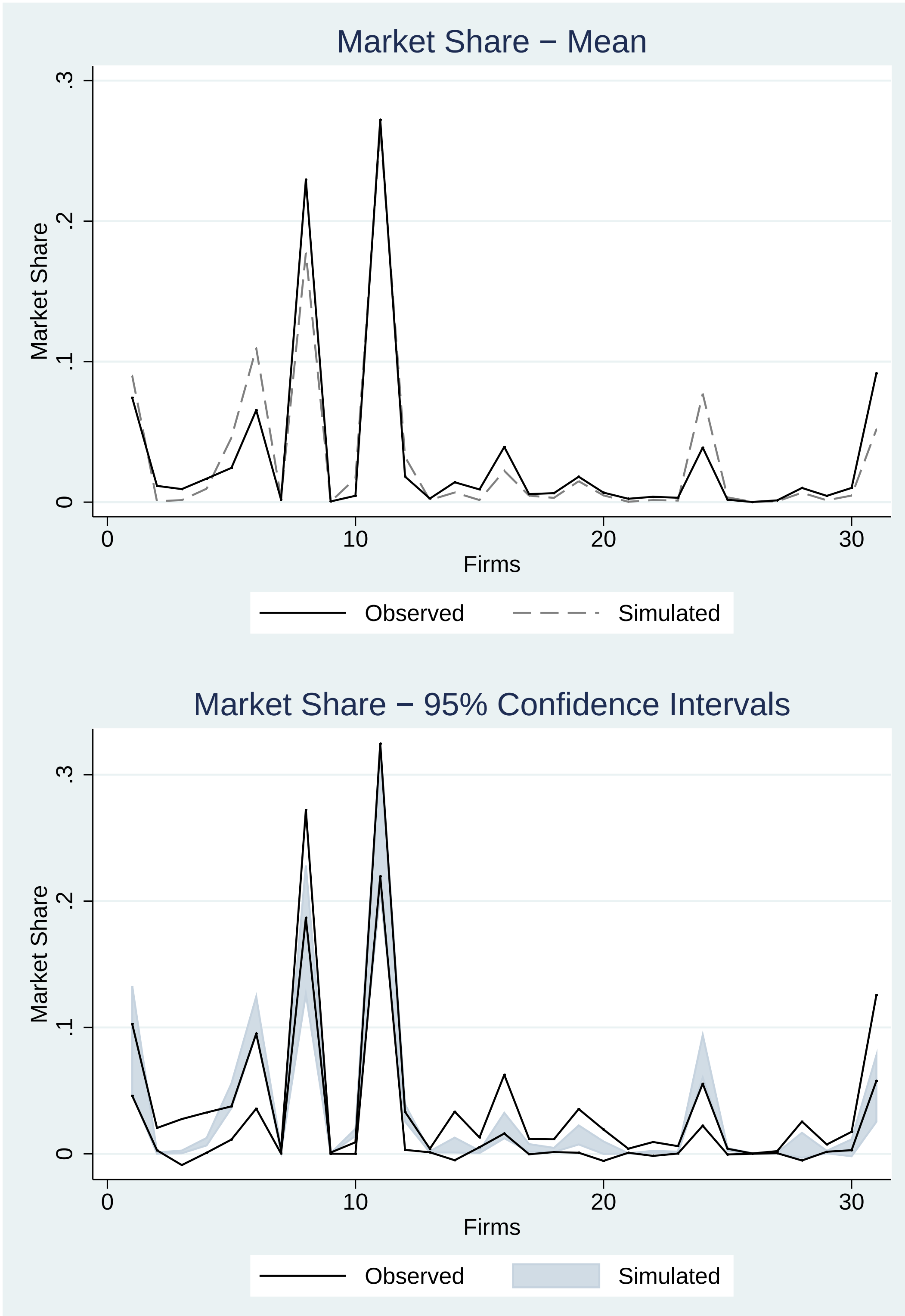

Table 10: Counter-Factual Outcomes

	HHI	Pct. Change	Lease Count	Pct. Change
Simulated	0.404 (0.2)		51620	
No Value to Spatial Concentration	0.184 (0.047)	-0.545	43955	-0.148
Royalty 25%	0.404 (0.2)	0	51621	0
Added Environmental Clause	0.424 (0.218)	0.049	51300	-0.006
Added Clause	0.507 (0.243)	0.253	50232	-0.027
Uniform Leasing	0.565 (0.301)	0.398	33810	-0.345
Lease Quality Adj. (1)	0.605 (0.26)	0.497	39260	-0.239
Firm Share	-0.327 (0.017)			
Constant	0.561 (0.002)			
Lease Quality Adj. (2)	0.591 (0.261)	0.463	40647	-0.213
Firm Share	-0.283 (0.004)			
Land size (sqft)	0.012 (0.005)			
Constant	0.527 (0.001)			
Lease Quality Adj. (3)	0.589 (0.26)	0.456	40724	-0.211
Firm Share	-0.283 (0.004)			
Land size (sqft)	0.013 (0.005)			
Wellpad Dist. (inv)	0.042 (0.003)			
Constant	0.518 (0.001)			
Observed	0.421 (0.168)	-0.039	52979	-0.026

Notes: (i) The columns report the HHI measures of concentration and counts of leases signed along with the resulting changes to these measures from each policy experiment; (ii) reports policy experiments that restrict the types of leases signed by firms; (iii) the policies "Lease Quality Adj." allow the quality to change with the changes to market structure as the model converges to a new equilibrium using estimates (reported) from simple OLS regressions; (iv) *Observed* reports the concentration and count of leases observed in the data, and the percent changes compares the observed data to the simulated data based on the estimated equilibrium matching model.

Table 11: Counter-Factual Outcomes

	Firm Size	Pct. Exit	Avg. Qual.	Exp. Profit	Land Size	Pipe Prox. (inv)	Well Prox. (inv)
				Pct. Changes			
Axia Land	1321	-0.4	0.33	0.52	0.96	32.4	0.01
Caffey	2252	-0.23	0.78	0.33	1.21	63.54	-0.14
Carrizo	6121	-0.5	0.78	0.08	-0.13	0.38	-0.11
Chesapeake	13994	-0.44	0.14	0.04	0.09	0.67	0.3
Dale	12731	-0.37	0.18	0.19	0.77	-0.36	0.01
Ddjet	1226	-0.15	0.44	-0.41	-0.19	0.75	0.12
Foursevens	1642	-0.22	0.11	0.94	1.32	1.06	-0.01
Grande	832	-0.24	0.44	2.32	1.98	-0.63	0.21
Hollis Sullivan	1370	-0.08	0.44	0.21	1.08	0.75	0.04
Paloma Barnett	3812	-0.36	0.30	-0.1	0.33	28.14	-0.07
Western	568	-0.43	0.10	2.99	2.58	11.43	-0.1
Xto	2232	-0.33	0.39	1.38	1.22	-0.31	-0.12

Notes: (i) The second column describes the changes to market structure broken down by firm under uniform leasing; (ii) the third column reports the average quality by firm; (iii) the last four columns report the changes to mean-level characteristics by firm that are attributable to the counter-factual policies; (iv) pct. changes are reported in decimals so the pct. change interpretation requires multiplying each decimal by 100.