Shale Gas Leases: Is bargaining efficient and what are the implications for homeowners if it is not?

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Abstract

With the dramatic growth of shale gas in the U.S., lease negotiations have become an important part of the energy landscape. Royalty payments are a potential source of benefit to homeowners and restrictions negotiated in lease clauses are a primary tool by which the shale gas industry is regulated. Bargaining associated with the transfer of mineral rights from lessor to lessee shares many features of the classic Coasian framework. If bargaining were indeed Coasian, efficiency would be achieved without the need for costly government oversight. Using a unique combination of data sets, we test for whether the lease negotiation process exhibits characteristics of Coasian efficiency in Tarrant Co., Texas. While our results show that important determinants of willingness-to-pay for avoiding shale gas development (e.g., income) do indeed affect bargaining outcomes, we also find significant differences across race groups, suggesting a failure of Coasian bargaining. Results of a hedonic analysis show that lease clauses are directly capitalized into housing values, meaning that failures of the lease negotiation process have important pecuniary implications. Moreover, lease clauses are correlated with the likelihood of certain kinds of violations, suggesting that they may also affect health and safety.

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1. Introduction

Natural gas stored in tight shale formations has grown to become a major source of U.S. energy supply. Facilitated by innovations in large-scale hydraulic fracturing and horizontal drilling, large quantities of this resource that had hitherto been considered inaccessible have been opened up to development. In addition to expanding domestic US energy supplies, this growth has increased the revenue of households who own the rights to the mineral reserves. However, these benefits of mineral rights development are accompanied by costs external to the production process, including higher levels of air pollution from wells (Colborn et al. 2012, Caulton et al. 2014, Roy et al. 2014), noise, road damage, air pollution and accidents associated with increased truck traffic (Gilman, J., B. Lerner, W. Kuster, and J. de Gouw 2013, Muehlenbachs and Krupnick 2014), and the potential for soil or water contamination caused by radioactive salts and metals or by the chemicals used to the treat the wells (Olmstead et al. 2013, Warner et al. 2013, Fontenot et al. 2013).

Under the U.S. legal structure, homeowners can be protected from these external costs in one of two ways. First, ordinances are passed (at the municipal, state, and federal level) that restrict activities at various stages of the drilling and production processes. Second, homeowners can negotiate for protections in the terms of the lease agreements they sign, which transfer mineral rights to operators who then develop the resource on behalf of the homeowner. Typically, the homeowner receives a royalty payment based on a percentage of the value of the resource sold by the operator in addition to a one-time fixed bonus payment at the time the mineral rights owner signs the lease.[1] In addition, the lease agreement can specify other terms that restrict the operator's

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[1] The royalty payments in Texas are roughly 18 to 25% of production pro-rationed by the acreage contribution to the producing well. The bonus payments can range from 500 to 22,000 as observed by the small sample of bonus payments observed in our data, but depend greatly on operator's expectations about the profitability of a particular tract.

activities – e.g., noise limitations, restrictions on how surface disruptions must be restored after drilling, and restrictions on how long the operator can let the minerals go undeveloped before rights revert back to their owner.

The leasing phase in most states is largely unregulated, yet it plays an important role in the *de facto* regulatory process. It is therefore reasonable to ask how the outcomes of the lease negotiation process perform in terms of the criteria that we would typically use to evaluate an environmental rule or regulation – efficiency and equity. The former is the traditional purview of environmental economics. In the context of lease negotiation, that discussion is most closely related to the literature on Coasian bargaining. The idea of Coasian bargaining (Coase 1960) is that, in the absence of transaction costs and in the presence of well-defined property rights (regardless of to whom those rights are assigned), producers and recipients of an externality will come to an efficient agreement about the quantity of externality to be generated. Efficiency is usually described in marginal terms, where the marginal benefit of the last unit of the externality-generating activity to the operator is equal to the social marginal cost of that activity experienced by all affected parties. The result of the Coase "theorem"[2] is attractive, in that it establishes an efficiency result without imposing a large information burden on a social planner.

This paper analyzes the outcomes of private lease negotiations that are used to transfer mineral rights for the purpose of shale gas development. We develop a new data set that describes the contents of a large sample of leases from Tarrant County, Texas. We match those data to information from the housing market and information about the race and income of homeowners. With this unique source of information, we empirically analyze the relationship between household characteristics (focusing on income and race) in negotiations over "private" regulation (i.e., lease

[2] Coase did not himself label this result as a "theorem", but it was later coined as such by George Stigler in *The Theory of Price* (Medema 2014).

clauses). Evidence that negotiated lease terms vary systematically with determinants of willingness-to-pay on the part of homeowners is consistent with efficient Coasian bargaining. Controlling for these factors, evidence that race matters in the determination of lease terms suggests some sort of bargaining failure; while not efficient from a Coasian perspective, this outcome is more relevant in the context of environmental (in)justice.[3] Using information about race and a variety of household characteristics from the American Community Survey, we make the case that bargaining failure is a concern. These results raise questions about the need for government regulation of the bargaining process (e.g., uniform lease terms), or greater regulation of environmental harms with "public" tools (i.e., stronger municipal ordinances).

This paper proceeds as follows. Section 2 reviews the relevant literatures that we draw upon. Section 3 describes the institutional and legal frameworks surrounding shale gas development in Texas. Section 4 motivates our empirical approach with a discussion of the Coase Theorem and its implications for bargaining outcomes. Section 5 describes our data, which combine a novel source of information about the outcomes of lease negotiations with proprietary data on housing transactions and publicly available data on the race and income of homeowners. Section 6 describes our empirical strategy and summarizes the results of our Coasian analysis. Section 7 outlines a hedonic model appropriate for the analysis of shale gas leases. We then use that model to measure the value placed on individual lease clauses by homeowners; results suggest that the distorted outcomes of lease negotiations described in Section 6 have pecuniary repercussions. Section 8 examines the role of lease clauses in the likelihood of violations committed by drillers, which we use as an indicator of risk faced by homeowners. Section 9 concludes with a discussion of our results and policy implications.

[3] For a useful survey of the environmental justice literature, see Banzhaf (2012).

2. Literature Review

In this paper, we analyze the determinants of the bargaining outcome associated with the leasing of rights for development of shale gas. In particular, we explore whether lease negotiations exhibit characteristics consistent with efficient Coasian bargaining, or whether other factors (e.g., race) play a role; in particular, we demonstrate that, after controlling for income, race is correlated with factors (e.g., education, English language skill) that affect information and bargaining ability. Our work is therefore related to the literatures on the Coase Theorem, environmental justice, and several literatures on the development of shale gas resources.

2.1 Coasian Bargaining

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

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

Jenkins, Maguire and Morgan (2004) take the size of the externality as given and model the determinants of the compensation payment. Our analysis differs in that we model the results of the negotiation over the level of the externality itself, and the subsequent division of the Coasian surplus. We argue in Section 4 that it is in the former where one should look for evidence of efficiency or inefficiency in the bargaining process.

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

2.2 Environmental Justice

The environmental justice literature has sought to document and explain disproportionate exposure to environmental harm for disadvantaged groups. The emergence of the modern environmental justice movement is associated with a series of protests that followed the selection of a landfill site in the predominantly African-American community of Warren County, North Carolina in 1982 for the disposal of PCB's that had been illegally dumped along roadways in fourteen N.C. counties (Bullard 1994). These protests were organized, in part, by the United Church of Christ's Commission for Racial Justice, which went on to author the first national-level analysis documenting the correlation between race and hazardous waste (UCC 1987). These protests also prompted the U.S. General Accounting Office to carry out a study in 1983 showing that landfills were disproportionately located in black communities in the U.S. South. US GAO

(1983) and UCC (1987) were followed by a series of papers that demonstrated the correlation between race, poverty and exposure to environmental harm (Bullard 1990, Mohai & Bryant 1992, Brown 1995, Szasz & Mueser 1997, Boer et al. 1997, Sadd et al. 1999, Ringquist 2005). These studies found a significant disparity in proximity by race (even after controlling for income), local land use patterns, the percentage of employees in manufacturing, population density, and other relevant variables. Other analyses focused specifically on risk-based measures of pollution exposure rather than proximity, but found similar results (Morello et al. 2001, Pastor et al. 2002, Bouwes et al. 2003, Ash and Fetter 2002 & 2004, Morello-Frosch and Jesdale 2006). In 2007, the UCC updated its 1987 analysis using information on hazardous waste facility locations and demographic data from the 2000 Census, finding that poor and minority groups were even more heavily concentrated around hazardous facilities than had been previously thought.

Analyses documenting the correlation between environmental harms and disadvantaged status (i.e., race and income) form the first strand of the environmental justice literature. A second strand seeks to explain the mechanism behind those correlations (Been 1994). Understanding that mechanism is crucial for the design of effective policy. One story explains correlations as the result of the siting of nuisances, paying particular attention to the demographics at the time of siting (Hamilton 1995, Arora & Cason 1999, Bullard 2000, Cole and Foster 2001, Saha & Mohai 2005, Wolverton 2010). A second story focuses instead on residential sorting – i.e., the tendency for disadvantaged groups to move into polluted areas where residences are less expensive ("coming to the nuisance"); see, for example, Been and Gupta (1997) and Depro, Timmins and O'Neil (2014).[4]

[4] There are a number of papers that directly compare the siting and sorting explanations. Pastor et al. (2001) show that, over a 30-year period, the correspondence between polluting facilities and minority communities in Los Angeles was based primarily on a pattern of disparate siting of facilities in existing communities of color, rather than on geographic shifts in these populations. Morello-Frosch et al. (2002) also find evidence of disproportionate siting,

We are not aware of any existing analyses of shale gas development from the perspective of environmental justice (either documenting or explaining the causes of disproportionate exposure). Similar to the first "strand" of the EJ literature, our paper seeks to document the existence of correlation between race, income and negotiated lease terms, and to then demonstrate that this correlation is consequential both in pecuniary terms and in terms of subsequent risks faced by homeowners.

2.3 Shale Gas

2.3.1 Housing Values

Hedonic models describe how homebuyers choose houses based on property and neighborhood characteristics. That choice process provides a theoretical construct with which to connect observed market outcomes to individual preferences, facilitating the measurement of welfare effects. Measuring the impacts of shale gas activity on property values is therefore one way to quantify its welfare effects. There has been limited prior research into how gas drilling affects nearby property values. A few notable exceptions include Boxall et al. (2005), who focus on sour gas wells in Alberta, and Klaiber and Gopalakrishnan (2012), who measure the temporal impact of shale gas wells in Washington County, Pennsylvania. Muehlenbachs et al. (2014) use data from all of Pennsylvania to conduct a triple-difference analysis of the effect of shale gas development on groundwater dependent homes, along with a double-difference analysis of the effect on all nearby homes regardless of water source. While that paper finds some evidence of small gains for houses dependent upon public water sources (likely from lease payments) it finds evidence of significant negative net effects on groundwater dependent houses. Other research has

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but no evidence of sorting behavior. Depro, Timmins and O'Neil (2014) demonstrate that the model used in these papers to identify the sorting process is unidentified; imposing structure on the model to achieve identification, they find strong evidence in favor of the sorting hypothesis.

found similar evidence of concerns over risks to a household's water source (Throupe, Simons and Mao 2013), or negative effects on house values more generally (James and James 2014), although other researchers have found much smaller effects (Delgado, Guilfoos, and Boslett 2014).

2.3.2 Health

Many of the most important ramifications of exposure to shale gas development have to do with health impacts. This becomes relevant in Section 8, where we examine the effect of lease clauses on the likelihood of well violations, many of which may have consequences for health and safety. To date, there have only been a handful of studies of these impacts. Colborn et al. (2011) details potential health impacts to the brain and nervous system, kidneys, endocrine system, and the immune and cardiovascular systems, as well as increased risk of cancer or mutation from exposure to the chemicals used in large-scale hydraulic fracturing operations. McKenzie et al. (2012) compares cancer risks from air emissions inside and outside of a ½ mile buffer around wells in Colorado, with a focus on benzene. Bamberger and Oswald (2012) use case-study interviews to document health impacts on humans and animals living near shale gas development, finding common reports of respiratory, gastrointestinal, dermatological and neurological problems.

Hill (2013) studies birth outcomes to mothers of singleton infants located in close proximity to wells in Pennsylvania between 2003 and 2010. Using a difference-in-differences strategy for identification, she finds dramatic impacts for mothers who reside within 2.5km of a well (relative to those in a control group consisting of mothers in the 2.5-5km distance range). Specifically, she finds an increased risk of low birth weight (+1.36 percentage points) and APGAR score less than 8 (+2.51 percentage points). An examination of household water source suggests that these impacts are driven by air pollution or stress from increased local activity (e.g., noise and light pollution), and falsification tests rule out alternative explanations besides drilling.

3. Legal and Institutional Detail

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

3.1 Hydraulic Fracturing and Horizontal Drilling

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

3.2 The Texas Railroad Commission and State-Level Regulation

The Texas Railroad Commission (TRC) oversees the majority of the oil and natural gas industry in the state of Texas, which includes the approval of permits to drill wells.[5] However, prior to permit approval, firms must first amass a large and sufficient mineral estate acreage that is spaced far enough away from existing well infrastructure to be approved and permitted by the TRC.[6] Natural gas firms obtain mineral estate acreage by signing leases with sets of mineral rights owners or by purchasing signed leases from third party "landmen." Households signing leases with natural gas firms or landmen are tasked with weighing the trade-offs between future income paid in the form of royalties and the potential risks of living near an active well. Once a well is permitted with the TRC, the operator typically has two to three years to begin drilling the well before the permit expires.

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

More specifically, federal and state regulators generally do not have direct jurisdiction over the private contracts drawn between landowners and parties interested in leasing land for exploration and production of oil and natural gas. Higher-level regulation is limited to royalty payments (stipulating when they are to be paid), the required information that must be provided

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

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

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

3.3 Municipal Regulation

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

Local ordinances are rendered preempted (or essentially invalid) if state-level legislation limits local power directly (expressed preemption); the state rules already occupy the field even though the language is not specific to that expressed by the local ordinance[7] (implied preemption); or if those rules conflict with existing state laws (Urban Lawyer, 545-546). The last of these usually restricts local zoning ordinances that loosen state rules, but in the event that local ordinances are stricter that state laws, the local ordinances are upheld.

3.4 Lease Components

Signing a comprehensive leasing document is important for households protecting their rights while they are royalty interest holders. In particular, lease terms can compensate for the absence of state or municipal regulations. Leasing agreements contain a set of *primary clauses* that are common to all leases drawn in the industry, and may also contain combinations of *auxiliary clauses* that are negotiable between lessors (mineral rights owners) and lessees (exploration and oil and natural gas production firms). Primary clauses include a careful description of the minerals leased to the lessee, information about the royalty payments owed to the lessor once the well begins to produce in paying quantities, the duration of the lease (i.e., primary term), and opportunities for extension once the primary term has expired. Auxiliary clauses are written into the agreement to protect one or both of the parties, but may not be included in all leases. Negotiators may draft surface damage clauses ensuring, for example, that the operator restores the surface to an agreed-upon condition once production is complete, environmental clauses restricting chemicals or requiring regular environmental quality tests on the surface water, ground water, or soil samples, and pooling restrictions ensuring that the leased land

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

value is not diluted in terms of by being grouped into an unnecessarily large acreage.

3.5 Split Estate

Up to this point, we have assumed that the signer of the lease is the household, or surface-rights owner; however, the state of Texas allows the mineral estate to be split (or "severed") from the surface estate. The individual signing a lease with a natural gas firm may not, therefore, be the individual living in the house positioned on the surface estate. As early as 1953, Texas courts declared that landowners may reserve mineral rights and the oil and gas contained as in the case Benge v. Scharbauer [259 S.W.2d 166 (Tex. 1953)], thereby enabling the mineral estate to be severed from the surface estate (Merrill, 19).[8] In the event of severance, the mineral estate dominates in terms of exploration and extraction, and the mineral lessee assumes the same rights owed to the mineral estate owner since the leasing document is perceived as a temporary transference of ownership.[9] Colloquially, the owner of the mineral estate may lease the minerals to third parties for exploration, but law only requires that the lessee (i) notify surface owners of the "intent to explore and drill;" (ii) have access to as much land as is necessary to explore and drill; (iii) remove trees and fences to make way for well and equipment; (iv) take up to one acre of land for the well pad; and (v) erect pipelines to transport the natural gas off the property (Rahm, 2979).[10]

As an independent entity, the mineral estate may exercise its rights without consulting the

[8] A grant or reservation of minerals by the fee owner affects a horizontal severance and the creation of two separate and distinct estates: an estate in the surface and an estate in the minerals [Acker v. Guinn, 464 S.W.2d 348, 352 (Tex. 1971)] (Fields, 1).

[9] If the minerals are not reserved at the sale date, the mineral estate automatically goes to the buyer along with the surface conveyance (Fambrough, 4).

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

surface estate owners. Subsequently, a firm leasing the mineral rights for purposes of oil and gas exploration and extraction need only negotiate with the mineral estate owners, whether they also own the surface estate or not. The owners of the mineral estate are only required to inform the surface estate when drilling is imminent on their property due to legislation passed in 2007 (Maxwell, 347).[11] Additionally, the mineral estate may use as much surface water from the leased land as is reasonably necessary to carry out operations, given that the use is not wasteful, and it may inject wastewater into sub-surface formations.[12] (Warren Petroleum Corp. v. Martin, 271 S.W.2d 410 (Tex. 1954)) Moreover, the mineral estate does not accept responsibility for the full restoration of the property (Warren Petroleum Corp. v. Monzingo, 304 S.W.2d 362 (Tex. 1957)), nor is it required to pay surface damages as long as the damage is not unreasonable. Texas has not passed a surface damage act to protect the surface estate, as has been passed in other states with prominent oil and natural gas industries (including New Mexico, Oklahoma, North and South Dakotas, and Montana). As mentioned above, surface owners are not owed any remuneration for the opportunity cost of the lost piece of their property during the drilling period nor must they be paid for reasonable damages to the land caused by drilling. If there is any perceived misuse of the land by mineral rights owners, surface owners are responsible for proving unreasonable conduct, which does not include surface damage or inconvenience. Surface owners are marginally protected by the Accommodation Doctrine, which protects existing surface owner uses.[13]

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

[12] 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, 238).

[13] Accommodation Doctrine: [W]here there is an existing use by the surface owner which would otherwise be precluded or impaired, and where under the established practices in the industry there are alternatives available to the [mineral owner] whereby the minerals can be recovered, the rules of reasonable usage of the surface may require the adoption of an alternative by the [mineral owner]. (Tarrant County Water Control & Improvement Dist. No. 1 v. Haupt, Inc., 854 S.W.2d 909, 911 (Tex. 1993)) (Merrill, 26).

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

4. Coasian Bargaining

For the purposes of modeling the theory surrounding lease negotiations, it is sufficient to group clauses into a few broad categories. These include clauses associated with the surface estate (e.g., restrictions on chemicals that might be used on the drilling site, limits on noise levels, restrictions on surface access or use of local water sources, or requirements to remediate surface damages after drilling is complete) and clauses associated with the mineral estate (e.g., royalty, lease term, Pugh clause, force majeure, and clauses related to the payment of attorney fees). Similarly, considering the attributes of households engaged in bargaining, we differentiate between two categories – those which describe characteristics that affect willingness to pay to avoid harms (e.g., income), denoted by Z_1, and those which describes other household characteristics (e.g., race), denoted by Z_2. Based on the way we define these vectors, we would expect each household's marginal external cost (MEC) from the externalities associated with drilling to be a function of Z_1 but not Z_2.

Figure 1 describes bargaining over a particular source of local disamenity, denoted by *X*. For example, *X* could refer to noise from drilling operations measured in decibels. It could also measure surface damage, or exposure to environmental harms; a separate graph could be drawn for each sources of nuisance. Treating X as decibels, MB_X represents the firm's marginal benefit from making additional noise. This marginal benefit is positive (i.e., abating noise on the drilling site requires the application of mufflers, which increases cost), but the marginal cost of noise reduction declines as decibels rise. We assume for simplicity of exposition that MB_X is a linear function.

There is a category of lease term that is associated with noise reduction; we assume that this is a discrete muffler technology that can either be implemented or not. Without a noise clause, the operator would choose to produce noise equal to X_0, where the marginal benefit of an additional decibel reaches zero. With a noise clause, the level of noise would drop to X_1; i.e., the reduction in noise associated with the clause corresponds to the adoption of the standard muffler technology.

MEC^* is used to denote a marginal external cost curve that crosses the operator's MB_X function exactly halfway between X_0 and X_1. Each household negotiating with the operator will have its own value of MEC that could be higher or lower than MEC^*. MEC^* is important, however, as under simple bargaining conditions, the operator will choose to adopt the noise clause in a lease negotiated with any household with $MEC > MEC^*$. To see why this is the case, begin by noting that, in the absence of any agreement, the household has property rights and the operator is limited to producing no noise. The operator would, of course, prefer to sign a noise clause and produce X_1, compensating the household with an amount at least as great as area B. In deciding whether to forego the noise clause and increase decibels to X_0, the operator compares the additional benefit from avoided noise abatement (C+D) to the minimum required compensation payment (D+E). Assuming MB_X is linear, C = E and these areas cancel each other out, making the operator indifferent between implementing and foregoing the clause. This is efficient. Society is equally indifferent – while a level of noise that equated MEC to MB_X would be an improvement, X_0 and X_1 (the only two options) are equally inefficient.

Of course, it is unlikely that any household will have a marginal external cost of noise that is exactly equal to MEC^*. If $MEC > MEC^*$, the new value of C < E and the value to the operator of extending noise to X_0 would be negative. The operator would choose to sign the noise clause and restrict noise to X_1. This would be efficient in the sense that, of the two feasible inefficient noise levels, X_1 yields a greater social surplus. A similar argument (in reverse) would lead to the noise clause not being implemented if $MEC < MEC^*$, which would also be efficient from a social point of view given the discrete options. The important point to take away from this example is that finding adoption of the noise clause to be an increasing function of variables that raise MEC (i.e., variables that increase willingness to pay to avoid *X*) is an indicator of efficient Coasian bargaining.

It is possible, however, for bargaining power to have a direct impact on the adoption of lease clauses, leading to inefficient lease clause adoption decisions. Suppose, for example, that (after controlling for income) race affects bargaining power, but not MEC (reasons could be because of differences in education, access to legal assistance, or outright discrimination). Suppose a household has $MEC = MEC^*$, but that its bargaining power is such that it is able to claim a substantial portion of the Coasian bargaining surplus associated with area C, along with requiring compensation of areas D and E in exchange for increasing decibels from X_1 to X_0. Society does not care about the distribution of surplus and is therefore indifferent to whether the noise clause is adopted or not, but the firm will choose to adopt the clause because the small portion of area C it claims by not adopting is not sufficient to offset the additional costs of compensation associated with area E – i.e., we get over-adoption from a social point of view. Conversely, if the household is particularly bad at bargaining, it might not even be able to recoup all of area (D+E) in compensation and, as such, the operator would not sign the noise clause even when society is indifferent to it, leading to under-adoption. The important point to take away from this example is that, after controlling for variables that affect MEC, finding adoption of the noise clause to be a function of variables (Z_2) that affect bargaining power is a sign of an inefficient bargaining outcome.

The previous arguments applied primarily to clauses that deal with the surface estate. Legal clauses, in contrast, deal primarily with the disposition of royalty payments and, hence, with the allocation of bargaining surplus. It would not be surprising to find that variables in (Z_2) affect this allocation even if bargaining were efficient from a Coasian perspective.

In deriving our estimating equation, for each lease clause category *k* we begin by specifying MEC_k^* as a function of the attributes of firm *j* (F_j), recognizing that those attributes affect the position of MB_k. Individual *i*'s MEC is modeled as a function of her attributes $Z_{1,i}$:

$$MEC^*_{j,k} = F_j'\gamma + \varepsilon_{1,j,k} \quad (1)$$

$$MEC_{i,k} = Z_{1,i}'\beta_1 + \varepsilon_{2,i.k} \quad (2)$$

Clause *k* is adopted if

$$Z'_{1,i}\beta_1 - F'_j\gamma \geq \underbrace{\varepsilon_{1,j,k} - \varepsilon_{2,i.k}}_{-u_{i,j,k}} \tag{3}$$

Assuming $\varepsilon_{1,i,k} \sim i.i.d.\,N(0,\sigma^2_{1,k})$, $\varepsilon_{2,j,k} \sim i.i.d.\,N(0,\sigma^2_{2,k})$ and $E[\varepsilon_{1,i,k},\varepsilon_{2,j,k}]=0$, and using $Y_{i,j,k}=1$ to denote adoption of clause *k* by individual *i* negotiating with firm *j* (= 0 otherwise), we estimate the following linear probability model:

$$Y_{i,j,k} = Z'_{1,i}\beta_1 - F'_j\gamma + u_{i,j,k} \tag{4}$$

Considering surface clauses, our test of Coasian bargaining efficiency simply includes elements of $Z_{2,i}$:

$$Y_{i,j,k} = Z'_{1,i}\beta_1 + Z'_{2,i}\beta_2 - F'_j\gamma + u_{i,j,k} \tag{5}$$

and we look for evidence that the hypothesis $H_0 : \beta_2 = 0$ can be rejected.

Our application considers a number of additional complications. In particular, it is likely that there are spillovers across different lease clauses on the same wellpad. For example, agreeing to an environmental clause may reduce the benefit to the firm from generating additional surface damage if the two are related in the production process. Given a value for MEC from surface damage, this would make the adoption of a surface damage clause more likely. Similarly, firms likely maximize profits not on a lease-by-lease basis, but rather simultaneously over all leases on a drilling permit, accounting for the fact that some inputs apply to multiple leases. For example, adopting an environmental clause on one lease may make the costs of adopting a similar clause on another lease much smaller. To deal with these potential complications, we estimate an equation that includes a vector of wellpad fixed effects.

5. DATA

Our analysis employs a unique combination of lease, well activity, violation, housing, and demographic data sets. This section details the sources of data and describes how certain variables are constructed. We have collected housing transaction and appraisal data from the Tarrant County Appraiser District office and Dataquick, a national real estate data aggregator. Dataquick data are utilized through a licensing agreement with Duke University. We link information about wells and leases to these data. Demographic information collected under the Home Mortgage Disclosure Act (HMDA) and drilling, inspection, and violation data from the Texas Railroad Commission are used as well. Finally, we have generated a variable identifying leases where the mineral estate is likely split from the surface estate.

5.1 Housing Data

The housing data is the nexus for several connections between our data sources. In particular, leases are merged to the housing data by address using various string matching methods. The housing data are merged to the HMDA data by lender name, loan amount, and a geographic identifier. Well information, and the associated violation and inspection information, is matched to the housing data using GIS mapping tools.

We use appraiser data describing the household attributes compiled from the Tarrant County Appraiser District (TAD) office and Dataquick, Inc. TAD provides us with historical records that document appraisals up to the present in addition to a file delineating all transactions in Tarrant County. We begin our sample with all appraisals occurring in 2003. We use this data to construct a cross-section of appraised values for each property. TAD also provides us with information on the house's water source (groundwater v. piped). We merge the TAD data with Dataquick, which serves as our source of loan information (lender name, loan amount, FHA loan indicator). By merging appraisal data with transaction information from Dataquick, we are also able to incorporate demographic information on the residents of the house at each appraisal date using the Home Mortgage Disclosure Act data, a match that will be described in more detail below. These merges, and merges associated with leases described below, are carried out using string matching methods described in Appendix A. Table 1 summarizes housing attributes in our full sample.

5.2 Lease Data

The lease and lease contents are a primary and unique source of data used to describe the outcome of the Coasian bargaining process. A lease is a contract drawn between two parties – the lessee (i.e., who is typically an operator or third party 'landman') and the lessor (i.e., the owner of the royalty interest, who is also the owner of the surface rights in the case of a full estate).[14] Signing the lease conveys the interests of the mineral estate from the lessor to the lessee. We have collected data describing the terms of these privately negotiated lease contracts. In particular, we have data describing the primary clauses (i.e., royalty rate and lease term) of all natural gas leases negotiated in Tarrant County, Texas between 2000 and 2013.

In addition to the primary clauses contained in the leasing agreements, we have also

[14] Full estates are sometimes referred to as fee-simple, or whole, estates.

collected auxiliary clauses for one third of the sample. The data period for auxiliary clauses with a large enough sample size begins in 2006 and ends in 2011. Our specific sample was collected from the "Drilling Down Series"[15] published by the *New York Times* from 2011 into 2012. We scraped these data and then mined the files for words and phrases indicating the existence of certain clauses using an algorithm written in *Python*. This is described in Appendix B. We use fifteen different auxiliary lease clause categories in our analysis. A list of these clauses, variable names used in the analysis, and clause descriptions is included in Appendix C.

The auxiliary lease clauses fall into several broad categories including strict legal requirements, clearer definitions of liability, additional environmental requirements, requirements for increased reporting by the lessee to the lessor regarding well activity, and restrictions on how a firm can access the mineral estate. A particularly important clause in Texas is the surface damage clause, which we capture by searching for phrases describing cleanup efforts and damage remediation. Surface owners are not owed any remuneration for the opportunity cost of the lost piece of their property during the drilling period or for reasonable damages to the land caused by drilling. If there is any perceived misuse of the land by mineral rights owners, surface owners are responsible for proving unreasonable conduct that does not include surface damage or inconvenience. Surface owners are marginally protected by the Accommodation Doctrine, which protects existing surface owner use.[16] Mineral rights owners can negotiate a surface damage clause into the leasing agreement to protect the surface and use during production and ensure remediation after production ends.

Table 2 summarizes primary clauses (royalty rate and term length in months) along with fifteen different auxiliary clauses that we use in our analysis.

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

[16] If there exist alternative extraction methods, then reasonable usage might require a change on the part of the lessee under the Accommodation Doctrine (Vanham, 240).

5.3 Well Exposure

Well permitting data are used to construct a variable describing well exposure from the perspective of the household at the time of the appraisal. Well permitting information comes from two sources: the Texas Railroad Commission and Drilling Info, a proprietary aggregator of drilling activity accessed through Duke University's Energy Institute. Exposure is tabulated at different distance buffers surrounding the house, and if an operator has begun drilling a well by the appraisal date, the well is included in the exposure variable. We tabulate exposure based on 500, 750, 1000, and 2000-meter buffers, and the calculation differentiates between wells that are permitted, spudded, and producing. The primary exposure variable used in our analysis is the count of wells that have either been spudded or are producing in a 2000-meter buffer. Table 3 summarizes well exposure over time, revealing the dramatic growth in shale gas development in Tarrant County between 2003 and 2013.

5.4 Home Mortgage Disclosure Act (HMDA)

To account for household income and race in our analysis, we merge the housing data to data collected in accordance with the Home Mortgage Disclosure Act (HMDA). This legislation was originally passed in 1975 and amended in 1989 to ensure fair and adequate lending and to limit discriminatory lending practices. The legislation requires mortgage companies to report information about the borrower and characteristics of the loan including the applicant's income, race, ethnicity, and gender, along with whether the loan is a second lien, variable or fixed rate mortgage, or backed by Federal Housing Administration (FHA) or Veterans Administration (VA). We merge HMDA to the housing data by matching the tract, lender name, and loan amount across

HMDA and Dataquick.

Table 4 summarizes the data on race, income, and housing appraisal value, highlighting the discrepancies between whites, blacks and Hispanics. We focus the majority of our discussion in the remainder of the paper on these three groups, who make up nearly 90% of the population in Tarrant County. We do not focus on Asians, who are a smaller minority with average income and house value similar to that of whites. We also do not focus on Native Americans and the "Other" race category, as they comprise a very small sample.

5.5 Violations Data

The next external source of data describes the well-level violations reported by the Texas Railroad Commission and dockets, both past and present, reviewed by the state regulator. The violation data are identified by the rule violated in Chapter 3 of the Texas Administrative Code, or the state-level regulations enforced by the TRC. None of these violations are a response to complaints from citizens; rather, they are the result of well inspections performed by TRC staff. Appendix D provides additional details on violations.

In the analysis, we tabulate the total accumulated number of violations assigned to each well, and then we merge the well violations to individual leases. The relevant violation types used in our analysis include improper identification of property, wells, and tanks, problems associated with Bradenhead pressure, and issues related to water protection. Table 5 summarizes the mean numbers of violations of each type.

5.6 Generation of Split Estate Identifier

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

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

Table 6 describes differences between houses and their leases depending upon the status of their mineral estate, and Table 7 reports the percentage of leases that are split by city within

Tarrant County. Table 8 describes lease clauses by the status of the mineral estate. Full estate leases are generally more likely to contain clauses that are beneficial to the lessor, although a large number of split estate leases contain these clauses as well.

5.7 Sample Compositions

Appendix E (still to come) describes how observations are selected from the raw data for use in the final analysis and what this implies for the composition of the sample.

6. EMPIRICAL MODEL

6.1 Analysis of Coasian Efficiency

Our empirical model treats each lease clause as a separate bargaining outcome, but allows for the fact that clauses were negotiated as part of a single bargaining process. As such, we combine the equations describing the outcomes of each lease clause into a system of Seemingly Unrelated Regressions, and results are described in Tables 9 – 12. Table 9 and 11 (a) and (b) describe lease clause outcomes for the sample of full estates, while Tables 10 and 12 (a) and (b) describe outcomes for split estates. The split estate estimations serve as a placebo test, as we would not expect the attributes of surface rights holders to matter for the contents of split estate leases. Tables 9 and 10 employ a simple specification that controls for house and homeowner attributes, along with vectors of firm, city, and year fixed effects. Tables 11 and 12 replace city fixed effects with wellpad fixed effects, which control in a flexible way for potential spillovers across leaseholders on a single lease bundle.

In each table, dependent variables are listed along the top row; each column represents a separate regression in the SUR system. Reported regression coefficients describe the impact of surface rights holder attributes on the likelihood of each clause being included in the lease. Lease clauses are generally defined to be "goods", in that inclusion should benefit the lessor, *ceteris paribus*; four exceptions are lease term, free surface water use, injection fluid, and subsurface easement.

Looking first at full estates without wellpad fixed effects in Tables 9 (a) and (b), we see strong effects of income on bargaining outcomes. Higher income translates into a higher royalty rate, a shorter lease term, a higher likelihood of indemnity, environmental, freshwater, top lease, force majeure, Pugh, attorney fee, noise, no surface access and drillcore reporting clauses. Higher income is also correlated with a lower likelihood of a subsurface easement clause.

Coefficients on the indicator for groundwater are harder to interpret. We might expect groundwater dependent houses to be more sensitive to surface pollution, but groundwater may also serve as a proxy for other sociodemographic variables. Surprisingly, groundwater dependent households are less likely to have surface damage and no surface access clauses. However, they are also less likely to have free surface water use and subsurface easement clauses. Groundwater is not a significant determinant of freshwater protection or environmental clauses.

Turning to race, we see clear and consistent effects of being black or Hispanic on lease outcomes, *conditional upon income*. In line with the conclusion that race affects negotiations over bargaining surplus, blacks and Hispanics are less likely to have top lease, force majeure, Pugh, indemnity, or attorney fee clauses. They both have longer lease terms, and Hispanics have smaller royalty rates. Looking at surface clauses, both groups are less likely to have environmental and noise clauses, and they are both more likely to have injection fluid and subsurface easement clauses. Hispanics are less likely to have a restriction on compression stations, and blacks are less likely to have a no surface access clause. The one result that goes against this otherwise consistent narrative is that Hispanics are more likely to have a surface damage clause.

Tables 11 (a) and (b) again consider the full estate sample but add wellpad fixed effects in order to control for any factors that are common across all leases on the same permit bundle. If, for example, Hispanics are less likely to negotiate for a certain clause and provision of that clause to one lessor makes it less costly to provide the same clause to other lessors, the percentage of Hispanics on the bundle could be an important determinant of an individual lessor's bargaining outcome. Wellpad fixed effects control for this, and any other, wellpad-level variable. Even with these controls, we see that many of the important results found in Tables 9 (a) and (b) persist. In particular, income is still an important determinant of royalty rate and lease term along with indemnity, environment, top lease, Pugh, attorney fee, noise and subsurface easement clauses. Whereas it did not have a strong effect on free surface water use and injection fluid in the simpler specifications, higher income now raises the likelihood of those clauses. Groundwater dependency continues to yield mixed results, reducing the likelihood of an injection fluid clause, but also reducing the likelihood of environmental or surface damage clauses.

Turning to race, we still find evidence that disadvantaged minority status is important to bargaining outcomes, even after controlling for income and wellpad fixed effects. Blacks and Hispanics have longer lease terms, are less likely to have environmental, top lease, Pugh, and attorney fee clauses. Hispanics, moreover, are less likely to have indemnity, force majeure, and noise, and compression station restriction clauses, and are more likely to have injection fluid and subsurface easement clauses. While Hispanics are still more likely to have surface damage clauses, blacks are less likely to have them once wellpad fixed effects are included.

Turning to the split estate samples, we focus on Tables 12 (a) and (b), which incorporate wellpad fixed effects. These results function as a placebo test, as we would not expect to see any impact of house or homeowner (i.e., surface rights holder) attributes on the bargaining outcome. Indeed, groundwater dependency no longer matters for any lease outcome. Income has a statistically weak effect on the likelihood of an environmental or attorney fee clause; surprisingly, it does have a stronger impact on the likelihood or a Pugh or compression station restriction clause. Hispanic race has only a weak statistical effect on the likelihood of force majeure, injection fluid, and Pugh clauses, and black race only matters for the likelihood of Pugh, attorney fee, and noise clauses. Some of these race effects, moreover, have counterintuitive signs and may be the result of outliers.

6.2 Explanations

We next consider a number of explanations for the race effects found in Tables 9 – 12. Interpreting race effects as a failure of efficient Coasian bargaining requires that they impact bargaining power, but not willingness to pay. In simple terms, willingness to pay to avoid the disamenities associated with environmental harm should not be a function of race after controlling for income. Tables 13 (a) and (b) examine what variables are explained by race after controlling for income, using a series of regressions using data from the 2012 ACS. This data allows us to identify specific individuals living in Tarrant County along with their PUMA of residence and to observe a variety of individual characteristics.[17] Focusing on household heads who own their homes (i.e., a sample similar to that which we have constructed using HMDA and Dataquick), we see, for example, that Hispanics tend to have more children under the age of 5. This might present a concern in that we would expect this variable to impact willingness to pay to avoid environmental harms. However, in this case, that attribute works in our favor – in particular, we

[17] These data were downloaded from https://usa.ipums.org/usa/.

would expect a Hispanic household with young children to have a *greater* MEC from environmental harm, making them *more* likely to negotiate for an environment clause. We find just the opposite in our analysis of bargaining outcomes, however, strongly suggesting a Coasian failure.

Considering other attributes, blacks are less likely to have a male household head and Hispanic household heads are likely to be younger. It is unclear what, if any, effect these variables would have on MEC. Hispanic household heads are significantly more likely to not "speak English well", and are more likely to be in the lower tail of the distribution of educational outcomes. These variables (particularly English speaking ability) can be interpreted as an indication of an informational disadvantage in the lease bargaining process. Asymmetric information is a standard explanation of Coasian bargaining failure.

6.3 Bonus Payments

We next estimate a model using the sample of 965 leases where we both (i) observe a reported bonus payment and (ii) can match the lease to Dataquick and HMDA (allowing us to record the race and income of the household that negotiated the lease). The goal of this analysis is to demonstrate that these bonus payments are not being used as a source of compensation that offsets the systematically worse lease terms received by poor and minority households. Specifically, we regress bonus payments on income, race, and vectors of city, firm and year fixed effects. In some specifications, we also include a groundwater indicator along with living area and land area (bonus payments are typically done on a per-acre basis). The results are reported in Table 14. We find that there is indeed no such bonus compensation for blacks and Hispanics. When bonuses are expressed in levels, these two groups receive significantly lower bonus payments than whites. Considering the log of bonus payments, this result is significant in two out of four specifications.

7. Hedonic Analysis

In this section, we use information from the housing market to determine the values ascribed to each of the different lease clauses described above. The goal is both to provide one-half of the input for cost-benefit analysis of different forms of *de facto* regulations carried out through leases, and to determine whether the outcomes of lease negotiations have pecuniary implications for homeowners. Mineral leases have the potential to affect utility in two ways – both directly, through the provision of royalty payments, and indirectly, through the restrictions imposed on the actions of operators. For full estates, we demonstrate that this requires two gradients to describe the total impact of lease clauses on utility, and go on to show how full and split estate households can be used together to recover willingness to pay estimates.

First, consider royalties, which provide direct payments to homeowners in the case of full estates, and payment to absentee mineral rights holders in the case of split estates. Royalty payments are determined along with other clauses as part of a lease negotiation process conducted between the drilling company or a third-party "landman" and a current or previous owner of the house – i.e., we are now modeling the tradeoffs made by the buyers of houses that already have wells and leases, not the negotiation of those leases. Complicating matters, bargaining over lease attributes at the time of signing may have included royalties, lease term, legal and environmental clauses, and a bonus payment. The bonus payment, however, is a one-time payment that is not capitalized into the value of the house. Because of the bonus payment, the relationship between royalty payments and the various lease clauses may not directly reflect the preferences of the original lessor, yet it is still reflects tradeoffs required of subsequent homeonwers. We therefore take it as an exogenous constraint facing the buyers of homes with mineral leases.

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

$$\max_{\{X,H,\sigma,\mu\}} \quad U(X,H,\sigma) \quad s.t. \quad X + P(\sigma,H) = I + \alpha(\mu)R(\sigma,H) \tag{1}$$

σ	lease clauses related to the surface estate
μ	lease clauses related to the mineral estate
H	vector of house (and neighborhood) attributes, including property area
$P(\sigma,H)$	annualized house value (appraisal value $\times$ 5%)
$R(\sigma,H)$	royalty rate $\times$ land area ($R = R(\sigma,H)$ if fee simple mineral rights; $R = 0$ if split estate)
$\alpha(\mu)$	scale parameter making royalty payments comparable to annualized house price in budget constraint
I	exogenous income (i.e., not including royalty payments)
X	numeraire commodity ($P_X = 1$)

H includes both the traditional list of house attributes (square footage, number of bedrooms and bathrooms, lot-size, water source), but also include a vector of municipal dummy variables (i.e., to proxy for local public goods) and a measure of well exposure (i.e., number of spudded wells within 2km). The appraisal value, $P(\sigma, H)$, is a function of these house attributes as well as the vector of surface clauses, σ, contained in the house's lease – exposure to a nearby well means something very different for house value if that well is subject to a noise restriction v. a case where it is not.

$R(\sigma, H)$ is a simple proxy for royalty payments; it is measured by the royalty rate (which typically varies between 0.2 and 0.25) multiplied by land area (measured in $ft^2/1000$). We allow this proxy to vary with surface clauses, σ, as they were jointly negotiated by the mineral rights holder and firm at the time when the lease was signed. A scale parameter, $\alpha(\mu)$, converts the proxy for royalty payments into units comparable with annualized house price. We allow $\alpha(\mu)$ to be a function of clauses related to the mineral estate, as these may impact the flow of royalty payments over time. In the current application, we model $\alpha(\mu)$ as a function of term length (measured in months) – $\alpha(\mu) = \alpha_0 + \alpha_1 TERM$. We would expect $\alpha_1 < 0$ as a longer lease term raises the potential for flow of royalty payments to be postponed. Other variables that might enter into $\alpha(\mu)$ include Pugh clause, force majeure, and top leasing.

Optimizing over the choice of *X* yields indirect utility:

$$\text{Full Estate: } V^F(I + \alpha(\mu)R(\sigma, H) - P(\sigma, H), \sigma, H) \quad (2)$$

$$\text{Split Estate: } V^S(I - P(\sigma, H), \sigma, H) \quad (3)$$

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

$$\frac{\partial V^F}{\partial X}\left[\alpha_0 \frac{dR}{d\sigma}\bigg|_F + \alpha_1\left(TERM\frac{dR}{d\sigma}\bigg|_F + \frac{dTERM}{d\sigma}\bigg|_F R\right) - \frac{dP}{d\sigma}\bigg|_F\right] + \frac{\partial V^F}{\partial \sigma} = 0$$

$$WTP_\sigma^F = \frac{\partial V^F / \partial \sigma}{\partial V^F / \partial X} = \left[\frac{dP}{d\sigma}\bigg|_F - \alpha_0 \frac{dR}{d\sigma}\bigg|_F - \alpha_1\left(TERM\frac{dR}{d\sigma}\bigg|_F + \frac{dTERM}{d\sigma}\bigg|_F R\right)\right] \tag{4}$$

For split-estate households:

$$\frac{\partial V^S}{\partial X}\left(-\frac{\partial P}{\partial q}\bigg|_S\right) + \frac{\partial V^S}{\partial q} = 0$$

$$WTP_q^S = \frac{\partial V^S / \partial q}{\partial V^S / \partial X} = \frac{\partial P}{\partial q}\bigg|_S \tag{5}$$

The practical problem is that we do not know the values of α_0 and α_1 that comprise the scaling parameter that determines how royalty $\times$ area is combined with house price in the budget constraint. Importantly, if we impose the constraint that all homebuyers have the same willingness to pay for surface clauses, we can combine the information from split and full estate homes to overcome this problem. Begin by writing down a hedonic price function for each type of house:

$$\text{Full Estate:} \quad P_i = \beta_0 + H_i'\beta_1 + \sigma_i'\beta_2 + \varepsilon_i \tag{6}$$

$$\text{Split Estate:} \quad P_i = \theta_0 + H_i'\theta_1 + \sigma_i'\theta_2 + \varsigma_i \tag{7}$$

Importantly, legal clauses do not have an impact on the surface estate and therefore are not capitalized into the value of the split-estate property. The royalty equation only applies to full-estate homes:

$$\text{Full Estate:} \quad R_i = \rho_0 + \sigma_i' \rho_2 + \omega_i \tag{8}$$

$$\text{Split Estate:} \quad R_i = 0 \tag{9}$$

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

$$\theta_1 = \beta_1 \tag{10}$$

$$\theta_2 = \beta_2 - \alpha_0 \left.\frac{dR}{d\sigma}\right|_F - \alpha_1 \left(TERM \left.\frac{dR}{d\sigma}\right|_F + \left.\frac{dTERM}{d\sigma}\right|_F R \right) \tag{11}$$

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

$$\begin{aligned} P_i = {} & \beta_0(1-s_i) + \theta_0 s_i + H_i'\beta_1 + (1-s_i)\sigma_i'\beta_2 \\ & + s_i\sigma_i' \underbrace{\left(\beta_2 - \alpha_0 \left.\frac{dR}{d\sigma}\right|_F - \alpha_1 \left(TERM_i \left.\frac{dR}{d\sigma}\right|_F + \left.\frac{dTERM}{d\sigma}\right|_F R_i \right) \right)}_{\theta_2} + \upsilon_i \end{aligned} \tag{12}$$

$$R_i = \rho_0(1-s_i) + (1-s_i)\sigma_i'\rho_2 + \zeta_i \qquad (13)$$

Table 15 reports the results of a regression of term length (in months) on surface clauses, which provides estimates of $\frac{dTERM}{d\sigma}$ for use in equation (12). Our estimated values of α_0 and α_1 are 965.24 (482.65) and -0.89 (4.67), respectively (with robust standard errors in parentheses). Tables 16 and 17 report estimates of the remaining parameters associated with equations (12) and (13). The value of household attributes can be seen by looking at the first ten rows of the column labeled Appraisal (Full) in Table 16. With the exception of house age, all of these estimates are statistically significant and have the expected signs. The values of surface clauses are most easily seen by looking at the Appraisal (Split) column. These are constructed values based on the constraint described in equation (11), and represent the willingness to pay for each clause of both split and full estate house owners. Willingnesses to pay for all clauses exhibit the expected sign and, with the exception of the injection fluid, all are statistically significant as well. The most valuable surface clauses are freshwater protection (+\$691.06) and restrictions on compression stations (+\$2,440.98). The most costly clause is that which allows for surface water use (-\$733.65) followed by subsurface easement (-\$200.82).

We also include controls for year and city, as well as a vector of dummy variables indicating the identity of the firm leasing the mineral rights, in the appraisal equation. Vectors of firm and year fixed effects are included in the royalty rate equation as well. These estimates are reported in Table 17. In nearly all cases, these estimates are statistically significant (the only exception is in the year effects on royalty rates, where rates were only significantly lower in the first year). City fixed effect estimates capture significant variation in local public goods (possibly explaining our difficulties in estimating a sensible coefficient on reading test scores)

8. Violations

In this section we report results using data on wellpad violations. In particular, we describe the relationship between surface-oriented lease clauses and the likelihood of nearby violations as reported in data from Texas Railroad Commission. These results are based on indicators of three types of violations – Bradenhead pressure; property, well and tank IDs; and water protection – occurring within 2000 meters of a household as of the time of the appraisal date. Appendix D describes these violation categories in more detail. Probit specifications regress the incidence of a violation of a particular type on the set of lease clauses and fixed effects describing city, firm, and year. A negative coefficient suggests the occurrence of a particular clause decreases the frequency a particular violation occurs within close proximity to the mineral estate. Table 18 reports the results of these violation regressions. As might be expected, environmental and freshwater protection clauses both play an important role in avoiding water protection violations. The same is true of compression station restrictions. A subsurface easement clause, conversely increases the likelihood of a water protection violation. Property, well and tank ID violations behave similarly to water protection violations. Like water protection, the likelihood of a Bradenhead pressure violation is reduced by a freshwater protection or compression station restriction clause, but is increased by the presence of an environmental clause.

9. Conclusions and Policy Implications

We analyze the outcomes of the bargaining process used to assign rights to shale gas development. With the dramatic growth of shale gas in the U.S. over the last decade, lease negotiations have become an important part of the energy landscape. The royalties they provide constitute an important potential source of benefits for homeowners. There are, however, many negative externalities associated with living near a shale gas well. Much of the regulation that oversees the behavior of firms with respect to these externalities is actually negotiated between lessor and lessee. The bargaining process associated with this transfer of mineral rights shares many features of the classic Coasian bargaining framework. If bargaining is, in fact, Coasian, it would reduce the need for costly government regulation of the leasing process. If not, it would suggest a need for additional government oversight.

Using a unique combination of data sets, we test for whether the bargaining process does indeed exhibit characteristics of Coasian efficiency in one of the most active shale gas counties in the U.S. – Tarrant Co., Texas. Our results suggest that a number of important determinants of willingness-to-pay for avoiding shale gas development (e.g., income) do affect bargaining outcomes. This result is suggestive of bargaining efficiency – those who we would expect to have a larger willingness-to-pay to avoid exposure to shale development indeed negotiate for stronger lease terms. However, the story does not end there. The argument in favor of Coasian efficiency becomes harder to sustain when we find similar results for race. Conditional upon income, there is little reason to expect different race groups to have a different willingness-to-pay to avoid environmental harm (and to the extent that there is, analysis of corresponding census data suggests further inefficiency).

The question then arises as to what enables that injustice. One possibility would be the leverage that operators can exert in lease negotiations due to forced pooling. This is a topic that we are taking up in other research. A second possibility is that it is the result of information asymmetry. There are many of potential sources of information asymmetry that one could think of in the lease bargaining process, but the simplest (which is also most relevant for the most disadvantaged minority group) would likely be related to education or language, both of which exhibit correlations with minority status.

These differences in lease outcomes are consequential. We demonstrate that surface clauses are capitalized into home values, meaning that bargaining has pecuniary impacts. Moreover, we find that important categories of violations, including those related to water quality, the integrity of the well casing, and general wellpad operations, are related to the outcomes of lease negotiations, suggesting that bargaining could also have implications for health and welfare.

Moving forward, there are several alternative paths for communities tasked with negotiating leases because of new natural gas discoveries. Access to information about lease negotiation is increasingly available that details the potential terms and implications. Usually, these are documents drawn by attorneys that represent property owners, and reading this information decreases the asymmetry in information between property owners and firms that are likely seasoned negotiators.

More broadly, states could adopt uniform leasing standards whereby leases are required to have a minimum set of terms deemed fair to households relinquishing the rights to their subsurface minerals for natural gas extraction. Establishing a minimum requirement ensures that all households are protected up to a minimum threshold established by the regulating body that could be based on the experience of communities with currently active natural gas industries.

Uniform leasing is not yet observed in practice, however there is some evidence of communities adopting stricter regulations to oversee the natural gas industry and its treatment of the surface and subsurface estates during and after production. In Texas, local municipalities are already allowed to exercise “home rule”, which means that they can pass stricter rules governing firms operating within their jurisdictions. As it stands, these rules are more or less strict across cities, with some requiring additional environmental testing, remediation and protection of the landscape, local permitting standards, and restricting noise and the hours of operation.[18] These rules are often considerably more focused on how the surface and subsurface are treated during and after operations and benefit people living nearby. More uniform adoption of these rules by local municipalities protects urban communities, and stricter rules at the state level protect rural households, as well.

Leasing is a largely an unregulated aspect of the natural gas industry, enabling firms to potentially exercise superior knowledge and market power to extract rents from households by negotiating lenient lease terms. Disproportionately targeting certain types of households can exacerbate existing sources of inequality. Policymakers can address these problems by specifying minimal leasing requirements that protect quality of life among households living near wells and decrease exposure to risk. In the absence of such requirements, policies that restrict how the industry operates can increase overall welfare such that residents are not required to sacrifice safety and aesthetics in exchange for payments from minerals.

[18] In our analysis, we rely on municipal or wellpad fixed effects to control for these differences in local regulation. However, local regulations do vary over time in our sample. We focus on the specifics of these evolving regulations at the municipal level in other ongoing research.

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Table 1: Housing Attributes

	(1) Mean	(2) Obs.	(3) Std. Dev.
Appraisal value	132,092	215,002	92,820
House age (at appraisal)	23.57	214,683	22.28
Bathrooms	2.123	136,097	0.653
Bedrooms	3.378	136,097	0.699
Living area (sqft)	2,138	136,097	877.7
Land area (sqft)	10,185	136,097	7,580
Groundwater	0.637	136,097	0.481

Table 2: Lease Clause Summary (Primary and Auxiliary)

	Mean	Std Dev
Primary:		
Term months	41.86	11.83
Royalty	0.236	0.0420
Auxiliary:		
Injection Fluid	0.0268	0.161
Drillcore Reporting	0.0179	0.133
Force Majeure	0.563	0.496
Indemnity	0.420	0.494
Top lease	0.0939	0.292
Freshwater	0.0304	0.172
Pugh Clause	0.433	0.496
Attorney fees	0.0985	0.298
Free Surface Water Use	0.0137	0.116
Compression Station Restriction	0.00823	0.0904
No Surface Access	0.772	0.420
Surface Damage	0.737	0.440
Noise Restriction	0.338	0.473
Environmental Bundle	0.435	0.496
Subsurface Easement	0.564	0.496
Observations	11,660	

Table 3. Average Number of Wells Within 2000 Meters of House

	Mean	N	Std. Dev.
2003	0.444	1,887	1.126
2004	0.781	4,033	2.344
2005	1.558	4,818	3.543
2006	2.794	11,323	4.593
2007	3.008	16,007	5.296
2008	8.413	24,259	9.897
2009	7.664	16,267	8.659
2010	6.597	38,624	7.032
2011	6.681	56,532	5.912
2012	8.323	23,296	8.225
2013	9.349	17,956	7.909

Table 4. HMDA Summary

	Percentage	Appraisal Value	Income (1,000s)
Hispanic	0.146	82,259	54.05
Asian	0.0376	135,183	83.88
Black	0.0720	105,058	68.94
White	0.678	134,457	92.02
Obs.	42,652		

Table 5. Violation Summary Statistics

	Auxiliary Clause Sample	
	Mean	Std Dev
Id Property, Wells, Tanks	0.160	0.366
Bradenhead Pressure	0.058	0.234
Water Protection	0.040	0.197
N	66,545	

Table 6. House and Resident Attributes by Full/Split Estate

	Full Estate			Split Estate		
	Mean	N	Std Dev	Mean	N	Std Dev
House Attributes:						
Appraisal value	120,772	10,675	83,354	123,735	985	89,239
House age (at appraisal)	27.72	10,659	19.29	30.62	985	20.94
Bathroom	2.118	8,382	0.604	2.074	743	0.600
Bedroom	3.384	8,382	0.659	3.285	743	0.594
Living area (sqft)	2,083	8,382	821.2	1,982	743	779.1
Land area (sqft)	10,035	8,382	6,289	9,803	743	5,796
Groundwater	0.717	8,382	0.450	0.678	743	0.467
Exposure (well within 2k)	6.482	10,675	5.296	5.774	985	5.220
HMDA Characteristics:						
Hispanic	0.165	10,675	0.371	0.125	985	0.331
Asian	0.0416	10,676	0.200	0.0508	986	0.220
Black	0.0868	10,677	0.282	0.0548	987	0.228
White	0.665	10,678	0.472	0.728	988	0.445
Income (in 1,000s)	82.80	10,679	104.1	92.46	989	97.75

Table 7. Mean Split Estates by City

	Mean	N	Std Dev
Arlington	0.0735	3,512	0.261
Azle	0.162	37	0.374
Bedford	0.0972	144	0.297
Benbrook	0.109	266	0.312
Bluemound	0.667	3	0.577
Burleson	0.273	11	0.467
Colleyville	0.0769	39	0.270
Crowley	0.0645	62	0.248
Dalworthington	0.0370	27	0.192
Edgecliff Village	0.111	9	0.333
Euless	0.0991	232	0.299
Everman	0.0652	46	0.250
Foresthill	0.0750	80	0.265
Fort Worth	0.0978	3,651	0.297
Grand Prairie	0.0434	553	0.204
Grapevine	0.101	109	0.303
Haltom City	0.0461	369	0.210
Haslet	0.0	3	0
Hurst	0.0731	301	0.261
Keller	0.0871	287	0.282
Kennedale	0.0303	66	0.173
Lakeside	0.0	2	0
Lakeworth	0.0513	39	0.223
Mansfield	0.0809	742	0.273
North Richland Hills	0.106	583	0.309
Pantego	0.0	1	
Richland Hills	0.0308	130	0.173
River Oaks	0.100	20	0.308
Saginaw	0.0800	25	0.277
Sansom Park	0.0	5	0
Southlake	0.137	102	0.346
Watauga	0.125	136	0.332
Westworth Village	0.0	2	0
White Settlement	0.177	62	0.385

Table 8. Lease Clause Summary by Mineral Estate

	Full Estate		Split Estate		t-statistic
	Mean	Std Dev	Mean	Std Dev	(Full – Split)
Term months	41.993	11.597	40.476	14.083	3.860
Royalty	0.236	0.039	0.226	0.064	7.205
Injection fluid	0.027	0.162	0.022	0.148	0.886
Drillcore Reporting	0.018	0.132	0.020	0.141	-0.601
Force majeure	0.568	0.495	0.499	0.500	4.209
Indemnity	0.423	0.494	0.382	0.486	2.552
Top lease	0.095	0.293	0.082	0.274	1.305
Freshwater	0.014	0.117	0.014	0.118	-0.076
Pugh	0.439	0.496	0.364	0.481	4.534
Attorney fees	0.100	0.300	0.079	0.270	2.121
Free water	0.031	0.173	0.027	0.163	0.596
Compression Station Restriction	0.008	0.089	0.010	0.100	-0.705
Surface access restriction	0.036	0.187	0.045	0.206	-1.309
No surface access	0.774	0.418	0.736	0.441	2.752
Surface damage	0.740	0.439	0.710	0.454	2.070
Noise restriction	0.340	0.474	0.302	0.459	2.467
Environmental	0.440	0.496	0.372	0.484	4.119
Subsurface easement	0.563	0.496	0.572	0.495	-0.552
Observations	10,675		985		

Table 9(a). Determinants of Lease Clauses (SUR), Full Estate Sample

VARIABLES	Royalty (%)	Lease Term (Months)	Indemnity	Environ Bundle	Surface Damage	Freshwater Protection	Free Surface Water Use	Top Lease	Force Majeure
Hispanic	-0.003***	2.409***	-0.077***	-0.065***	0.050***	-0.002	-0.001	-0.045***	-0.044***
	(0.001)	(0.291)	(0.010)	(0.010)	(0.010)	(0.004)	(0.003)	(0.006)	(0.011)
Asian	0.000	0.957*	-0.009	-0.015	-0.011	-0.006	-0.018***	-0.008	-0.013
	(0.002)	(0.491)	(0.019)	(0.020)	(0.017)	(0.006)	(0.003)	(0.011)	(0.020)
Black	-0.000	1.238***	-0.063***	-0.071***	-0.017	0.002	0.000	-0.027***	-0.039***
	(0.001)	(0.372)	(0.013)	(0.013)	(0.012)	(0.005)	(0.004)	(0.008)	(0.014)
HH Income	0.033***	-18.796***	0.734***	0.634***	0.096	0.172***	0.007	0.444***	0.443***
	(0.007)	(2.413)	(0.092)	(0.094)	(0.082)	(0.044)	(0.027)	(0.065)	(0.094)
$(\text{HH Income})^2$	-0.020***	12.933***	-0.508***	-0.495***	-0.041	-0.121***	-0.002	-0.255***	-0.304***
	(0.005)	(2.805)	(0.098)	(0.113)	(0.070)	(0.042)	(0.018)	(0.070)	(0.111)
Groundwater	-0.008**	-1.821**	-0.030	-0.034	-0.135***	-0.008	-0.019***	-0.159***	0.041
	(0.003)	(0.714)	(0.026)	(0.024)	(0.033)	(0.012)	(0.004)	(0.018)	(0.035)
Year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wellpad FEs	No	No	No	No	No	No	No	No	No
N	10,907	10,907	10,907	10,907	10,907	10,907	10,907	10,907	10,907
R^2	0.141	0.229	0.388	0.408	0.335	0.105	0.122	0.230	0.336

Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 9(b). Determinants of Lease Clauses (SUR), Full Estate Sample

	Injection fluid	Pugh Clause	Attorney Fees	Noise Bundle	Compression Station Restriction	No Surface Access	Subsurface Easement	Drillcore Reporting
Hispanic	0.011**	-0.042***	-0.032***	-0.074***	-0.012***	0.003	0.040***	-0.002
	(0.004)	(0.011)	(0.005)	(0.010)	(0.001)	(0.010)	(0.010)	(0.003)
Asian	0.015*	0.020	-0.016	-0.012	-0.006**	0.022	-0.028	0.007
	(0.008)	(0.020)	(0.011)	(0.019)	(0.003)	(0.016)	(0.019)	(0.007)
Black	0.023***	-0.071***	-0.031***	-0.061***	-0.003	-0.035***	0.059***	-0.006
	(0.007)	(0.014)	(0.008)	(0.013)	(0.003)	(0.013)	(0.013)	(0.004)
HH Income	-0.004	0.705***	0.432***	0.774***	0.010	0.292***	-0.500***	0.059**
	(0.033)	(0.099)	(0.068)	(0.095)	(0.024)	(0.077)	(0.095)	(0.025)
$(\text{HH Income})^2$	0.044	-0.576***	-0.263***	-0.551***	-0.015	-0.137*	0.432***	-0.031*
	(0.043)	(0.121)	(0.068)	(0.112)	(0.016)	(0.070)	(0.116)	(0.017)
Groundwater	0.016	-0.054*	-0.094***	-0.042*	-0.028***	-0.173***	-0.241***	0.015***
	(0.012)	(0.029)	(0.015)	(0.022)	(0.004)	(0.031)	(0.034)	(0.002)
Year Fes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wellpad FEs	No	No	No	No	No	No	No	No
N	10,907	10,907	10,907	10,907	10,907	10,907	10,907	10,907
R^2	0.117	0.321	0.250	0.352	0.073	0.280	0.424	0.077

Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 10(a). Determinants of Lease Clauses (SUR), Split Estate Sample

VARIABLES	Royalty (%)	Lease Term (Months)	Indemnity	Environ Bundle	Surface Damage	Freshwater Protection	Free Surface Water Use	Top Lease	Force Majeure
Hispanic	0.013**	1.440	0.011	-0.005	-0.004	0.008	-0.005	-0.019	0.081*
	(0.006)	(1.325)	(0.041)	(0.041)	(0.043)	(0.010)	(0.006)	(0.019)	(0.045)
Asian	-0.021*	1.350	-0.017	-0.039	-0.388***	0.124*	-0.002	0.128**	-0.186***
	(0.013)	(2.048)	(0.076)	(0.080)	(0.090)	(0.066)	(0.007)	(0.064)	(0.072)
Black	0.006	1.852	0.036	-0.030	-0.084	0.009	0.014	0.003	-0.002
	(0.009)	(2.143)	(0.062)	(0.059)	(0.073)	(0.008)	(0.026)	(0.047)	(0.064)
HH Income	0.026	0.124	0.814**	1.085***	-0.307	0.344**	-0.081*	0.305	0.992***
	(0.044)	(8.876)	(0.356)	(0.371)	(0.317)	(0.163)	(0.049)	(0.210)	(0.372)
$(\text{HH Income})^2$	0.007	16.570*	-1.276***	-1.656***	0.431	-0.262*	0.099	-0.536*	-1.491***
	(0.056)	(9.680)	(0.377)	(0.409)	(0.344)	(0.155)	(0.067)	(0.288)	(0.378)
Groundwater	-0.025	1.179	-0.054	-0.120	-0.045	0.040	0.053	-0.044	-0.089
	(0.025)	(3.320)	(0.082)	(0.083)	(0.096)	(0.073)	(0.053)	(0.037)	(0.093)
Year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wellpad FEs	No	No	No	No	No	No	No	No	No
N	770	770	770	770	770	770	770	770	770
R^2	0.529	0.449	0.370	0.372	0.313	0.279	0.107	0.293	0.404

Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 10(b). Determinants of Lease Clauses (SUR), Split Estate Sample

	Injection fluid	Pugh Clause	Attorney Fees	Noise Bundle	Compression Station Restriction	No Surface Access	Subsurface Easement	Drillcore Reporting
Hispanic	0.040*	0.058	0.000	0.018	-0.006	0.093**	0.027	-0.008*
	(0.023)	(0.041)	(0.025)	(0.040)	(0.014)	(0.045)	(0.044)	(0.005)
Asian	0.029	-0.279***	0.095	-0.045	0.101*	-0.114	-0.157*	-0.014*
	(0.054)	(0.056)	(0.064)	(0.074)	(0.056)	(0.089)	(0.084)	(0.008)
Black	-0.003	-0.027	-0.061*	0.041	-0.014	-0.015	-0.081	0.041
	(0.017)	(0.066)	(0.034)	(0.064)	(0.010)	(0.070)	(0.071)	(0.035)
HH Income	0.028	0.965***	0.541**	0.832**	-0.073	0.084	-0.303	-0.058
	(0.128)	(0.365)	(0.247)	(0.333)	(0.099)	(0.295)	(0.341)	(0.037)
$(\text{HH Income})^2$	-0.052	-1.657***	-0.734**	-1.250***	0.026	-0.045	0.588*	0.049
	(0.137)	(0.501)	(0.326)	(0.376)	(0.116)	(0.327)	(0.348)	(0.041)
Groundwater	-0.030	-0.029	0.041	-0.031	-0.014	-0.228*	-0.116	0.010
	(0.022)	(0.139)	(0.071)	(0.081)	(0.010)	(0.132)	(0.142)	(0.007)
Year Fes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wellpad FEs	No	No	No	No	No	No	No	No
N	770	770	770	770	770	770	770	770
R^2	0.146	0.350	0.285	0.306	0.137	0.311	0.352	0.060

Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 11(a). Determinants of Lease Clauses (SUR), Full Estate Sample

VARIABLES	Royalty (%)	Lease Term (Months)	Indemnity	Environ Bundle	Surface Damage	Freshwater Protection	Free Surface Water Use	Top Lease	Force Majeure
Hispanic	-0.001	1.499***	-0.061***	-0.045***	0.042***	0.004	0.002	-0.047***	-0.026**
	(0.001)	(0.303)	(0.010)	(0.010)	(0.010)	(0.003)	(0.003)	(0.006)	(0.012)
Asian	0.000	0.762	0.001	0.001	-0.015	-0.007	-0.006***	0.003	0.007
	(0.002)	(0.494)	(0.017)	(0.018)	(0.018)	(0.005)	(0.002)	(0.007)	(0.021)
Black	-0.001	1.076***	-0.009	-0.034***	-0.023*	0.003	0.001	-0.020***	-0.011
	(0.001)	(0.362)	(0.012)	(0.013)	(0.012)	(0.004)	(0.003)	(0.006)	(0.015)
HH Income	0.026***	-9.109***	0.415***	0.337***	0.004	-0.027	0.025	0.146***	0.042
	(0.008)	(2.414)	(0.082)	(0.083)	(0.101)	(0.027)	(0.027)	(0.047)	(0.090)
$(\text{HH Income})^2$	-0.019***	5.531**	-0.299***	-0.296***	-0.056	0.019	-0.010	-0.100**	-0.032
	(0.006)	(2.496)	(0.064)	(0.062)	(0.127)	(0.018)	(0.016)	(0.039)	(0.085)
Groundwater	-0.005*	-1.846**	-0.069**	-0.082***	-0.032	-0.018	0.028***	-0.026	-0.014
	(0.003)	(0.838)	(0.028)	(0.028)	(0.024)	(0.014)	(0.007)	(0.019)	(0.032)
Year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wellpad FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	11,415	11,415	11,415	11,415	11,415	11,415	11,415	11,415	11,415
R^2	0.255	0.340	0.553	0.548	0.418	0.527	0.330	0.563	0.424

Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 11(b). Determinants of Lease Clauses (SUR), Full Estate Sample

	Injection fluid	Pugh Clause	Attorney Fees	Noise Bundle	Compression Station Restriction	No Surface Access	Subsurface Easement	Drillcore Reporting
Hispanic	0.008*	-0.029***	-0.029***	-0.069***	-0.006***	0.004	0.058***	0.001
	(0.004)	(0.011)	(0.005)	(0.009)	(0.002)	(0.011)	(0.011)	(0.003)
Asian	0.015	0.038*	-0.007	-0.011	-0.004*	0.033*	-0.035*	0.006
	(0.010)	(0.020)	(0.010)	(0.016)	(0.002)	(0.018)	(0.019)	(0.007)
Black	0.004	-0.034**	-0.016**	-0.018	0.002	-0.014	0.014	-0.002
	(0.007)	(0.014)	(0.007)	(0.011)	(0.002)	(0.013)	(0.013)	(0.004)
HH Income	0.055*	0.341***	0.174***	0.426***	-0.002	0.195**	-0.404***	0.029
	(0.031)	(0.086)	(0.055)	(0.077)	(0.016)	(0.078)	(0.090)	(0.029)
$(\text{HH Income})^2$	-0.018	-0.327***	-0.099**	-0.336***	0.001	-0.072	0.403***	-0.038
	(0.041)	(0.069)	(0.040)	(0.058)	(0.011)	(0.058)	(0.096)	(0.031)
Groundwater	-0.020**	-0.069**	-0.035	-0.086***	-0.000	-0.009	0.013	0.002
	(0.010)	(0.029)	(0.022)	(0.027)	(0.000)	(0.028)	(0.029)	(0.002)
Year Fes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wellpad FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	11,415	11,415	11,415	11,415	11,415	11,415	11,415	11,415
R^2	0.231	0.450	0.472	0.556	0.597	0.350	0.503	0.214

Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 12(a). Determinants of Lease Clauses (SUR), Split Estate Sample

VARIABLES	Royalty (%)	Lease Term (Months)	Indemnity	Environ Bundle	Surface Damage	Freshwater Protection	Free Surface Water Use	Top Lease	Force Majeure
Hispanic	0.012	1.043	-0.027	0.044	-0.101	0.002	-0.001	0.001	0.178**
	(0.010)	(2.107)	(0.067)	(0.069)	(0.072)	(0.021)	(0.005)	(0.025)	(0.071)
Asian	-0.053**	-1.536	-0.063	-0.090	-0.424***	0.081	-0.005	0.069	-0.140
	(0.025)	(4.598)	(0.103)	(0.114)	(0.115)	(0.050)	(0.007)	(0.067)	(0.099)
Black	-0.016	-0.986	0.039	0.028	-0.085	0.006	-0.004	0.044	0.108
	(0.025)	(3.892)	(0.099)	(0.097)	(0.139)	(0.019)	(0.004)	(0.070)	(0.098)
HH Income	0.097	7.238	0.516	0.787	0.135	0.363	-0.094	0.229	0.443
	(0.087)	(17.374)	(0.538)	(0.563)	(0.561)	(0.241)	(0.080)	(0.405)	(0.581)
(HH Income)^2	0.011	7.859	-0.672	-0.894	0.395	-0.206	0.092	-0.323	-0.458
	(0.109)	(18.917)	(0.530)	(0.552)	(0.606)	(0.252)	(0.079)	(0.463)	(0.650)
Groundwater	-0.015	-1.860	-0.137	-0.130	-0.000	-0.005	-0.026	-0.053	-0.033
	(0.018)	(3.643)	(0.095)	(0.098)	(0.088)	(0.050)	(0.026)	(0.053)	(0.099)
Year Fes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wellpad FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	818	818	818	818	818	818	818	818	818
R^2	0.446	0.517	0.586	0.589	0.511	0.441	0.645	0.549	0.615

Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 12(b). Determinants of Lease Clauses (SUR), Split Estate Sample

VARIABLES	Injection fluid	Pugh Clause	Attorney Fees	Noise Bundle	Compression Station Restriction	No Surface Access	Subsurface Easement	Drillcore Reporting
Hispanic	0.055*	0.122*	0.017	0.045	0.022	0.078	-0.016	-0.011
	(0.031)	(0.065)	(0.043)	(0.061)	(0.021)	(0.066)	(0.085)	(0.009)
Asian	0.080	-0.278***	0.013	-0.212**	0.128*	-0.131	-0.184	-0.042
	(0.086)	(0.099)	(0.066)	(0.083)	(0.067)	(0.115)	(0.125)	(0.039)
Black	0.008	0.152**	-0.107**	0.191**	0.005	0.104	-0.104	-0.001
	(0.032)	(0.075)	(0.045)	(0.086)	(0.011)	(0.110)	(0.127)	(0.003)
HH Income	-0.160	0.907*	0.622	0.319	-0.362***	-0.281	0.322	-0.159
	(0.113)	(0.511)	(0.416)	(0.514)	(0.137)	(0.495)	(0.527)	(0.113)
$(\text{HH Income})^2$	0.136	-1.090**	-0.651	-0.430	0.355**	0.681	0.218	0.124
	(0.116)	(0.530)	(0.461)	(0.525)	(0.150)	(0.590)	(0.576)	(0.089)
Groundwater	0.019	-0.123	-0.029	-0.119	-0.004	-0.001	0.042	0.002
	(0.023)	(0.099)	(0.061)	(0.090)	(0.015)	(0.093)	(0.102)	(0.004)
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wellpad Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	818	818	818	818	818	818	818	818
R^2	0.483	0.598	0.483	0.542	0.569	0.541	0.492	0.512

Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table: 13(a). Tarrant County IPUMS Data, Conditional Correlations

	Children Under Age 5	Male	Age	Speaks English Well
Asian	0.1322***	0.1694***	-5.9662***	-0.1661***
	(.0342)	(.0399)	(1.1722)	(.0156)
Black	-0.0217	-0.0802***	-0.5564	0.0196*
	(.0236)	(.0276)	(.8108)	(.0108)
Hispanic	0.1280***	0.0192	-10.3992***	-0.2086***
	(.0191)	(.0223)	(.6551)	(.0087)
Family Inc	8.08E-07***	2.33E-06***	-8.10E-05***	2.94E-07***
	(1.69E-7)	(1.98E-7)	(5.8E-6)	(7.7E-8)
$(\text{Family Inc})^2$	-1.12E-12***	-3.35E-12***	1.20E-10***	-4.29E-13***
	(3.39E-13)	(3.97E-13)	(1.16E-11)	(1.55E-13)
Constant	0.0255	0.4150***	63.0814***	0.9812***
	(.0288)	(.0337)	(.9877)	(.0131)
PUMA FEs	Yes	Yes	Yes	Yes
N	4247	4247	4247	4247
R^2	0.0265	0.0562	0.1243	0.1959

Sample includes household heads who are homeowners in in Tarrant County, TX in 2012 ACS. Race was assigned using single race identification code. Hispanic was assigned to any individual indicating Hispanic, Spanish, or Latino origin regardless of race.

Table: 13(b). Tarrant County IPUMS Data, Conditional Correlations

	Less Than High School	High School Dropout	Some College	College Graduate	Post Graduate Education
Asian	0.0696***	0.0100	-0.0874**	-0.0264	0.0937***
	(.0171)	(.0163)	(.0353)	(.0346)	(.0282)
Black	-0.0161	0.0234**	0.0583**	-0.0864***	-0.0033
	(.0118)	(.0113)	(.0244)	(.024)	(.0195)
Hispanic	0.2164***	0.0773***	-0.0786***	-0.1284***	-0.0570***
	(.0095)	(.0091)	(.0197)	(.0194)	(.0157)
Family Inc	-5.42E-07***	-5.60E-07***	-6.17E-07***	1.91E-06***	1.67E-06***
	(8.43E-8)	(8.07E-8)	(1.74E-7)	(1.71E-7)	(1.39E-7)
$(\text{Family Inc})^2$	8.04E-13***	8.70E-13***	3.28E-13	-2.76E-12***	-1.50E-12***
	(1.69E-13)	(1.62E-13)	(3.5E-13)	(3.44E-13)	(2.8E-13)
Constant	0.0433***	0.0651***	0.2749***	0.1932***	0.0868***
	(.0144)	(.0138)	(.0297)	(.0292)	(.0237)
PUMA FEs	Yes	Yes	Yes	Yes	Yes
N	4247	4247	4247	4247	4247
R^2	0.1894	0.0482	0.0253	0.0736	0.0973

Sample includes household heads who are homeowners in in Tarrant County, TX in 2012 ACS. Race was assigned using single race identification code. Hispanic was assigned to any individual indicating Hispanic, Spanish, or Latino origin regardless of race. “Speaks English Well” was assigned to any individuals reporting “Yes, speaks only English”, “Yes, speaks very well”, or “Yes, speaks well”, but not to other categories.

Table 14. Determinants of Bonus Payment

	Bonus Payment				Log(Bonus Payment)			
Hispanic	-3,222.28***	-1,761.40***	-3,059.86***	-1,669.12***	-0.627**	-0.182	-0.592**	-0.155
	(687.15)	(526.03)	(643.16)	(496.19)	(0.244)	(0.189)	(0.242)	(0.187)
Asian	-1,510.78	780.43	-1,084.24	741.20	-1.124**	-0.309	-1.057*	-0.359
	(1,097.92)	(493.93)	(1,158.57)	(551.71)	(0.557)	(0.307)	(0.566)	(0.311)
Black	-2,856.50***	-447.68	-2,837.43***	-554.38	-0.902**	-0.356	-0.904**	-0.368
	(741.26)	(513.97)	(739.84)	(509.30)	(0.368)	(0.279)	(0.368)	(0.274)
Income	19,010.95***	4,179.99*	5,684.99*	-3,570.64	2.943***	0.965	0.319	-0.476
	(2,999.71)	(2,329.54)	(3,295.98)	(2,227.44)	(0.846)	(0.656)	(1.114)	(0.860)
$(\text{Income})^2$	-11,936.10***	-2,177.18	-4,107.49*	2,387.29*	-2.015***	-0.637	-0.477	0.193
	(3,047.76)	(1,540.34)	(2,411.95)	(1,428.11)	(0.729)	(0.471)	(0.762)	(0.567)
Groundwater			-6,809.40***	-2,536.09			-1.807	-1.544
			(2,094.52)	(1,661.07)			(1.155)	(1.117)
Living area (ft^2)			1.28***	1.19***			0.000**	0.000***
			(0.31)	(0.23)			(0.000)	(0.000)
Land area (ft^2)			188.67***	16.21			0.031***	-0.018**
			(33.94)	(24.94)			(0.009)	(0.009)
Observations	965	965	965	965	965	965	965	965
R-squared	0.450	0.752	0.496	0.764	0.429	0.698	0.444	0.705
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	No	Yes	No	Yes	No	Yes	No	Yes

Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 15. Hedonic Estimation, First Stage (Dependent Variable = Term Length in Months)

	Estimate	Std Error
Environmental Bundle	-4.25***	0.23
Surface Damage Bundle	3.26***	0.19
Freshwater Protection	-4.57***	0.45
Free Surface Water Use	-0.30	0.60
Injection fluid	1.92***	0.46
Noise Bundle	-1.79***	0.27
Compression Station Restriction	12.17***	0.80
No Surface Use Bundle	2.50***	0.21
Subsurface Easement	5.70***	0.22
Constant	37.53***	0.23

Table 16. Hedonic Estimation

	Appraisal (Full)		Royalty (Full)		Appraisal (Split)	
	Estimate	Std Error	Estimate	Std Error	Estimate	Std Error
House Age	-2.10	1.81				
Bathrooms	102.27***	11.70				
Bedrooms	-0.99***	0.26				
Living Area	1963.47***	275.47				
$(\text{Living Area})^2$	244.34***	58.26				
Land Area	-888.16***	42.43				
$(\text{Land Area})^2$	1047.89***	65.89				
Groundwater	491.4***	140.91				
Drilling Exposure	-56.37***	4.36				
Environmental Bundle	172.7***	50.72	0.00	0.03	164.83***	50.72
Surface Damage Bundle	108.8**	50.88	-0.13***	0.03	233.66***	50.88
Freshwater Protection	863.57***	153.98	0.18**	0.07	691.06***	153.98
Free Surface Water Use	-260.69*	143.48	0.51**	0.20	-733.65***	143.48
Injection fluid	-197.34**	72.39	-0.15***	0.05	-50.82	72.39
Noise Bundle	332.63***	64.07	0.23***	0.05	113.78*	64.07
Compression Station Restriction	1426.4***	364.56	-1.07***	0.10	2440.98***	364.56
No Surface Use Bundle	273.18***	44.99	0.05	0.04	229.89***	44.99
Subsurface Easement	-46.69	61.39	0.18***	0.04	-200.82***	61.39
Constant	-923.01	650.70	3.85***	0.59	-577.35	654.20

Split estate appraisal estimates are calculated from estimated model parameters and cross equation restrictions.

Table 17. Hedonic Estimation – Firm, City and Year Fixed Effects

	Appraisal		Royalty			Appraisal	
Firm Fixed Effects:	Estimate	Std Error	Estimate	Std Error	**City Fixed Effects:**	Estimate	Std Error
Carrizo	-1186.28***	225.74	-1.34***	0.36	Arlington	214.72	190.50
Chesapeake	-1125.58***	212.05	-0.91**	0.36	Bedford	1105.87***	218.79
Dale	-1437.4***	205.68	-0.9**	0.36	Benbrook	582.14***	210.32
DDjet	-597.28***	227.76	-0.71*	0.36	Euless	1397.59***	200.10
Fleet	-1069.55***	228.14	-1.29***	0.36	Forest Hill	-651.92***	219.77
Fort Worth	2264.96***	473.57	-0.65*	0.38	Fort Worth	1117.28***	222.46
Four Sevens	824.21***	223.95	-0.67*	0.36	Grand Prairie	-198.00	197.06
Harding	-814.24***	233.21	-0.9**	0.36	Grapevine	4212.23***	279.26
Hillwood	747.13**	348.07	0.83*	0.45	Haltom City	-85.53	204.01
Hollis Sullivan	-743.13***	227.41	-1.4***	0.37	Hurst	825.61***	201.62
Llano royalty	-920.67***	234.87	-0.53	0.37	Keller	2688.5***	243.90
Paloma Barnett	-1448.29***	203.17	-1.07***	0.35	Kennedale	457.16*	268.56
Range	-394.13	303.64	-0.71	0.43	Mansfield	399.62**	200.70
Small Firm	-788.17***	225.39	-1.06***	0.37	North Richland Hills	528.6***	195.86
Thunderbird	-1915.29***	311.43	-1.54***	0.40	Richland Hills	-40.67	211.64
XTO	157.35	221.38	-0.08	0.36	South Lake	5285.06***	333.91
Year Fixed Effects:					Watauga	-112.27	207.85
2005	260.14	986.81	-1.42***	0.47	White Settlement	32.67	211.56
2006	2153.36	1790.06	1.02	0.84			
2007	1058.33**	486.63	-0.73	0.47			
2008	1255.49**	489.25	-0.62	0.47			
2009	1093.44**	484.73	-0.79*	0.46			
2010	1047.98**	484.01	-0.79*	0.46			
2011	1096.85**	486.34	-0.55	0.46			
2012	1122.61**	487.44	-0.69	0.46			

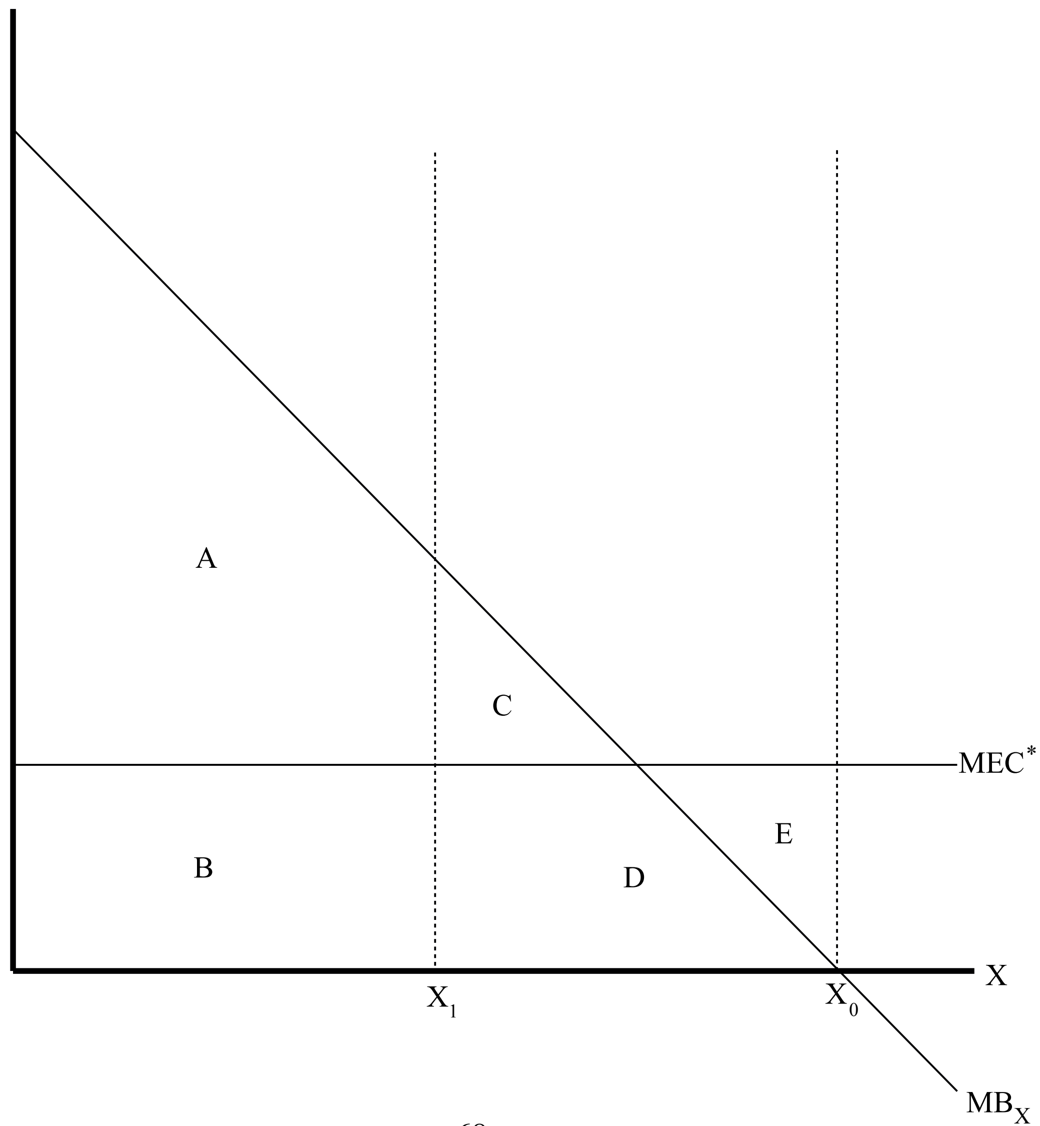
Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

Table 18. Determinants of Violations

	(1) Id Property, Wells, Tanks	(2) Bradenhead Pressure	(3) Water Protection
Environmental	-0.375***	0.168***	-0.218***
	(0.024)	(0.030)	(0.034)
Surface damage	0.111***	0.043	0.162***
	(0.023)	(0.032)	(0.034)
Freshwater protection	-0.694***	-0.724***	-0.532***
	(0.076)	(0.088)	(0.104)
Free water	-0.259***	-0.727***	-0.338***
	(0.073)	(0.083)	(0.083)
Injection fluid	-0.056	0.075	-0.001
	(0.050)	(0.084)	(0.088)
Compression station restriction	-0.353***	-0.718**	-0.774**
	(0.103)	(0.330)	(0.385)
No surface access	-0.120***	0.013	0.043
	(0.019)	(0.030)	(0.029)
Subsurface easement bundle	0.109***	0.005	0.109***
	(0.023)	(0.028)	(0.033)
Observations	65,407	58,068	60,287
City FE	Yes	Yes	Yes
Period FE	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Figure 1



APPENDIX A: String Matching

The address merge between leases and housing data (and between the two housing data sets, TAD and Dataquick) is executed in a series of steps that separate addresses into parallel pieces and control for misspellings. The lease data (in particular, the variables used to match leases to other data sets) are particularly dirty in their raw state in that all variables are generated using strings. We address this problem using a multi-step procedure. The first step of the address merge is to parse both sets of data into the address categories like a house number, suite or apartment number, street, street type, city, state, and zip code. The second step corrects misspelled words in the street city names. We construct a user-defined function that embeds a function, *strgroup,* designed by Julian Reif at the University of Chicago. This function calculates the Levenshtein distance between all of the strings being fed to the function, and normalizes by the length, or "edit distance", of the smallest string in the group.[19] If the normalized distance is less than a specified threshold, the strings are grouped together and outputted into a new group variable. Our function assumes that the "correct" spelling is the spelling used most frequently across both data sets, applies *strgroup* iteratively, and assigns the correct spelling to all misspelled words. In the end, we assemble a list of acceptable spellings of cities and streets that are then merged back to the original data set and used to match the lease addresses to the housing data.

The address match is performed roughly fifty times using different combinations of address variables that differ in the restrictiveness of the match. Using the described methods, we merge roughly 73 percent of our leases to specific properties based on the provided grantor addresses.

[19] The Levenshtein distances uses an algorithm to determine a string distance based on the number of changes necessary to turn the first word into the second. For example, "lessor" and "lessee" would have a Levenshtein distance of two as one needs to change the "or" to "ee" in order to make the two words identical.

Appendix B: Scraping of Lease Clauses

For each auxiliary clause category, we use *Python* code to search a set of roughly 90,000 text documents that were converted from the original PDF scans using OCR software for a set of identifying words or phrases. We constructed a list of patterns for each clause that were used to search and identify leases containing those clauses. The use of regular expression functions allows us to search for fragments of words, and account for misspellings and superfluous punctuation that might prevent a perfect match of phrase. Perfect matches are particularly difficult in converted documents (PDF to text) because the conversion is imperfect, resulting in misplaced spaces, characters, numbers, and letters. For example, below we describe the code used to search for surface damage and restricted surface access clauses; several patterns were employed to extract words used to communicate these added restrictions including the following:

1. No Surface Use:
    a. "No surface use": r'[rmn][ao0][\s+]*su[rmn]f[ao0][\w+]*[\s+]*use',\
    b. "No surface operations": r'[rmn][ao0][\s+]*[\w+]*[\s+]*[\\~|>/!\%_,.-
    `"\'()$?@#\d:;]*[\s+]*su[rmn]f[ao0][\w+]*[\s+]*[ao0]pe[rmn][ao0]t\w+'
    c. "Lessee shall not conduct any surface operations":
    r'[l1]es[s]*[\w+]*[\s+]*sh[ao0][l1][l1]*[\s+]*[rmn][ao0]t[\s+]*c[ao0][rmn]d\w+[\s
    +]*[\w+]*[\s+]*[\\~|>/!\%_,.-
    `"\'()$?@#\d:;]*[\s+]*su[rmn]f[ao0][\w+]*[\s+]*[ao0]pe[rmn][ao0]t\w+'
    d. "Lessee shall not enter upon w surface":
    r'[l1]es[s]*[\w+]*[\s+]*sh[ao0][l1][l1]*[\s+]*[rmn][ao0]t[\s+]*e[rmn]te[rmn][\s+]*
    up[ao0][rmn][\s+]*[\w+]*[\s+]*[\\~|>/!\%_,.-
    `"\'()$?@#\d:;]*[\s+]*su[rmn]f[ao0][\w+]*'
    e. "Within (d) feet w w land (no surface use at all)":
    r'withi[rmn][\s+]*\w+[\s+]*[({\[|)}\]]*[\\~|>/!\%_,.-`"\'$?@#]*[\d+]*[\\~|>/!\%_,.-
    `"\'()$?@#]*[\s+]*[\d+]*[\\~|>/!\%_,.-
    `"\'$?@#]*[\s+]*[\d+]*[({\[|)}\]]*[\s+]*fe[e]*t[\s+]*[\w+]*[\s+]*[\w+]*[\s+]*[l1][a
    o0][rmn]d',\

2. Surface Damage:
    a. "Lessee shall pay for damage":
    r'[l1]es[s]*[\w+]*[\s+]*sh[ao0][l1][l1]*[\s+]*p[ao0][v\\/y][\s+]*[\w+]*[\s+]*d[ao0]
    [rmn][ao0]g[\w+]*'

The numerical description is the clause type and the alpha-description is the phrase or pattern used in the text search to identify leases containing the identified clause. Following the pattern is the regular expression used by *Python* to search for the phrase accounting for the listed idiosyncrasies of the converted text files. After the initial extraction, the data were cleaned further using regular expression functions and quantified into the binary form used for analysis using *STATA*. Finally, the auxiliary clauses were matched to the observational lease data using a record number assigned by the county clerk office.

APPENDIX C: Lease Clause Definitions

Primary Clauses

1. Lease Term: The lease often includes both primary and secondary terms in units of months or years. The primary term is the length of time allowed to drill a well and begin production. Given that the well is producing in paying quantities, or is capable of producing in paying quantities, the primary term rolls-over into the secondary term of the lease, which remains in effect as long as the well is producing. A typical primary lease term ranges between three and five years. A longer lease term is generally considered to be bad from the point of view of the lessor, as it allows the lessee to hold mineral rights for a longer period without paying royalties.
2. Royalty: The fraction of earnings from the producing well paid to the lessors owning royalty interest in the well based on the acreage contribution of an individual lease to the producing well.
3. Bonus: A signing bonus is often negotiated at a per acre increment and is exchanged between the lessor and lessee at the time when the lease is signed. Bonus payments are frequently not reported in recorded lease agreements.

Auxiliary Clauses

1. No Surface Access: Leases can restrict the access a firm has to the mineral estate via the surface estate. Lease may stipulate that all acreage must be pooled especially if the lessee owns a smaller tract of land. Other language may constrain where a well can be drilled in the context of a pooled agreement, for example, stating that the minerals may only be accessed through a well drilled on another pooled tract of land (might also be interpreted as a surface protection clause).
2. Surface Damage: In general, the lessee is not required to compensate the lessor for reasonable and necessary use of the surface to access the mineral estate. Lessors can negotiate on a variety of dimensions; however, it is important to note that in large urban areas many of these dimensions are regulated through municipal ordinance. Lease may require lessees to restore the property to the state before the well was drilled through surface damage/cleanup language.
3. Top Leasing: Occurs when the lessor leases the mineral estate to the same lessee twice during overlapping dates or to two different lessees (divergent), and this technique is used to increase competition to begin drilling and extracting resources.
4. Pugh Clause: This clause relinquishes ownership of the mineral estate back to the lessor at the end of the primary term in the event the producing well is not drawing from that portion of the lease.
5. Force Majeure: These clauses are often included to protect the lessee in the event of uncontrollable circumstances limiting or altogether halting operations on a well. To protect the lessor, additional clauses limiting the extent of delay or the definition of force majeure can be included.

6. Noise Restrictions: Most commonly, leases will limit the amount of noise by restricting production to certain times of day or requiring mufflers be used with loud equipment.
7. Environmental Clause: Leases clause limiting the types of substances allowed for use in executing exploration and extraction activities. This clause encourages the use of safeguards to prevent contamination of soil, water, and surface and subsurface strata. Includes limits the use of hazardous substances as defined by the Comprehensive Environmental Response Compensation and Liability Act (CERCLA), and additional pollution restrictions and control mechanisms required by lessees
8. Freshwater Protection: Lease may prohibit disposal, including discharge of oil field brines, geothermal resource waters, or other mineralized waters, or other drilling fluids, into any watercourse or drainage-way, including any drainage ditch, dry creek, flowing creek, river, or other body of surface water. Lease may prohibit use of pit for storage of oil or oil products, oil field fluids, or oil and gas wastes.
9. Free Surface Water Use: Lessees have a right to use the surface and sub-surface water during drilling operations like hydraulic fracturing or secondary operations, and some leases more explicitly state the free use of water, oil, and gas produced on the land for operations.
10. Compressor Station Restriction: Requires that firms not locate a compressor station within a specified distance of a residence.
11. Injection Fluid: In the preamble, the leases list the rights of the lessee, which in this case includes the right inject gas, water, and other fluids and air into the subsurface strata.
12. Indemnity: An indemnity clause shifts liability from the lessor to the lessee in the event that a third party claims negligence on the part of the lessor for lessee activities. The indemnity clause is strengthened by satisfying the "express negligence" rule; otherwise the court system is likely to not uphold the indemnity clause. This is achieved by including the phrase "including claims alleging that the lessor is guilty of negligence of other misconduct."
13. Reporting Requirement (Drill Core): Lessors may stipulate what information is to be provided by lessees, including any reports on production or activity, geological or seismic surveys, assignments, description of the pooling unit, royalty calculations, and contracts for selling the oil and gas.
14. Subsurface (Perpetual) Easement: Leases may state that the lessee gives the right to use the property to access wells located on other property which may not be used to develop the lease signed, and that the easements can remain in place after the lease expires. This language seems particularly relevant for gathering lines.
15. Attorney Fees: Lessor assumes responsibility for attorney fees that may arise from future negotiations.

APPENDIX D: Violations

The docket data come from a mainframe database maintained by TRC tracking all cases by permit, well, and lease, depending on the circumstances. The data include all relevant dates, which might include the date the case was initially filed, any hearing dates, when a settlement is proposed, the date of the counter-offer, and the date when the case is closed, if relevant. Additionally, the database describes the type of case, operators involved, and settlement values. Our data cover the entire state of Texas; however, we are only using the Tarrant County portion and they are merged to our other well data by lease name and well number.

The following violation descriptions correspond directly to those listed in the Texas Administrative Code, Chapter 3.[20]

(1) Improper Identification of Properties, Wells, and Tanks

(2) Water Protection

- Prohibited disposal: The disposal methods prohibited by this paragraph include, but are not limited to, the un-permitted discharge of oil field brines, geothermal resource waters, or other mineralized waters, or drilling fluids into any watercourse or drainage-way, including any drainage ditch, dry creek, flowing creek, river, or any other body of surface water.
- Prohibited pits: No person may maintain or use any pit for storage of oil or oil products. Except as authorized by this subsection, no person may maintain or use any pit for storage of oil field fluids, or for storage or disposal of oil and gas wastes, without obtaining a permit to maintain or use the pit.
- Disposal permitting
- Recycling

(3) Bradenhead Pressure: A Bradenhead pressure violation refers to the pressure in the casing exceeding the reliability of the casing to prevent oil, gas, and other well materials from penetrating protected strata along the well bore. If a certain amount of pressure is detected, further cementing must be approved by the commission. If the well is found leaking, the commission runs a test on the Bradenhead, and pressure might require condemning the casing and beginning a new production.

APPENDIX E: Sample Definitions (TO BE ADDED)

Describes how we go from the full sample to the sample used for estimation, what gets cut at each stage, and how sample characteristics change with major cuts.

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[20] http://info.sos.state.tx.us/pls/pub/readtac$ext.ViewTAC?tac_view=4&ti=16&pt=1&ch=3&rl=Y