Valuing Leases for Shale Gas Development*

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Abstract

With the 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 on drilling and production activities that are negotiated in leases are an important tool by which the industry is regulated. We demonstrate how the value of lease clauses to homeowners can be recovered from the hedonic price gradient in the market for split-estate houses, and show how split-estate status can be recovered from lease records and transaction data using string matching techniques. However, we also note that the distribution of split-estate house prices is truncated, creating the potential for selection bias. We show how the dual-gradient hedonic model can be used to recover an expression for willingness-to-pay for lease clauses from the full-estate housing market. Combining data from the full and split housing markets overcomes any potential selection problems and yields consistent estimates of willingness-to-pay for lease clauses. Results provide a measure of the benefits to homeowners from the regulations negotiated in leases, and suggest that factors affecting the outcomes of lease negotiations will have pecuniary impacts on homeowners.

Keywords: Hedonics, Shale Gas, Hydraulic Fracturing, Mineral Rights, Split-Estate, Lease Negotiation, Selection Bias

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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 U.S. energy supplies, the ability to extract natural gas from tight-shale formations has increased the revenue of households who own the rights to the mineral reserves. However, the benefits of mineral rights development are accompanied by costs that are 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 et al. 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, Hunt and Hildebrand 2013).

Under the U.S. legal structure, homeowners can be protected from these external costs in one of two ways: government ordinances and privately negotiated natural gas leases. 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 who are also the owners of mineral rights can sign lease agreements, which transfer those rights to operators who then develop the resource on behalf of the homeowner. Typically, the mineral rights holder receives a royalty payment based on a percentage of the value of the resource sold by the operator in addition to a one-time fixed bonus payment 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 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. The outcomes of lease negotiations can affect housing amenities and exposure to environmental nuisances, with consequences for both health and property. We might

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

therefore expect the value of lease clauses and the protections they provide to be capitalized into home values. With that in mind, this paper analyzes the outcomes of private lease negotiations that are used to transfer mineral rights for the purpose of shale gas development. We demonstrate how the value of lease clauses to homeowners can be recovered from the hedonic price gradient in the market for split-estate houses, but note that the distribution of split-estate house prices is truncated, creating the conditions for selection bias. We show how the dual-gradient hedonic model (Rosen 1979, Roback 1982) can be used to recover an expression for willingness-to-pay from the full-estate housing market. Subsequently combining data from the full and split housing markets overcomes potential selection bias and yields consistent estimates of willingness-to-pay for lease clauses. These values suggest that the restrictions on industry negotiated directly into lease agreements are valuable to homeowners. Moreover, they suggest that the outcomes of lease negotiations have important pecuniary implications for homeowners.

This paper proceeds as follows. Section 2 reviews the relevant literatures that we draw upon. Section 3 describes our data, which combine a novel source of information about the outcomes of lease negotiations with proprietary data on housing transactions, drilling activities, and mineral rights. Section 4 outlines the dual-gradient hedonic model, which explicitly incorporates leases and royalty payments into the homebuyer's optimization problem. Section 5 reports the results of several simple hedonic specifications followed by those from the dual-gradient model, and uses those results to measure the value placed on individual lease clauses by homeowners. Results suggest that the outcomes of lease negotiations described in Timmins and Vissing (2015), who look at the role of race and income in determining lease bargaining outcomes, have pecuniary repercussions. Section 6 concludes with a discussion of our results and policy implications. Finally, we provide a series of appendices that describe the institutional and legal frameworks surrounding shale gas development in Texas (Appendix A), discuss the string matching, text scraping, and other procedures that are used to create our data (Appendix B), and detail the specific clauses that we extract from lease document (Appendix C).

2 Literature Review

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

There is a small (and growing) literature on the house price impacts of nearby shale gas development. No papers to date, however, have explored the effect of shale gas development on property values while controlling for leasing activity, nor have they measured the direct impact of shale gas leases on property values (either as sources of revenue to homeowners or as *de facto* regulations). In an early paper, Boxall, Chan and McMillan (2005) measured the house price effects of nearby (non-shale) sour gas wells in Alberta. More recently, Klaiber and Gopalakrishnan (2014) measure the temporal impact of shale gas wells in Washington County, Pennsylvania. Muehlenbachs, Spiller and Timmins (2015) use data from all of Pennsylvania to conduct a triple-difference analysis of the effect of shale gas development on groundwater dependent homes, along with a double-difference analysis of the effect on all nearby homes regardless of water source. While that paper's results suggest small gains for houses dependent upon public water sources (likely from lease payments), it finds evidence of significant negative net effects on groundwater dependent houses. Other research has found similar evidence of concerns over risks to a household's water source (Throupe, Simons and Mao 2013), or large negative effects on house values more generally (James and James 2014), although other researchers have found much smaller effects (Delgado, Guilfoos and Boslett 2014). Boslett, Guilfoos and Lang (2016) find a drop in house prices accompanying a moratorium on hydraulic fracturing in New York, suggesting that shale gas development is good for house values. Jacobsen (2015) finds evidence of increased house prices, rents and wages using a multi-county geography to define exposure to shale gas development. A related literature explores the impacts of shale gas development (and resource booms more generally) on employment and income.[2]

[2] See Black, McKinnish and Sanders (2005), Allcott and Keniston (2014), Fetzer (2014), Mastromonaco and Maniloff (2014) and Jacobsen and Parker (2016).

3 Data

Our analysis employs a unique combination of lease, well activity, violation, housing, and demographic data sets. This section details those sources of data and describes how certain variables are constructed. We have collected housing transaction and appraisal data from the Tarrant County Appraiser District office. We link information about wells and leases to these data through a series of string-based address and name matches. Drilling data from the Texas Railroad Commission are used in conjunction with information from DrillingInfo. Finally, we generate a variable identifying leases where the mineral estate is likely split from the surface estate. Additional information about our data set and the procedures used to construct it is provided in Appendix B.

3.1 Housing Data

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

We use appraiser data describing the household attributes compiled from the Tarrant County Appraiser District (TAD) office. TAD records document appraisals up to the present in addition to a file delineating all transactions in Tarrant County. We focus our analysis on appraised values because Texas is a non-disclosure state, meaning buyers and sellers are not required to report the transaction value of the house. We use a sample of houses with observed appraisals occurring between 2003 and 2013, and we construct a cross-section of those appraised values for each property. TAD also provides us with information on the houses' water sources (groundwater v. piped), and other geographic descriptions that can be merged to the data directly or spatially mapped to the houses using GIS software. Table 1 summarizes housing attributes in our full sample of appraised houses and our estimation sample. A detailed description of the composition of that sample follows at the end of this section.

The appraisal value, age of the house, and drilling exposure (producing wells within a 1000-meter buffer at the appraisal date) are summarized using each of possibly many repeat appraisals for a given house. The house characteristics and groundwater use are summarized using unique property observations resulting in a smaller sample size for those variables. Comparing the house attributes of our estimation sample to the full sample, we see the estimation sample has more expensive and larger homes with less use of groundwater and more exposure to producing wells within a 1000-meter buffer at each appraisal date.

3.2 Lease Data

The lease and lease contents are a primary and unique source of data used to describe the outcome of the bargaining process conducted between two parties – the lessee (i.e., who is typically an operator or third party 'landman') and the lessor (i.e., the owner of the mineral rights, who is also the owner of the surface rights in the case of a full estate).[3] Signing the lease conveys the interests of the mineral estate from the lessor to the lessee.

Signing a comprehensive leasing document is important for households 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.

We have collected data describing the terms of these privately negotiated lease contracts. In particular, we have data describing the primary clauses (i.e., royalty rate and lease term) of all natural gas leases negotiated in Tarrant County, Texas between 2000 and 2013. In addition to the primary clauses contained in the leasing agreements, we have also collected auxiliary clauses for one third of the sample. The data period for auxiliary clauses with a large enough sample size begins in 2006 and ends in 2011. Our specific sample was collected from the "Drilling Down Series"[4] published by the *New York Times* from 2011 into 2012. We scraped these data and then mined the

[3]Full estates are also referred to as fee-simple, or whole, estates.
[4]`http://www.nytimes.com/interactive/us/DRILLING_DOWN_SERIES.html`

files for words and phrases indicating the existence of specific clauses using an algorithm written in Python. This process is described in Appendix B. We use six different auxiliary lease clause categories in our analysis. A list of these clauses and clause descriptions is included in Appendix C.

The full set of auxiliary lease clauses fall into several broad categories including strict legal requirements, clearer definitions of liability, additional environmental requirements, requirements for increased reporting by the lessee to the lessor regarding well activity, and restrictions on how a firm can access the mineral estate. A particularly important clause in Texas is the surface damage clause, which we capture by searching for phrases describing cleanup efforts and damage remediation. Mineral rights owners can negotiate a surface damage clause into the leasing agreement to protect the surface and use during production and ensure remediation after production ends. Surface owners are not owed any remuneration for the opportunity cost of the piece of their property lost during the drilling period or for reasonable damages to the land caused by drilling. If there is any perceived misuse of the land by mineral rights owners, surface owners are responsible for proving unreasonable conduct that does not include surface damage or inconvenience. Surface owners are somewhat protected by the Accommodation Doctrine, which protects existing surface owner use,[5] and surface owners can negotiate a separate addendum to the lease requiring surface protections.

Table 1 summarizes primary clauses (royalty rate, indicator for term length > 36 months) along with six different auxiliary clauses and four categories of violations that we use in our analysis. The table is split between the set of houses merged to leases with descriptions of auxiliary clauses and our estimation sample (i.e., the subset of those houses with active leases). Our estimation sample has a greater royalty rate and a longer term length, and among auxiliary clauses, the estimation sample has more environmental, noise restrictions, and indemnity clauses while the other clause occur with nearly the same frequency or are fewer.

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

3.3 Well Exposure

Well permitting data are used to construct a variable describing well exposure from the perspective of the household at the time of the appraisal. Well permitting information comes from two sources: the Texas Railroad Commission and DrillingInfo, a proprietary aggregator of drilling activity information. Exposure is tabulated at different distance buffers surrounding the house, and if an operator has begun drilling a well by the appraisal date, the well is included in the exposure variable. We tabulate exposure based on 500, 750, 1000, and 2000-meter buffers, and the calculation differentiates between wells that are permitted, spudded, and producing. The primary exposure variable used in our analysis is the count of wells that are producing within a 1000-meter buffer. Table 3 summarizes well exposure over time for the full and estimation samples, revealing the dramatic growth in shale gas development in Tarrant County between 2003 and 2013. The exposure variable for wells located within 1000 meters of an appraised house in the estimation sample is large beginning in 2008.

3.4 Generation of Split Estate Identifier

Appendix A.4 provides legal background on the ability to sever mineral rights from the surface estate in Texas. We generate an indicator variable for each leased property describing whether the mineral rights are likely severed from the surface estate. This is an important variable to use as a control because owners of severed surface rights will not receive any royalty payments even if those payments are described in a lease. Unfortunately, split estates are not directly identified by the data. Rather, we determine what is a likely split estate based on a series of string matches that eventually compare the names of mineral rights owners signing leases with those of the individuals buying and selling properties in our housing data sets. After matching as many leases to properties as possible, we begin by merging all of the lease records and property identification numbers back to a list of all buyers and sellers associated with each house and each date of transaction to determine if and when names match between the housing and lease data.

We first look for perfect matches between names of individuals signing leases and buying or selling houses. We then proceed to identify close spellings using the Levenshtein string distance measure described in Appendix B. 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 4 describes differences between houses and their leases depending upon the status of their mineral estate. Split estate homes tend to be smaller, older, and less expensive. They are on smaller plots of land and are exposed to fewer wells. Tables 5 and 6 report the percentage of leases that are split by city and by appraisal year in Tarrant County.

3.5 Sample Cuts

Considering how our data are assembled, Table 7 summarizes the house attributes based on whether a house has been successfully merged to a lease, whether that lease has a full description of auxiliary terms, and whether the lease is considered active at the appraisal date (i.e., signed prior to the appraisal date). We begin with a sample of 215,962 house observations of which 95,686 houses are matched to leases. Of those 95,686 houses matched to leases, we have full descriptions of auxiliary clauses for 25,782 leases. Similarly, out of our sample of houses matched to leases, 69,386 of those leases are active at the time when the house is assessed. Finally, 6,592 houses have an active lease, a full description of auxiliary clauses, and drilling within 1,000 meters. We limit our analysis to only houses with drilling nearby, as the details of leases associated with these houses are more readily available to the assessor.

4 A Dual Gradient Hedonic Model of Shale Gas Leases

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

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

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

$$max_{\{X,H,L\}} \quad U(X,H,L) \quad \text{s.t.} \quad X + P(L,H) = I + e^{\alpha} R(L,T,H) \tag{1}$$

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

H includes the traditional list of house attributes (square footage, number of bedrooms and bathrooms, lot-size, water source), a vector of municipal dummy variables (i.e., to proxy for local public goods), and a measure of well exposure (i.e., number of spudded wells within 2km). The appraisal value, $P(L,H)$, is a function of these house attributes as well as the vector of auxiliary clauses, L, contained in the house's lease. $R(L,T,H)$ is a simple proxy for royalty payments; it is measured by the royalty rate (which typically varies between 0.18 and 0.25) multiplied by land area (measured in $\text{ft}^2/1000$). We allow this proxy to vary with the vector of auxiliary lease clauses (L) and lease term (T), since they were jointly negotiated (along with any bonus payments)[6] by the mineral rights holder and lessee at the time when the lease was signed. A scale parameter, e^α, converts the proxy for royalty payments into units comparable with annualized house price.

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

$$\text{Full Estate: } V^F(I + e^\alpha R(L,T,H) - P(L,H), L, H) \tag{2}$$

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

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

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

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

$$WTP_l^F = \frac{\partial V^F/\partial l}{\partial V^F/\partial X} = \frac{dP}{dl}\Big|_F - e^{\alpha}\frac{dR}{dl}\Big|_F \tag{4}$$

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

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

$$WTP_l^S = \frac{\partial V^S/\partial l}{\partial V^S/\partial X} = \frac{dP}{dl}\Big|_S \tag{5}$$

While it is therefore possible to recover willingness-to-pay for lease clause l from the split estate housing market price gradient alone, the strong statistical relationship between lease clauses and split estate status suggests a selection problem that will lead to biased estimates. Without a clear exclusion restriction (i.e., a variable that will predict split-estate status but is excluded from the price equation), the traditional Heckman correction (Heckman 1979) cannot be implemented. Instead, we rely on a simple assumption – that the home buyer's willingness-to-pay for a lease attribute is the same regardless of which housing market the individual operates in. We can then combine information from all house assessments – split and full.

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

$$\text{Full Estate: } P_i = \beta_0 + H_i'\beta_1 + L_i'\beta_2 + \epsilon_i \tag{6}$$

$$\text{Split Estate: } P_i = \theta_0 + H_i'\theta_1 + L_i'\theta_2 + \xi_i \tag{7}$$

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

$$\text{Full Estate: } R_i = \rho_0 + H_i'\rho_1 + L_i'\rho_2 + \omega_i \tag{8}$$

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

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

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

$$\theta_2 = \beta_2 - e^{\alpha} \frac{dR}{dl}\Big|_F \tag{11}$$

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

$$P_i = \beta_0(1 - s_i) + \theta_0 s_i + H_i'\beta_1 + L_i'\beta_2 - s_i L_i' \frac{dR}{dL}\Big|_F e^{\alpha} + \nu_i \tag{12}$$

$$R_i = \rho_0(1 - s_i) + (1 - s_i)H_i'\rho_1 + (1 - s_i)L_i'\rho_2 + \xi_i \tag{13}$$

In the results that follow, one can therefore read willingness-to-pay for auxiliary clauses and other lease attributes (e.g., violations associated with signing firm) from the split-estate parameters, which are estimated subject to the constraints described above.

5 Results

5.1 Simple Hedonic Model

We begin with a simple property value hedonic specification using the annualized appraisal value (i.e., 5% of appraisal value adjusted for inflation using the consumer price index and January 2000 as the base year), housing attributes, lease characteristics, violation counts, and dummy variables to control for the city where the property is located and the appraisal year. We restrict attention to houses with active drilling, as we do not expect housing assessors to necessarily be aware of lease characteristics for leased houses without active drilling. We focus our attention on column (2) of Table 9, where we restrict our attention to houses from the split estate sample, as the model in the previous section demonstrates that we can indeed learn about homebuyers' preferences for lease clauses from the gradient recovered from this market. These results make no use of information from the full-estate housing market, nor do they control for selection into split-estate status.

Very few variables in the split estate specification are statistically significant. We do find that households place a positive value on *Defend Title*, a large negative value on *Injection fluid*, and an even larger negative value on the log of the count of water protection violations committed by the firm signing the lease, measured at the time of appraisal. Counterintuitively, the interaction of water protection violations and a groundwater indicator is statistically insignificant.

Column (1) of Table 9 reports values for a simple hedonic using only full-estate houses. As the residents of these houses receive royalty payments, we include the royalty rate as a regressor. However, as the model in the previous section makes clear, there is no welfare-theoretical interpretation for this equation. We provide these results here simply for the sake of comparison. More coefficient estimates are significant and have sensible signs, although it is not clear how to interpret them in a welfare context.

5.2 Dual-Gradient Hedonic Model

Tables 10, 11, and 12 report the results from the dual-gradient hedonic model of shale leasing. Table 10 reports the coefficients shared by both full and split estate households in the hedonic equations, including house attributes, proximity to drilling activity, access to groundwater, and the mean values of being located in specific cities across Tarrant County Texas (city-level fixed effects). Coefficient values are consistent with priors, and most are statistically significant. Beginning with the top panel of Table 10, we find that our coefficients for house attributes make intuitive sense. Further, controlling for rural households, we find that accessing groundwater has a negative relationship with house appraisal values. All houses in the estimation sample are exposed to drilling at the time of the appraisal. The effects of the number of wells is not statistically significant, but the point estimate is negative if the house relies on groundwater, echoing the results in Muehlenbachs, Spiller and Timmins (2015).

The second panel reports the city-level fixed effects that describe the mean relationship between the location of a particular house and appraisal values. Most of these coefficients are statistically significant, and the largest range of values exists between houses located in Burleson (-2164.22) and Grapevine (2360.58). The two highest-valued communities correspond to casual evidence on school quality. The Grapevine-Colleyville School District contains eleven “National Blue Ribbon” schools, and has high-schools ranked among *U.S. News* and *Newsweek's* “Best High Schools” lists. The Burst-Euless-Bedford School District similarly was given a “What Parent's Want” Award each year from 1994-2012 from *SchoolMatch*, and the Education Resources Group named it a top school district in Texas in 2011 and in earlier years. Moreover, from 2007-2014, the American Music Conference recognized the district's Suzuki Strings program for creating one of the "Best Communities for Music Education" in Texas.[7]

Table 11 reports the coefficients for each of the lease clauses across split- and full-estate hedonic and royalty equations. The interpretable column includes the hedonic coefficients for the split-estate households (first column), where constraints are imposed so that these estimates have a willingness-to-pay interpretation. In the reported specification, we find that the *Environmental* bundle, *No surface access*, and *Defend title* clauses are all valued by households. Title defense plays an important role in shale gas development areas, as lending institutions have started to recognize the risks inherent in lending to shale properties, and forcing drillers to defend the title goes a long way towards protecting the lender's investment. Both the dual-gradient and simple hedonic specifications recover a positive value for *Defend title*, but the simple hedonic specification does not recognize the value of either the *Environmental* bundle or the *No surface access* clause. These two clauses represent primary defenses to the surface estate. The simple hedonic specification does find a negative value for *Injection fluid*, but this turns out to be 77% larger than that found using the dual-gradient model. The dual-gradient model also finds significant negative values for larger numbers of *Casing Violations* and *Water Protection Violations*, when the house is groundwater-dependent. *Bradenhead Pressure* and *Producing Wells* violations have negative point estimates, but are not significant at usual levels.

6 Conclusions

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

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Table 1: House Attributes by Full and Estimation Samples

	Full Sample			**Estimation Sample**[a]		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
Appraisal value[b]	132082.8	215962	92869.83	104683.6	6592	66382.44
Age (house)	23.61	215638	22.27	23.96	6573	18.39
Land (sqft)[c]	10244.81	136754	7857.05	9535.7	3708	6592.66
Living area (sqft)	2136.43	136754	878.32	1938.6	3708	724.17
Bedroom	3.38	136754	0.7	3.33	3708	0.63
Bathroom	2.12	136754	0.65	2.03	3708	0.51
Groundwater	0.64	136754	0.48	0.7	3708	0.46
Drilling (within 1000 m)[d]	0.78	215962	1.6	1.79	6592	1.34

[a] Properties with an active lease, observed auxiliary clauses, and a drilled well located within 1000 meters.

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

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

[d] Exposure to wells located within 1000 meters of any appraised house at the appraisal date.

Table 2: Lease Attributes by Full and Estimation Samples

	Full Sample		**Estimation Sample**	
	Mean	Std. Dev.	Mean	Std. Dev.
Primary:				
Royalty rate	0.23	0.04	0.23	0.04
Term length (¿36 months)	0.11	0.32	0.27	0.45
Auxiliary:				
Environmental	0.31	0.46	0.35	0.48
Freshwater protection	0.02	0.15	0.06	0.23
Injection fluid	0.02	0.14	0.03	0.17
No surface access	0.56	0.5	0.71	0.45
Subsurface easement bundle	0.42	0.49	0.6	0.49
Defend Title	0.23	0.42	0.25	0.44
Violations (log):				
Producing Wells	3.7	2.48	3.62	2.55
Casing Viol.	1.25	1.15	1.45	1.3
Bradenhead Pres.	0.14	0.36	0.17	0.41
Water Prot.	1.15	1.25	1.3	1.33
Royalty Obs	56,711		18,435	
Term Obs	92,978		18,765	
Clause Obs	25,633		18,995	

Table 3: Count of Producing Wells Within 2000 Meters

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

	Full Sample			**Estimation Sample**		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
2003	0.01	1887	0.09	0	0	0
2004	0.05	4040	0.29	0	0	0
2005	0.13	4845	0.49	0	0	0
2006	0.25	11376	0.73	5.5	2	6.36
2007	0.33	16118	1.04	6	7	4.04
2008	1.12	24383	2.15	2.76	127	2.53
2009	0.92	16341	1.85	2.01	229	1.44
2010	0.69	38771	1.48	1.62	1251	1.13
2011	0.72	56762	1.19	1.62	2820	1.01
2012	1.15	23388	2.01	1.76	1110	1.36
2013	1.29	18035	2.05	2.27	1105	1.74

Panel (b): Minimum distance to producing wells

	Full Sample			**Estimation Sample**		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
2003	1233.38	403	430.06	0	0	0
2004	1171.26	1043	469.12	0	0	0
2005	1089.13	1959	498.57	0	0	0
2006	1070.92	6212	514.86	456.1	2	91.68
2007	1107.62	10110	508.48	514.52	7	174.83
2008	894.65	21034	488.05	587.27	127	202.13
2009	894.56	14651	465.99	605.49	229	203.38
2010	909.44	35583	438.99	630.91	1251	212.68
2011	927.72	50109	426.92	669.45	2820	208.38
2012	904	21232	457.79	667.64	1110	216.28
2013	890.99	16936	448.75	667.42	1105	201.29

Table 4: Household Characteristics by Mineral Estate Status (Split vs. Full), Estimation Sample

	Full Estates			**Split Estates**		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
Estimation Sample: Active lease and drilling						
Appraisal value	105,115.3	6,100	65,442	100,274.9	551	75,352.5
Age (house)	23.69	6,081	18.22	25.96	551	19.54
Land (sqft)[a]	10,029.11	4,558	7843.43	9,228.27	422	5,887.02
Living area (sqft)	2,010.27	4,558	753.47	1,920.79	422	789.92
Bedroom	3.36	4,558	0.65	3.29	422	0.58
Bathroom	2.06	4,558	0.52	2.05	422	0.59
Groundwater	0.66	4,558	0.47	0.64	422	0.48
Drilling (within 1000 m)	1.79	6,100	1.32	1.83	551	1.53

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

Table 5: Percentage Split Estates by City (Estimation Sample)

	Full Sample			Estimation Sample		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
Arlington	0.08	23663	0.27	0.08	1930	0.27
Azle	0.15	312	0.36	0.08	48	0.28
Bedford	0.14	1042	0.34	0	1	0
Benbrook	0.11	1233	0.31	0.07	200	0.26
Burleson	0.09	654	0.29	0.19	31	0.4
Colleyville	0.1	1595	0.31	0	1	0
Crowley	0.09	912	0.29	0.07	82	0.26
Dalworthington	0.1	164	0.3	0	8	0
Edgecliff Village	0.09	141	0.28	0	4	0
Euless	0.07	1973	0.25	0.07	30	0.25
Everman	0.1	298	0.31	0.12	74	0.33
Forest Hill	0.11	809	0.31	0.11	83	0.31
Fort Worth	0.11	32648	0.31	0.09	2379	0.29
Grand Prairie	0.06	3693	0.23	0.05	500	0.22
Grapevine	0.08	1845	0.28	0.14	21	0.36
Haltom City	0.1	2094	0.29	0.08	238	0.27
Hurst	0.09	2170	0.29	0.02	41	0.16
Keller	0.1	2297	0.3	0.4	10	0.52
Kennedale	0.1	485	0.3	0.05	84	0.21
Lakeworth	0.14	235	0.34	0.13	32	0.34
Mansfield	0.07	6385	0.25	0.08	390	0.27
N. Richland Hills	0.08	4158	0.27	0.08	292	0.26
Richland Hills	0.09	999	0.29	0	32	0
River Oaks	0.12	437	0.33	0.04	24	0.2
Saginaw	0.13	551	0.34	0.28	29	0.45
South Lake	0.07	2610	0.26	0	0	0
Watauga	0.1	1319	0.3	0.26	19	0.45
White Settlement	0.11	586	0.31	0.12	34	0.33

Table 6: Percent Split Estate by Year (Estimation Sample)

	Full Sample			Estimation Sample		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
2003	0.06	963	0.24	0	0	0
2004	0.07	2120	0.25	0	0	0
2005	0.06	2373	0.25	0	0	0
2006	0.07	4646	0.26	0	2	0
2007	0.09	7383	0.29	0	7	0
2008	0.11	8990	0.32	0.08	127	0.27
2009	0.12	6242	0.32	0.11	229	0.32
2010	0.09	19094	0.29	0.08	1251	0.27
2011	0.09	26261	0.29	0.09	2820	0.29
2012	0.09	10473	0.28	0.08	1109	0.27
2013	0.09	7094	0.29	0.07	1105	0.25

Table 7: House Attributes by Sample Cuts

	Lease Match			**No Lease**		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
Appraisal value	128397.4	95686	94656.55	135014.7	120276	91317.69
Age (house)	28.91	95525	22.07	19.4	120113	21.52
Land (sqft)	10476.88	61537	7507.12	10054.94	75217	8127.27
Living area (sqft)	2063.55	61537	865.15	2196.06	75217	884.5
Bedroom	3.34	61537	0.68	3.4	75217	0.72
Bathroom	2.09	61537	0.66	2.15	75217	0.64
Groundwater	0.69	61537	0.46	0.59	75217	0.49
Drilling (within 1000 m)	0.48	95686	1.05	1.02	120276	1.89
	Auxiliary Clauses			**No Auxiliary Clauses**		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
Appraisal value	119036.3	25782	85667.03	131850	69904	97537.69
Age (house)	28.85	25731	21.13	28.93	69794	22.4
Land (sqft)	10337.01	25782	6870.89	10977.19	69904	8388.58
Living area (sqft)	2089.52	25782	853.49	2147.83	69904	922.56
Bedroom	3.36	25782	0.68	3.36	69904	0.71
Bathroom	2.09	25782	0.65	2.12	69904	0.72
Groundwater	0.65	25782	0.48	0.67	69904	0.47
Drilling (within 1000 m)	0.52	25782	1.12	0.46	69904	1.02
	Active lease			**Not active lease**		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
Appraisal value	123985.2	69386	92635.96	135916	146576	92734.39
Age (house)	30.3	69271	21.85	20.45	146367	21.76
Land (sqft)	10077.68	16672	6510.39	10625.23	44865	7840.19
Living area (sqft)	2019.14	16672	818.96	2080.05	44865	881.14
Bedroom	3.33	16672	0.66	3.35	44865	0.68
Bathroom	2.06	16672	0.62	2.1	44865	0.68
Groundwater	0.68	16672	0.47	0.7	44865	0.46
Drilling (within 1000 m)	0.58	69386	1.12	0.88	146576	1.77
	Active lease & drilling			**Active lease & no drilling**		
	Mean	N	Std. Dev.	Mean	N	Std. Dev.
Appraisal value	104683.6	6592	66382.44	122517.8	12400	91375.64
Age (house)	23.96	6573	18.39	32.53	12385	20.71
Land (sqft)	9535.7	3708	6592.66	9871.64	6659	5529.41
Living area (sqft)	1938.6	3708	724.17	1970.13	6659	793.14
Bedroom	3.33	3708	0.63	3.32	6659	0.64
Bathroom	2.03	3708	0.51	2.07	6659	0.61
Groundwater	0.7	3708	0.46	0.75	6659	0.44
Drilling (within 1000 m)	1.79	6592	1.34	0	12400	0

Table 8: Lease Attributes by Mineral Estate Status (Split vs. Full), Estimation Sample

	Full Estates		**Split Estates**	
	Mean	Std. Dev.	Mean	Std. Dev.
Primary:				
Royalty rate	0.23	0.04	0.22	0.08
Term length (> 36 months)	0.28	0.45	0.23	0.42
Auxiliary:				
Environmental	0.36	0.48	0.32	0.47
Freshwater protection	0.06	0.23	0.05	0.22
Injection fluid	0.03	0.17	0.03	0.16
No surface access	0.71	0.45	0.69	0.46
Subsurface easement bundle	0.6	0.49	0.61	0.49
Defend Title	0.26	0.44	0.21	0.41
Violations (log):				
Producing Wells	3.65	2.55	3.31	2.53
Casing Viol.	1.46	1.3	1.34	1.27
Bradenhead Pres.	0.17	0.41	0.16	0.39
Water Prot.	1.31	1.34	1.17	1.25
Royalty Obs	6100		551	
Term Obs	6100		551	
Clause Obs	6100		551	

Table 9: Simple Hedonics With Lease Attributes and Firm Fixed Effects[a]

	(1) Full estate	(2) Split estate
House age (appraisal date)	-10.783***	31.707
	(2.974)	(21.291)
Land area (1000 sqft)	1,427.600***	406.141
	(177.103)	(688.050)
Land area^2 (1000 sqft)	-136.882***	-70.245
	(30.164)	(121.110)
Living area (1000 sqft)	1,968.297***	732.042
	(371.584)	(898.740)
Living area^2 (1000 sqft)	120.760	505.447***
	(78.443)	(181.928)
Bedroom	-734.411***	-677.692***
	(68.523)	(238.414)
Bathroom	821.721***	2,434.579***
	(104.889)	(476.752)
Rural	1,545.196***	1,268.948*
	(433.341)	(691.492)
Groundwater	-310.889	1,108.485*
	(278.276)	(666.029)
Well exposure	-5.781	100.034
	(44.507)	(166.894)
Exposure*GW	-33.408	-75.840
	(52.409)	(175.122)
Royalty rate	733.294	
	(606.747)	
Environmental	79.934	-399.942
	(93.145)	(296.706)
Freshwater protection	1,138.865***	39.671
	(253.631)	(430.493)
Injection fluid	-47.905	-890.013**
	(87.874)	(387.388)
No surface access	236.744***	100.970
	(64.737)	(233.127)
Subsurface easement bundle	-342.903***	-5.288
	(96.379)	(236.277)
DefendTitle	293.658**	565.086*
	(132.664)	(297.553)
Firms' Total Well Count (logged)	-1,296.348***	2,717.370**
	(477.463)	(1,375.064)
Casing Violation (logged)	-155.604***	43.864
	(37.646)	(168.562)
Bradenhead Presssure Violation (logged)	-492.866	630.437
	(442.143)	(883.708)
Water Protection Violation (logged)	790.003*	-3,036.038*
	(410.677)	(1,725.681)
Water Protection Violation*GW	-147.470**	-250.121
	(61.926)	(219.242)
Observations	5,962	509
R-squared	0.725	0.776
City, Period FE	yes	yes
Firm FE	yes	yes

[a] Sample includes those observations (properties) located within 1000 meters of drilling activity and with a signed, active lease that includes information about lease characteristics.

Table 10: Non-Linear Hedonics With Firm Fixed Effects

	Est.	Std. Err.	P-value
Constant	3861.66	(3380.15)	0.25
Age (house)	-7.65	(3.34)	0.02
Land (1000 sqft)	1401.98	(182.4)	0
Land^2 (1000 sqft)	-133.91	(33.01)	0
Living area (1000 sqft)	1881.19	(394.65)	0
Living area^2 (1000 sqft)	149.8	(82.09)	0.07
Bedroom	-752.66	(67.07)	0
Bathroom	932.64	(105.43)	0
Rural	1355.65	(424.73)	0
Groundwater	-277.46	(249.55)	0.27
Drilling (within 1000 m)	5.18	(43.77)	0.91
GW*Drill	-21.41	(51.03)	0.68
Scale Param.	-1.65	(0.76)	0.03
City-level Fixed Effects			
Arlington	-279.73	(164.36)	0.09
Azle	-563.83	(618.28)	0.36
Burleson	-2164.22	(493.27)	0.00
Crowley	-551.22	(276.01)	0.05
Euless	2083.52	(204.84)	0.00
Everman	-589.75	(226.34)	0.01
Foresthill	-1290.09	(205.03)	0.00
Fortworth	-564.05	(228.03)	0.01
Grandprairie	-284.44	(170.06)	0.09
Grapevine	2360.58	(405.07)	0.00
Haltomcity	-264.4	(187)	0.16
Hurst	623.12	(240.79)	0.01
Kennedale	-274	(270.33)	0.31
Lakeworth	-895.13	(259.33)	0.00
Mansfield	83.49	(203.29)	0.68
Northrichlandhills	312.39	(170.31)	0.07
Richlandhills	-189.85	(239.07)	0.43
Riveroaks	-1189.28	(426.43)	0.01
Saginaw	-584.4	(303.59)	0.05
Whitesettlement	-427.71	(243.52)	0.08

Table 11: Non-Linear Hedonics *(cont.)*

	Hedonic Split Est. Eq.			**Hedonic Full Est. Eq.**			**Royalty Equation**		
	Est.	Std. Err.	P-value	Est.	Std. Err.	P-value	Est.	Std. Err.	P-value
Environmental	159.19	(92.73)	0.09	51.39	(92.73)	0.58	65.53	(81.5)	0.42
Freshwater protection	345.41	(247.04)	0.16	1116.59	(247.04)	0.00	-468.75	(153.61)	0.00
Injection fluid	-501.91	(88.31)	0.00	-43.85	(88.31)	0.62	-278.42	(85.91)	0.00
No surface access	105.02	(64.44)	0.1	260.68	(64.44)	0.00	-94.62	(64.49)	0.14
Subsurface easement	63.77	(97)	0.51	-293.21	(97)	0.00	216.99	(81.76)	0.01
Defend Title	551.29	(128.41)	0.00	293.37	(128.41)	0.02	156.78	(90.87)	0.08
Term months							-142.28	(65.1)	0.03
Violation Coefficients (logged)									
Producing Wells	-924.06	(658.6)	0.16	-853.32	(658.6)	0.2	0.00	(0)	0.00
Casing Viol.	-170.78	(38.08)	0.00	-147.48	(38.08)	0.00	-43	(69.53)	0.54
Bradenhead Pres.	-573.44	(444.47)	0.2	-426.88	(444.47)	0.34	-14.17	(29.71)	0.63
Water Prot.	827.72	(399.04)	0.04	679.97	(399.04)	0.09	-89.08	(235.71)	0.71
Water Prot.*GW	-233.92	(60.4)	0.00	-142.21	(60.4)	0.02	89.81	(151.87)	0.55

Table 12: Non-Linear Hedonics *(cont.)*

	Hedonic Equation			**Royalty Equation**		
	Est.	Std. Err.	P-value	Est.	Std. Err.	P-value
Firm Fixed Effects						
Carrizo	-291.58	(247.97)	0.24	1487.78	(206.84)	0.00
Chesapeake	1420.52	(1302.32)	0.28	1736.76	(326.7)	0.00
Circle	-3835.93	(3368.49)	0.26	999.65	(328.04)	0.00
Conglomerate	-3755.05	(3352.1)	0.26	1175.53	(335.62)	0.00
Dale Property	-1114.77	(1038.93)	0.28	1911.05	(261.15)	0.00
Ddjet	-3903.29	(3344.91)	0.24	1050.36	(310.48)	0.00
Devon	1252.82	(909.95)	0.17	4088.15	(545.92)	0.00
Finley	-2600.49	(2083.78)	0.21	893.37	(327.45)	0.01
Fleet	-3762.69	(3340.68)	0.26	1122.91	(305.92)	0.00
Four Seven	2308.68	(1065.89)	0.03	2165.27	(423.77)	0.00
Glencrest	-4014.72	(3348.62)	0.23	1408.99	(337.05)	0.00
Harding	-2120.14	(2083.55)	0.31	1350.19	(333.9)	0.00
Hillwood	-2549.69	(3360.94)	0.45	773.69	(295.53)	0.01
Hollis Sullivan	352.31	(1196.65)	0.77	1396.92	(391.69)	0.00
Llano Royalty	-2350.05	(2685.68)	0.38	1584.1	(309.5)	0.00
Paloma Barnett	-3990.74	(3345.53)	0.23	1465.6	(316.42)	0.00
Poteta	-4059.04	(3348.83)	0.23	1097.8	(318.97)	0.00
Quicksilver	500.73	(658.86)	0.45	692.46	(285.47)	0.02
Range	-1157.94	(855.08)	0.18	2685.59	(411.99)	0.00
Small Firm	664.75	(1119.22)	0.55	2498.85	(956.71)	0.01
Snow Operating	-3599.16	(3345.02)	0.28	1470.19	(399.48)	0.00
Thunderbird	-5612.62	(3344.84)	0.09	2449.36	(434.44)	0.00
Tierra	-3130.06	(3364.58)	0.35	1036.71	(307.71)	0.00
Tip	-3128.94	(3372.7)	0.35	1055.03	(317.39)	0.00
Whitestone	-3272.19	(3343.35)	0.33	1021.23	(302.63)	0.00
Woodcrest	-4082.62	(3358.63)	0.22	1148.1	(332.52)	0.00
Xto	1345.98	(1138.53)	0.24	2949.38	(231.01)	0.00
Year Fixed Effects						
2006	58.84	(279.78)	0.83	2547.28	(254.95)	0.00
2007	-1076.04	(190.41)	0.00	7.86	(239.35)	0.97
2009	320.48	(156.15)	0.04	-43	(273.91)	0.88
2010	437.35	(174.77)	0.01	-119.02	(239.68)	0.62
2011	77.33	(160.75)	0.63	-239.05	(234.68)	0.31
2012	199.96	(152.03)	0.19	-95.58	(235.51)	0.69
2013	348.32	(154.29)	0.02	12.54	(236.4)	0.96