I can hear my neighbors' fracking: The effect of natural gas production on housing values in Tarrant County, TX

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Abstract

The technique of hydraulic fracturing has made it possible to produce vast new quantities of oil and natural gas, yet the process has associated risks, and has been a controversial issue in popular media. In this study we estimate the effect hydraulically fractured natural gas wells have on residential real estate prices. We exploit variation in distance to nearby gas wells in home sales prices to estimate this effect. Our study is the first to focus on a relatively densely populated area, a section of the Dallas-Ft. Worth-Arlington urban area. Our data is from Texas over the period 2005-2011. We find robust evidence that increased proximity to a fractured well leads to reduced home sale prices. Existence of wells within 3,500 feet of a property reduces property values by approximately 3%.

Keywords: Hydraulic fracturing, spatial dependence, hedonic valuation
JEL Codes: Q35, Q33, R21

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Introduction

The International Energy Agency projects that by 2020 the United States will overtake Saudi Arabia as the world's largest oil producer, largely because of increasing exploitation of unconventional deposits of hydrocarbons, made possible by hydraulic fracturing, known colloquially as "hydrofracking", or "fracking." By 2007 unconventional production already accounted for 46% of US natural gas production (Navigant Consulting, 2007). Aside from creating thousands of jobs (Weber 2011, Marchand 2012), and enhancing US energy security, hydraulic fracturing can make the US economy less carbon intensive because it is used more heavily in natural gas production (EIA 2008). Yet hydraulic fracturing has attendant impacts and risks, which have been frequently highlighted in popular media.[1] The issue is growing in significance because as of 2013, 15.3 million Americans live within 1 mile of a hydraulically fractured well.[2] Hydraulic fracturing causes earthquakes.[3] Leaking well casing can contaminate air and groundwater (Jackson et al. 2013). Above ground infrastructure may provide dis-amenities to homeowners; it can even explode.[4] One way to measure a *portion* of the potential costs and benefits of hydraulic fracturing—those costs and benefits borne by residential property owners—is through hedonic regression. Our paper uses sales data in Tarrant County, TX to add to a growing literature (Gopalakrishnan and Klaiber 2012, and Muehlenbach *et al.* 2012) that uses variation in homes sales price and spatial variation in well location to quantify the costs (benefits) of hydraulic fracturing from the perspective of homeowners.

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[1] For example http://www.dangersoffracking.com/ (connected with GasLand) http://www.nytimes.com/2010/07/24/business/energy-environment/24gas.html?pagewanted=all&_r=0 or http://www.star-telegram.com/living/family/moms/article3827288.html

[2] Gold, Russell, and McGinty, Tom. "Energy Boom Puts Wells in America's Backyard," Wall Street Journal, Oct 25, 2013, http://www.wsj.com/articles/SB10001424052702303672404579149432365326304 .

[3] Earthquakes caused by injection were demonstrated by the US Army disposing of waste fluid in Rocky Mountain Arsenal near Denver; subsequently the Rangley Oil Field Experiments demonstrated scientifically that earthquakes occur when injection pressure exceeds 3,700 psi. (Walker, 1982, pg 116-117). For specifics related to fracking, see (Frohlich, 2012). http://stateimpact.npr.org/texas/tag/earthquake/

[4] A 2009 pipeline explosion in Amarillo, TX registered a 4.0 magnitude earthquake (Rahm 2011).

Our study area is economically important and of policy relevance because we are the first to investigate the effect of hydraulic fracturing in an urban context. Tarrant County overlies the prodigious Barnett Shale, which alone accounts for 6% of natural gas production in the United States (EIA 2009). The formation spans multiple counties; however, in just Tarrant County, the appraised mineral value of natural gas deposits exceeds $2.54 billion.[5] Moreover, Tarrant County, which is centered on Ft. Worth, is largely urbanized, much of it being spanned by municipalities. Here the costs and benefits of hydraulic fracturing are of larger policy relevance because of the denser population exposed to these costs and benefits. Previous studies focus on comparatively rural Washington County, Pennsylvania (Gopalakrishnan and Klaiber 2012, and Muehlenbach *et al.* 2012). These studies show hydraulic fracturing to be associated with reduced home values, but only when interacted with groundwater usage. In our urbanized study area, the entire population falls within the purview of the Tarrant Regional Water District, and so groundwater usage is of less concern.[6]

We primarily employ hedonic regression to isolate the effect of hydraulic fracturing on residential housing values. In this framework, houses can be thought of as a bundle of attributes. Given thick markets, each housing attribute is associated with an implicit price. By regressing sales price on an observed vector of housing attributes, these implicit prices can be recovered. Transformation of the coefficients (and in some cases the coefficients themselves) yields the marginal willingness to pay for each attribute. We buttress our primary methodology by using repeat sales to identify the same effect. The question is whether proximity to a hydraulically fractured well is an important attribute for the buyers and sellers of residential real estate. Are homebuyers willing to pay a premium or must they be compensated with a lower home price in order to live near these wells? A well may positively affect sales price if the property has attached mineral rights and receives royalty payments from the well. Moreover, the economic boom ignited by hydraulic

[5] Tarrant Appraisal District, MNRL file downloaded Aug 1, 2014.
[6] We include, however, a robustness check to further control for possible drinking water source.

fracturing may stimulate housing demand in general. This impact may lead to increased housing prices for the region, but is unlikely to only impact housing prices within small distances from wells. On the other hand, a home sited in close proximity to a gas well may sell for reduced value if there is some dis-amenity associated with gas production, perhaps because of degradation of groundwater or air, increased noise and traffic during drilling, or through the potential for spills and other environmental hazards (Lipscomb *et al.* 2011).

Our data set comprises 127,556 observed home sales during the time period 2005-2011 from the multiple listing service in Tarrant County, TX. We match these data to property records provided by the county. Natural gas well information is provided by DrillingInfo, including spatial location of wells, and completion date. We find that hydraulically fractured wells negatively affect home values, and that this effect persists long after well construction has been completed. We find that sales within 3,500 feet of a completed well have prices reduced significantly by about 3%, or around $5,000, evaluated at the mean, and sales within 3,500 feet of a well under construction suffer a statistically significant 2% reduction in price. Using the repeat sales approach, we find an additional completed well within 3,500 feet of a sale significantly reduces price by 1.5%.

The paper proceeds as follows. Section 2 provides a background on hydraulic fracturing, and places this paper within the context of prior research. Section 3 discusses the implementation and specification of the hedonic regression. Section 4 documents the data. Section 5 presents and analyzes the results. Section 6 concludes.

Background

Two advances in drilling technology have allowed for economically viable exploitation of natural gas deposits in the Barnett Shale. These advances are hydraulic fracturing and horizontal drilling. The process of hydraulic fracturing involves pumping water mixed with certain chemicals at high pressure into the reservoir rock to fracture the rock. Gas can then flow along the fractures at economic rates to the well-face and then to the surface. Horizontal drilling allows more of the well-face to be exposed to the production zone, and thus produced. For example, if the target formation is 20 feet thick and oriented horizontally, a vertical well would only be exposed to those 20 feet; on the other hand, a horizontal well could run a much longer length of the formation, draining a much larger area. This means fewer horizontal wells are required to drain a field. Horizontal drilling combined with fracturing has led to the shale gas boom.

Hydraulic fracturing was first experimented with in Texas in the 1950s (EIA 2009). The basic principles however were tried (perhaps inadvertently) far earlier in 1901, when producers in Pennsylvania first dynamited tapped out wells to fracture rocks and increase the rate of production (Yergin 2001). Hydraulic fracturing was implanted in the Barnett Shale in 1986, the first horizontal well in 1992 (EIA 2009).

The natural gas (oil) exists in the pore space of rocks, thousands of feet below the surface. The weight of the overlying rock pressurizes the hydrocarbons to thousands of pounds per square inch. A conventional vertical well creates an area of low pressure in the rock. The oil/ gas then flows through the interconnected pore space to the area of lower pressure at the well-face, and on to the surface. What makes the Barnett Shale special is its ultra low permeability (the pores in the rock are not well connected). Conventional reservoirs have permeabilities in excess of 100 millidarcies[7], but the Barnett shale permeability is several orders of magnitude lower, ranging between 0.01 and 0.00001 millidarcies, (EIA 2009). With conventional drilling technology extraction would not be profitable; the gas could not flow rapidly enough to the surface to be economical. Hydraulic fracturing and horizontal drilling overcomes these difficulties in two ways: the hydraulic fracturing opens new pathways in the rock along which the natural gas can flow; simultaneously, horizontal drilling exposes more production piping to the resource bearing strata, so the natural gas has less distance to travel through rock in order to

[7] http://www.geomore.com/porosity-and-permeability-2/

reach the production area.[8] Moreover, from an economic perspective fracturing is extremely cost effective: multiple wells can be drilled from a single production area, making the surface footprint smaller; these wells can be extended in any direction; the horizontal drilling means fewer wells are needed for recovery; because the wells are concentrated, less pipeline and fewer access roads are needed.

Horizontal drilling allows for multiple wells to be drilled from a single production area (called a "pad"), averaging around ½ acre. The construction process proceeds as follows. Before the well is drilled, the operator must receive a drilling permit from the Texas Railroad Commission, and negotiate lease payments to mineral owners. Once the rights having been obtained, drilling and fracturing commence, which is the most conspicuous time in the lifecycle of the well. A drilling derrick in excess of 150 ft tall is brought in to bore the well. From the vertical well, 3-4 horizontal wells are drilled in any direction into the pay area far below (Devon Energy). The horizontal wells come in three varieties depending on the horizontal distance it takes the well to go from vertical to horizontal. Long radius wells require more than a thousand feet to reach 0° level, and, from there, can then be extended several thousand feet farther. Short and medium radius horizontal wells have sharper turns, and because of this, are more difficult to extend and do not reach as far. During the drilling process casing is cemented in along the way to isolate the production area and provide structure to the well to prevent collapse. When surface valving is added, the well is said to be completed.

These horizontal wells must then be fractured.[9] Trucks are brought in to pump fracturing liquids into the well. The number of trips is substantial: Gopalakrishnan and Klaiber (2012) report over 800 one-way heavy truck trips, and well over 1,500 one-way light truck trips are necessary per well. The process of fracturing is loud, registering 50 decibels at 1000 feet.[10] The process is also water

[8] The increased length of pipe exposed to the pay zone reduces the pressure drop around the well bore, lowers fluid viscosities, and reduces sand production, among other things.

[9] This process takes between 3-10 days (Halliburton).

[10] http://www.earthworksaction.org/issues/detail/oil_and_gas_noise#.VNFEw2jF98F

intensive, requiring 2-3 million gallons per well. 15-80% of these fracturing fluids return to the surface where they are stored in above ground pool awaiting permanent disposal.[11] Fracturing fluid is mostly water but has numerous chemical additives. The specific chemicals are often proprietary trade secrets, but the EIA reports that additives typically include acids to dissolve minerals clogging pore spaces, biocides to prevent bacterial growth, corrosion inhibitors to protect equipment, sand to keep fractures propped open, friction reducers to aid flow, gels to suspend the sand in water, and surfactants to increase fluid viscosity (EIA 2009, pg 63, exhibit 36).

Once fractured, the wells become comparatively unobtrusive, with only 5-6 feet of surface valving left behind per well if the wells are connected directly to pipeline. Without pipelines, surface storage is necessary and trucks must periodically come to empty these storage units. The well can produce an average of two years before it needs to be serviced, and in some cases be refractured multiple times.

The EIA estimates that the Barnett shale has 327 TCF (trillion cubic feet) of gas originally in place, of which 44 TCF is technically recoverable. In 2008 the Barnett Shale accounted for 6% of US Production. The appraised value of mineral deposits is estimated at 2.54 billion in 2014 (TAD). What is unique is the Barnett shale's urban location. It underlies both Dallas and Ft. Worth, and spans several urban counties. Tarrant county, our study area, is home to 1.9 million people as of 2013 (estimate, US Census).

The urban setting brings unique challenges and concerns. In certain ways hydraulic fracturing and horizontal drilling are uniquely suited to urban drilling. These techniques reduce the surface footprint as mentioned earlier: fewer wells are required to drain a field, wells can be concentrated on a pad requiring fewer roads and pipelines. Drilling innovations have also brought legal innovations. Split estates,

[11] There are three options for disposal: the water may be reinjected into the well, treated and discharge into surface water, or applied to land surface. All options for disposal require permits.

where one agent owns the surface rights, and a different agent owns the mineral rights, are commonplace in Texas. It is taken for granted that for the mineral rights to have any value, the mineral rights owner must be granted the surface access necessary to withdraw the minerals. Furthermore, this "access" allows for the building of roads and the installation of wells without necessarily requiring remunerating the surface owner for damages. However, horizontal drilling allows access to minerals below a property without the need for surface access to the property. When estates are split, it is now possible to exclude the mineral rights owner from surface access.[12] This can attenuate the negative perceptions of oil and gas production to property owners. Furthermore, when the surface owner also owns the mineral rights, horizontal drilling can make these rights comparatively more valuable, because surface damages do not need to be incurred to extract the minerals.

Natural gas production and hydraulic fracturing have many potential costs, whether through environmental quality, health and safety, land footprint, or the potential for spills. The attendant benefits to hydraulic fracturing are the rents generated, some of which are paid to lease owners as royalties, job creation, and stimulating housing demand. We examine each of these in turn.

Environmental degradation is one of the overarching concerns in regards to hydraulic fracturing. First, the technique requires a large amount of water, yet Tarrant County has a semi-arid climate and is often in drought. Leaking well casing can result in unintended methane emissions above ground, and can pollute aquifers with gas and fracturing chemicals below ground. Such pollution has alarming health and safety consequences. Rahm (2011) cites study of exposure of households in Dish, Texas,[13] 65% of whom had toluene in their system, 53% xylene. Additionally, the EPA issued an endangerment order requiring immediate action by the city of Ft.

[12] The deed language implies that the mineral rights are severed but the mineral rights owner has no access (no right of ingress or egress over, upon, or across) to the surface to extract (explore, drill, mine, produce, or store) the minerals.
[13] Located in Denton County, Tarrant's neighbor to the north.

Worth to protect residents from methane exposure, after reports of inflammable taps and bubbling drinking water. [14]

Oil industry equipment comes with other safety concerns and dis-amenities which may affect sales price (Lipscomb *et al* 2011). For example, pipelines occasionally explode[15]; however, Boxall *et al.* (2005) find no evidence that pipelines negatively affect sales price. Gopalakrishnan and Klaiber (2012) document increased truck traffic and noise during construction and fracturing which may provide nuisance for homeowners. Land footprints during construction may be large and unsightly. Moreover, for buyers of split estates with no surface exclusion, there is risk they may have to yield surface use without reparation at some future date. The threat of accidents and spills may also depress sales prices.

There are different methods for estimating the costs and benefits of hydraulic fracturing. In this paper, we pursue hedonic regression to demonstrate whether these costs and benefits are capitalized in real estate value; however, it is important to understand that this method does not account for the full costs or full benefits of fracturing. Several previous studies have implemented this method; this is the first study to focus on a largely urbanized area.

The first study to examine the effect of oil and gas infrastructure on real estate prices was Boxall *et al.* (2005), which examines the impact of gas wells on property values in rural areas of Alberta. A particular feature of the paper is that many of the gas wells are "sour," producing hydrogen sulfide gas as a byproduct. The added hazard requires emergency planning zones to protect residents against

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[14]Federal regulation is muddled with regard to the oil and gas industry, and exemptions have been granted to the industry under many statutes. Discharge of oil and gas related production water falls under the purview of the Clean Water Act, with permits granted under the National Pollutant Discharge Elimination System; however, the Energy Policy Act of 2005 excludes the oil and gas industry from having to apply for a permit for water discharged in the *preparation* of a well. The US 9th Circuit has ruled that this preparation water still needs permits for sediments in the water that contribute to violations of the Clean Water Act. Wells are also subject to national regulation from the Safe Drinking Water Act, which monitors and can close wells that are contaminating public water. CERCLA is not relevant because oil and gas are not considered hazardous substances and are not required to report releases under the Toxic Release Inventory. The oil and gas industry is also exempted from the Resource Recovery and Conservation Act (1976) (EIA 2009).

[15] A 2009 pipeline explosion in Amarillo, TX registered a 4.0 magnitude earthquake (Rahm 2011).

exposure. The authors find that a 1% increase in the number of wells within 4 km of a home reduces property values by .04%.[16] When, however, wells are separated into "sweet" wells (wells that do not produce hydrogen sulfide) and sour wells, the sweet wells have no statistically significant effect; nor do pipelines.

Gopalakrishnan and Klaiber (2012) use sales data from Washington County, PA over 2008-2010 to examine the effect of hydraulic fracturing on real estate values. They focus on interactions with groundwater usage, finding that permitting of a well within one mile and within six months prior to a sale reduces sales price significantly by $1,256. This effect is localized both temporally and spatially. The authors find no significant effects of permitting a well more than a mile away, or twelve months prior to the sale. Without the interaction term, the effect on sales price is actually positive, which may be due to royalty payments.

Muehlenbachs *et al* (2012) use data from the same Washington County from 2004-2009 in a similar hedonic study. The authors employ a difference-in-difference-in-difference approach, comparing sales prices for homes inside and outside a 2000m buffer of well pads, with the second difference being homes that rely on groundwater versus public water. The authors find that homes within the 2000m buffer that rely on groundwater suffer a reduction in value of 23.6% ($30,027 for the mean sales price); however, homes with municipal water receive a 10% increase in price, likely due to lease payments from the wells.

Our study makes three important contributions to the literature. Foremost, the study is the first to examine how hydraulic fracturing affects property values in urban areas. The higher population densities of urban areas imply a much larger number of parcels affected by hydraulic fracturing, with higher prices per unit of land. These together heighten the policy relevance as the externality costs to private land owners (and also public lands) are increased. Second, differences in land use are predicted to have different effects in urban and rural areas (Lipscomb *et al.*

[16] Mineral rights in Canada are government property, and can be leased, but not owned. http://www.nrcan.gc.ca/mining-materials/policy/legislation-regulations/8726 Still, there may be lease payments to surface owners for compensation of damages.

(2012). Finally, previous studies have concentrated on the effect of hydraulic fracturing for groundwater users. Most of Tarrant County is spanned by municipal areas, and receives municipal water. Our study focuses on the broader impacts of hydraulic fracturing.

Methodology

We primarily employ hedonic regression to estimate the impact of having a well nearby on transaction price. The methodology was developed by Rosen (1974). In thick housing markets, a residential property can be decomposed into a bundle of attributes for which consumers have some willingness to pay. By regressing home price on the attributes, the average marginal willingness to pay can be recovered—they are the estimated coefficients. Our question is whether, conditional on other housing attributes, people demand compensation (or are willing to pay) in order to live within a certain distance of a well. The equation we estimate is

$$\ln P_{ijt} = \alpha + \Gamma W_{it} + \Omega X_i + \phi_t + \mu_j + \varepsilon_{ijt} . \qquad [1]$$

The dependent variable, P_{ijt}, is the natural log of the transaction price for a home *i* in ZIP code *j* at time *t*. The vector W_i comprises a series of identifiers on whether the home is within 3,500, 5,000, or 6,500 feet of a well.[17] Thus, the estimands, Γ, test the hypothesis that landowners require lower prices due to proximity to hydraulic fracturing. The vector X_i includes a standard set of observed property characteristics, such as number of bedrooms, number of bathrooms, and square footage; it also includes location (dis)amenities such as distance to the central business district and indicators of being nearby lakes, railroads, highways, or rivers. The hedonic model includes time dummies, ϕ_t, and ZIP code fixed effects, μ_j.

An alternative specification is the Box-Cox model which has been shown to yield a better fit when including spatial and temporal fixed effects (Kuminoff *et al.* 2010).

[17] These identifiers vary by specification and may also include if the home is nearby a construction well or close to a specified count of wells.

$$(P_{ijt}^{\theta} - 1)\theta^{-1} = \alpha + \Gamma W_{it} + \Omega X_i + \phi_t + \mu_j + \varepsilon_{ijt} \qquad [2]$$

θ is a fit parameter between -1 and 1 to be estimated, other variables are the same as before. This transformation of the standard hedonic model allows for a more flexible estimating functional form, but the resulting coefficients must be converted to marginal changes to be interpreted.

Lastly, we estimate a repeat sales model as a robustness check to our primary specification. A major concern with hedonic models the presence of unobservable characteristics of the properties. By looking at repeat sales, the unobservables are held constant.[18] The estimating equation is

$$\ln(P_{ijt+\tau} / P_{ijt}) = \Gamma(W_{it+\tau} - W_{it}) + \sum_{j=1}^{n} \eta_j D_{ij} + \varepsilon_{ijt} \qquad [3]$$

Each property included in the repeat sales method experiences at least two transactions; the original transaction price at time t is given by P_{ijt} with the second price at time $t+\tau$ denoted $P_{ijt+\tau}$. The percentage change in price is explained by the change in proximity to hydraulically fractured wells. We also include the standard D matrix identifying the sales dates.[19]

Data

Our sales data in current dollars comes from the Multiple Listing Service over the period 2005-2011, containing over 129,000 transactions, 64% of which are single transactions. The MLS data is merged by address with appraisal data from the Tarrant Appraisal District[20] in order to gain information on property attributes, including number of bedrooms, number of bathrooms, year built, number of

[18] Of course, the repeat sales method has drawbacks as well. Particularly, the significant loss in transaction data as it requires a particular home to be sold more than once during a short time span(which by itself may signal that the home is different in some way) and the assumption that the home is not significantly altered during the study period.
[19] This matrix identifies the quarter of each transaction and is determined at a specific geographic area, j. We utilize a few different geographic areas, county, city, and school district level, so we keep equation [3] general in terms the number of areas. As the number of repeat sales properties is significantly lower than the total transaction dataset, we are unable to evaluate at the ZIP code level.
[20] This data is available for download at the TAD website. *AAAA* file, downloaded April 4th, 2014.

structure, acreage, area, central heating and air, and garage characteristics. The file is only available for 2014, so the merge makes the assumption that properties have not changed significantly over the period of study. We eliminate all non-residential properties, properties with missing information, and non-armslength transactions, those with sales prices below $10,000. This leaves 127, 556 observations.

Well information for Tarrant County comes from *DrillingInfo*, and includes well activity and completion date. 99% of the wells are classified as natural gas production wells, 97% are drilled in the Newark East field, 95% are drilled into the Barnett Shale formation. Finally 85% of wells are registered as horizontal wells. We've included both active (95%) and inactive wells, and both horizontal and vertical wells. Our reasoning is that inactive wells and vertical wells may still provide a dis-amenity to homeowners, and if so, is an effect we want to measure. If buyers and sellers do not care about inactive wells or vertical wells, then it should attenuate our estimate towards 0.

Data are plotted in ArcGIS to create spatial variables. ESRI map files are used to overlay municipal areas, counties, ZIP codes, school districts, roads, lakes, and railways. We then create buffers around sales of 3,500, 5000, and 6,500 feet and count the number of wells within each concentric ring. We refer to these buffers as ring 1, ring 2, and ring 3, respectively. From these counts, we generate identifiers, w_{3500}, w_{5000}, and w_{6500}, which are equal to one when the well count in the ring is greater than 0. We also explore pad effects and generate identifiers which are equal to one when the count in the ring is between 1 and 6, 7 and 12, and over 13.

Summary statistics are presented in Table 1. For our full sample the average sale has 3 bedrooms, and 2 bathrooms; 70% of households have a two-car garage, 97% have central heating and air, and 15.7% have a swimming pool. Notice that sales price is slightly lower but not statistically different for those houses with at least one well nearby than the full sample average. Properties without a nearby well are slightly larger and are more likely to have a swimming pool, but are older and farther from the city center. In order to control for the observable differences in structures we now turn to our hedonic regressions.

Results

Table 2 shows the estimation results for equation 1. We use five specifications which vary due to the inclusion of dummy variables for whether there is a well within a ring of 3,500 feet of the sale, within 3,500-5000 feet of the sale, and within 5,000-6,500 feet of the property. Alternatively we measure pad effects by generating indicator variables for 1-6 wells, 7-12 wells, and more than 13 wells within each ring. We also vary the fixed effects within the model.

The first column of table 2 reports coefficient estimates for a standard hedonic regression. Standard errors are clustered at the zip code level, and quarter-year fixed effects and zip code fixed effects are also included. Signs and significance are as expected with the exception of bedrooms. Another bedroom reduces sale price by 3.7%. It should be remembered that this specification controls for the size of the house and property, thus cramming another bedroom into the same sized house may well reduce the value. Most importantly, control coefficients remain stable across specifications.

Specifications 2 and 3 include well indicator dummy variables for each of the three rings; the difference is the inclusion of the interaction fixed effects.[21] Properties with hydraulically fractured wells within 3,500 feet have reduced transaction prices, controlling for observable home and location amenity effects. The magnitude of the reduction in price ranges from 2.8% to 3.5%, or evaluated at the mean transaction price between $4,720 and $5,900. As expected, table 2 shows wells farther away have less effect on home price; the effects are not statistically significant and are of reduced magnitude (between 0.3% and 1.3%).

[21] Specification 2 incorporates quarter-year and ZIP code fixed effects whereas specification 3 contains additional fixed effects for the interaction between quarter-year and ZIP code.

Table 2 also shows the pad effects; we use the number of wells within the rings to determine if the property is nearby one, two, or more than two pads.[22] In the preferred specification, which includes space-time interaction fixed effects (specification 5), a pad within 3,500 feet reduces home value by 3.2%. The inclusion of the space-time interaction fixed effects reduces the coefficient estimates indicating that there is some unobserved difference over time within ZIP code that may be influencing the results. Interestingly, a property with more than one pad in close proximity does not affect the transaction price.[23] Properties with three or more pads within 3,500 feet are rare, only 1.5% of the total transaction sample. We suspect transactions with so many wells in close proximity include mineral rights and subsequent revenues.

Table 3 presents a Box-Cox transformed hedonic regression (equation 2) on the same specifications as in table 2.[24] The optimal transformation parameter, θ, is estimated prior to the hedonic regression and ranges between .216 and .220. The results show an almost identical pattern; properties with wells or pads (up to 2) within 3,500 feet suffer from reduced sales prices. The hydraulic fracturing effects are not found in the second or third ring when controlling for space-time interaction fixed effects. The interpretation of the coefficients in table 3 is altered; in order to calculate the marginal effect on transaction price, the coefficients must be transformed as follows:

$$Marginal.Effect = \overline{P}^{1-\theta}\Gamma \qquad [4]$$

Table 4 shows the marginal effects for both the standard hedonic and Box-Cox transformed regressions.[25] Under the preferred specifications (specification 3 and 5), which included the space-time interaction fixed effects, we find the marginal

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[22] As the average pad contains 4-6 wells, we create dummy variables for homes with 1-6, 7-12, and 13 or more wells within each ring.

[23] The effect of two pads is nearly the same magnitude of one pad, -2.8%, but the estimate is just outside the standard significance level of 10 percent. If we employ a one-tailed test (the null hypothesis is that the effect is positive), then the estimate is statistically significant at the 10% level.

[24] Results for variables are slightly more precisely estimated under the Box-Cox transformation.

[25] The standard hedonic effects are calculated from the mean sales price.

effect of a well within 3,500 feet is approximately $4,725. The concession required to accept a well in the second nearest ring is about $1,200, but insignificant. The effect continues to taper with distance to sale, which is consistent with spatial attenuation.

Previous studies of hydraulic fracturing find that the effect of home values differs during the lifecycle of the well (Gopalakrishnan and Klaiber 2012) We therefore examine the impact of drilling on sales that occur within six months of well completion, and also sales made after well completion. Table 5 shows that the effects of completed wells are very similar to the results from earlier specifications; however, construction well effects are found to also have an effect on transaction price. Short-term disamenities from construction appear to have an effect while not altering the long-term effects of proximity to hydraulically fractured wells.

Focusing on the specifications with the space-time interaction fixed effects (specifications 7 and 9), we find properties with at least one construction well within 3,500 feet sale for 1.8% less. The second ring effects are also statistically significant and indicate a reduction of 1%, while the third ring effect is an insignificant 0.4%. This pattern is continued when examining pad effects. A property with a pad within 3,500 feet sells for 1.8% lower price; the second and third pad effects are not statistically significant but are larger in magnitude than the first ring effect (2.4% and 6.4%, respectively). A single pad between 3,500 and 5,000 feet away from a property reduces transaction price by 1.1%. The third ring effects are not statistically significant.

Lastly, we estimate a repeat sales model to control for all unobservable characteristics at the property level as a robustness check. We have a relatively short time period which leads to a very small sample of properties sold more than once, about 15,000 properties. We are also concerned about investors “flipping” or making very quick significant improvements to these properties; so, we limit our sample to those properties that have 6 months between sales.[26] Lastly, external validity to the larger housing market is reduced as homes selling more than once may be different than homes that sold only once.

Table 6 presents the estimation of equation 3 for four different specifications. In all specifications we estimate a price index by including the standard matrix for sales dates where the first transaction in the pair takes value -1 and the second takes 1. The specifications differ based on the scope of the price index. Specification 1 takes Tarrant County as a whole and finds significant impacts of proximity to hydraulically fractured wells in each ring on transaction price. The magnitudes are very similar to the hedonic results. Since we do not imagine the entire county constitutes the local housing market we focus the price index down to the school district-level in specification 2 and find significant reductions in sales price for homes with wells in rings 1 and 2.[27] Narrowing further, we estimate the price index for each of Tarrant County's 43 cities in specifications 3 and 4. These are the preferred specifications and find significant impacts on transaction prices when homes have wells or one pad within rings 1 and 2. The magnitudes suggest prices are reduced by 1.9% and 1.6% for the existence of a well in ring 1 and ring 2, respectively. Evaluated at the mean sales price for the repeat sales sample ($176,065) the effect translates to a reduction of $2,817 to $3,345. Pad effects are of similar size.

Conclusion

We find hydraulic fracturing is associated with a reduction in property values. Hedonic regressions using both Box-Cox and logarithmic transformation find that a natural gas wells reduce the sales price of homes from 1% to about 3.5%. With this figure in mind, policy makers can better understand some of the costs of hydraulic fracturing. It should be kept in mind that this estimate represents a lower bound of

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[26] We have tried longer holding times and while the transaction count is reduced the magnitude and significance of the results largely remains unchanged.
[27] 18 different school districts are represented in our sample.

the actual true cost to property, which is itself a lower bound to the true cost of hydraulic fracturing.

Works Cited

Boxall, P. C., W. H. Chan, and M. L. McMillan (2005). The impact of oil and natural gas facilities on rural residential property values: a spatial hedonic analysis. Resource and Energy Economics 27, 248–269.

Council, G. W. P. and A. Consulting (2009, April). Modern shale gas development in the united states: A primer. Technical report, US Department of Energy.

Gopalakrishnan, S. and H. A. Klaiber (2012). Is the shale boom a bust for nearby residents? evidence from housing values in pennsylvania.

Kuminoff, N., C. Parmeter, and J. Pope (2010). Which hedonic models can we trust to recover the marginal willingness to pay for environmental amenities? Journal of Environmental Economics and Management 61(3), 145–60.

Lipscomb, C. A., Y. Wang, and S. J. Kilpatrick (2012). Unconventional shale gas development and real estate issues. The Review of Regional Studies 42, 161–175.

Marchand, J. (2011). Local labor market impacts of energy boom and bust in western canada. Journal of Urban Economics.

Muehlenbachs, L., E. Spiller, and C. Timmins (2012, September). Shale gas development and property values: Differences across drinking water sources. Working Paper 18390.

Rahm, D. (2011). Regulating hydraulic fracturing in shale gas plays: The case of Texas. Energy Policy 39, 2974–2981.

Rosen, S. (1974, January-February). Hedonic prices and implicit markets: Product differentiation in pure competition. Journal of Political Economy 82(1), 34–55.

Weber, J. (2011). The effects of a natural gas boom on employment and income in Colorado, Texas, and Wyoming. Energy Economics.

Table 1. Descriptive statistics.

	Full Sample		At least one well within 3500 feet		At least one well between 3500 and 5000 feet		At least one well between 5000 and 6500 feet		No wells within 6500 feet	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Sales Price (dollars)	168,594	157,672	168,949	112,022	145,534	117,663	150,742	134,654	183,492	178,784
Log of Sales Price	11.80	0.66	11.73	0.60	11.68	0.64	11.70	0.65	11.87	0.67
Number of bedrooms	3.35	0.74	3.39	0.71	3.32	0.70	3.29	0.70	3.36	0.76
Number of bathrooms	2.13	0.71	2.10	0.58	2.06	0.63	2.05	0.66	2.17	0.77
Living area (sqft)	2096.80	937.59	2096.31	827.71	2001.50	824.84	1997.39	862.40	2132.01	1004.02
Swimming pool	0.16	0.36	0.09	0.29	0.11	0.31	0.13	0.34	0.19	0.40
Land area (acres)	0.25	0.34	0.28	0.50	0.23	0.27	0.23	0.26	0.24	0.29
Central Heating	0.97	0.17	0.98	0.15	0.97	0.18	0.96	0.19	0.97	0.17
Central Air-conditioning	0.97	0.17	0.97	0.16	0.96	0.19	0.96	0.20	0.97	0.17
Garage, 1 car	0.07	0.26	0.05	0.23	0.08	0.27	0.09	0.28	0.07	0.26
Garage, 2 car	0.72	0.45	0.77	0.42	0.73	0.44	0.71	0.45	0.70	0.46
Garage, 3 or more cars	0.11	0.31	0.10	0.29	0.07	0.26	0.08	0.26	0.12	0.33
Distance from city center (miles)	11.28	4.41	10.67	3.85	10.44	4.25	10.40	4.31	11.82	4.57
Within 1/2 mile of a major lake	0.03	0.17	0.03	0.17	0.03	0.17	0.03	0.16	0.03	0.17
Within 1/2 mile of a railroad	0.18	0.38	0.23	0.42	0.21	0.41	0.20	0.40	0.14	0.35
Within 1/2 mile of a major highway	0.15	0.36	0.13	0.34	0.16	0.37	0.18	0.39	0.15	0.36
Within 1/2 mile of a major river	0.07	0.26	0.07	0.26	0.08	0.26	0.08	0.27	0.07	0.25
Age of house at time of sale	23.28	19.88	16.22	18.70	23.99	21.18	28.11	21.31	24.99	19.16
Structure count	1.00	0.08	1.00	0.08	1.00	0.07	1.00	0.07	1.00	0.08
Number of observations	127,556		27,290		15,011		11,576		73,679	

Notes: Residential sales transaction data for Tarrant County, Texas between January 1st 2005 and September 30th 2011.

Table 2. Standard hedonic regressions.

Dependent variable = ln(Sales Price)										
Specification:	(1)		(2)		(3)		(4)		(5)	
	Coeff.	Std. Err.	Coeff.	Std. Err.	Coeff.	Std. Err.	Coeff.	Std. Err.	Coeff.	Std. Err.
Hydraulic Fracturing Effects										
Ring 1 - within 3500 feet										
One or more wells	.	.	-0.035***	0.011	-0.028**	0.012	.	.	.	.
One to six wells	.	.	.	.	.	.	-0.037***	0.011	-0.032**	0.012
Seven to twelve wells	.	.	.	.	.	.	-0.037***	0.015	-0.028	0.018
Thirteen or more wells	.	.	.	.	.	.	-0.008	0.034	-0.004	0.039
Ring 2 - between 3501 and 5000 feet										
One or more wells	.	.	-0.013	0.008	-0.007	0.008	.	.	.	.
One to six wells	.	.	.	.	.	.	-0.014*	0.008	-0.010	0.008
Seven to twelve wells	.	.	.	.	.	.	-0.013	0.014	0.000	0.016
Thirteen or more wells	.	.	.	.	.	.	-0.004	0.022	0.013	0.025
Ring 3 - between 5001 and 6500 feet										
One or more wells	.	.	-0.010	0.009	-0.003	0.009	.	.	.	.
One to six wells	.	.	.	.	.	.	-0.012	0.008	-0.006	0.009
Seven to twelve wells	.	.	.	.	.	.	-0.001	0.012	0.015	0.014
Thirteen or more wells	.	.	.	.	.	.	-0.006	0.018	0.019	0.017
Property Characteristic and Amenity Effects										
Number of bedrooms	-0.037***	0.009	-0.037***	0.009	-0.036***	0.009	-0.037***	0.009	-0.036***	0.009
Number of bathrooms	0.049***	0.008	0.048***	0.008	0.049***	0.008	0.048***	0.008	0.049***	0.008
Living area (sqft)	0.036***	0.002	0.036***	0.002	0.035***	0.002	0.036***	0.002	0.035***	0.002
Swimming pool	0.109***	0.009	0.109***	0.009	0.109***	0.009	0.109***	0.009	0.109***	0.009
Land area (acres)	0.143***	0.012	0.144***	0.012	0.144***	0.012	0.144***	0.012	0.143***	0.012
Central Heating	0.110**	0.045	0.108**	0.045	0.117***	0.042	0.108**	0.045	0.118***	0.042
Central Air-conditioning	0.170***	0.032	0.171***	0.033	0.165***	0.033	0.171***	0.033	0.164***	0.032
Garage, 1 car	0.134***	0.017	0.134***	0.017	0.134***	0.017	0.134***	0.017	0.134***	0.017
Garage, 2 car	0.292***	0.022	0.292***	0.022	0.291***	0.023	0.292***	0.022	0.291***	0.023
Garage, 3 or more cars	0.375***	0.021	0.375***	0.022	0.375***	0.022	0.375***	0.021	0.374***	0.022
Distance from city center (miles)	-0.002	0.009	-0.000	0.009	-0.001	0.009	-0.001	0.009	-0.002	0.009
Within 1/2 mile of a major lake	0.107**	0.043	0.104**	0.043	0.106**	0.043	0.104**	0.043	0.105**	0.044
Within 1/2 mile of a railroad	-0.036**	0.016	-0.034**	0.016	-0.035**	0.016	-0.034**	0.016	-0.035**	0.016
Within 1/2 mile of a major highway	-0.015	0.014	-0.016	0.014	-0.017	0.014	-0.016	0.014	-0.017	0.014
Within 1/2 mile of a major river	0.063***	0.021	0.066***	0.021	0.065***	0.021	0.065***	0.021	0.064***	0.021
Age of house at time of sale	-0.005***	0.001	-0.005***	0.001	-0.005***	0.001	-0.005***	0.001	-0.005***	0.001
Structure count	0.073	0.083	0.076	0.083	0.097	0.072	0.076	0.083	0.097	0.072
Constant	10.768***	0.165	10.774***	0.166	10.500***	0.165	10.780***	0.162	10.513***	0.160
Quarter fixed effects	Yes		Yes		Yes		Yes		Yes	
Zip Code fixed effects	Yes		Yes		Yes		Yes		Yes	
Zip Code*Quarter fixed effects	No		No		Yes		No		Yes	
N	127556		127556		127556		127556		127556	
R^2	0.836		0.836		0.845		0.836		0.845	

Notes: Standard errors are clustered at the zip code level. *, **, *** denotes significance at the 0.10, 0.05, 0.01 level, respectively.

Table 3. Box-Cox transformed hedonic regressions.

Dependent variable =(Sales Price$^{\theta}$-1)/θ										
Specification:	(1)		(2)		(3)		(4)		(5)	
	Coeff.	Std. Err.	Coeff.	Std. Err.	Coeff.	Std. Err.	Coeff.	Std. Err.	Coeff.	Std. Err.
Hydraulic Fracturing Effects										
Ring 1 - within 3500 feet										
One or more wells	.	.	-0.498***	[0.145]	-0.398**	[0.158]	.	.	.	.
One to six wells	.	.	.	.	.	.	-0.493***	[0.141]	-0.411***	[0.150]
Seven to twelve wells	.	.	.	.	.	.	-0.633***	[0.213]	-0.500*	[0.251]
Thirteen or more wells	.	.	.	.	.	.	-0.414	[0.562]	-0.337	[0.586]
Ring 2 - between 3501 and 5000 feet										
One or more wells	.	.	-0.179*	[0.107]	-0.111	[0.112]	.	.	.	.
One to six wells	.	.	.	.	.	.	-0.185*	[0.099]	-0.138	[0.100]
Seven to twelve wells	.	.	.	.	.	.	-0.216	[0.201]	-0.071	[0.223]
Thirteen or more wells	.	.	.	.	.	.	-0.037	[0.267]	0.153	[0.288]
Ring 3 - between 5001 and 6500 feet										
One or more wells	.	.	-0.166	[0.114]	-0.079	[0.119]	.	.	.	.
One to six wells	.	.	.	.	.	.	-0.185*	[0.111]	-0.122	[0.113]
Seven to twelve wells	.	.	.	.	.	.	-0.067	[0.156]	0.111	[0.171]
Thirteen or more wells	.	.	.	.	.	.	-0.075	[0.224]	0.203	[0.206]
Property Characteristic and Amenity Effects										
Number of bedrooms	-0.791***	[0.119]	-0.797***	[0.119]	-0.734***	[0.114]	-0.797***	[0.119]	-0.734***	[0.114]
Number of bathrooms	0.875***	[0.103]	0.873***	[0.102]	0.828***	[0.097]	0.873***	[0.102]	0.828***	[0.097]
Living area (sqft)	0.533***	[0.027]	0.539***	[0.027]	0.510***	[0.026]	0.539***	[0.027]	0.510***	[0.026]
Swimming pool	1.543***	[0.124]	1.552***	[0.123]	1.482***	[0.117]	1.552***	[0.123]	1.482***	[0.116]
Land area (acres)	2.059***	[0.161]	2.098***	[0.163]	1.995***	[0.157]	2.098***	[0.163]	1.989***	[0.157]
Central Heating	0.873*	[0.522]	0.862	[0.529]	0.926*	[0.474]	0.860	[0.528]	0.931*	[0.472]
Central Air-conditioning	1.686***	[0.375]	1.708***	[0.383]	1.580***	[0.369]	1.711***	[0.378]	1.574***	[0.362]
Garage, 1 car	1.712***	[0.194]	1.740***	[0.195]	1.660***	[0.190]	1.740***	[0.195]	1.659***	[0.190]
Garage, 2 car	3.213***	[0.273]	3.251***	[0.277]	3.105***	[0.272]	3.251***	[0.276]	3.106***	[0.271]
Garage, 3 or more cars	4.799***	[0.251]	4.855***	[0.255]	4.635***	[0.247]	4.854***	[0.253]	4.631***	[0.245]
Distance from city center (miles)	-0.019	[0.120]	0.000	[0.121]	-0.005	[0.117]	-0.003	[0.120]	-0.014	[0.116]
Within 1/2 mile of a major lake	1.582**	[0.632]	1.566**	[0.635]	1.511**	[0.611]	1.562**	[0.636]	1.497**	[0.615]
Within 1/2 mile of a railroad	-0.439**	[0.202]	-0.406*	[0.208]	-0.398*	[0.200]	-0.407*	[0.208]	-0.398*	[0.200]
Within 1/2 mile of a major highway	-0.216	[0.171]	-0.237	[0.175]	-0.236	[0.169]	-0.236	[0.174]	-0.233	[0.168]
Within 1/2 mile of a major river	0.933***	[0.301]	0.977***	[0.306]	0.925***	[0.291]	0.976***	[0.306]	0.921***	[0.291]
Age of house at time of sale	-0.064***	[0.011]	-0.067***	[0.011]	-0.064***	[0.011]	-0.067***	[0.011]	-0.064***	[0.011]
Structure count	1.279	[0.999]	1.331	[1.007]	1.497*	[0.839]	1.331	[1.007]	1.500*	[0.840]
Constant	43.770***	[2.103]	44.186***	[2.133]	32.982***	[1.954]	44.220***	[2.097]	33.108***	[1.890]
Theta	0.219		0.220		0.216		0.220		0.216	
Quarter fixed effects	Yes		Yes		Yes		Yes		Yes	
Zip Code fixed effects	Yes		Yes		Yes		Yes		Yes	
Zip Code*Quarter fixed effects	No		No		Yes		No		Yes	
N	127556		127556		127556		127556		127556	
R^2	0.860		0.861		0.867		0.861		0.867	

Notes: Standard errors are clustered at the zip code level. *, **, *** denotes significance at the 0.10, 0.05, 0.01 level, respectively.

Table 4. Box-Cox transformed hedonic regressions, marginal willingness to pay (MWTP).

Dependent variable =(Sales Price$^{\theta}$-1)/θ				
Specification:	(2)	(3)	(4)	(5)
	MWTP	MWTP	MWTP	MWTP
Hydraulic Fracturing Effects				
Ring 1 - within 3500 feet				
One or more wells	-$6,017.18	-$4,751.38		
One to six wells			-$6,175.77	-$5,148.56
Seven to twelve wells			-$7,929.54	-$6,263.46
Thirteen or more wells			-$5,186.14	-$4,221.57
Ring 2 - between 3501 and 5000 feet				
One or more wells	-$2,162.80	-$1,325.13		
One to six wells			-$2,317.48	-$1,728.71
Seven to twelve wells			-$2,705.81	-$889.41
Thirteen or more wells			-$463.50	-$1,916.62
Ring 3 - between 5001 and 6500 feet				
One or more wells	-$2,005.73	-$943.11		
One to six wells			-$2,317.48	-$1,528.28
Seven to twelve wells			-$839.30	-$1,390.49
Thirteen or more wells			-$939.52	-$2,542.96

Notes: All specifications identical to Table 3. The MWTP reported corresponds to the appropriate coefficient in Table 3.

Table 5. Standard hedonic regressions with construction wells.

Dependent variable = ln(Sales Price)								
Specification:	(6)		(7)		(8)		(9)	
	Coeff.	Std. Err.	Coeff.	Std. Err.	Coeff.	Std. Err.	Coeff.	Std. Err.
Hydraulic Fracturing Effects								
Ring 1 - within 3500 feet								
One or more completed wells	-0.033***	[0.010]	-0.026**	[0.012]				
One to six completed wells					-0.034***	[0.010]	-0.029**	[0.012]
Seven to twelve completed wells					-0.033**	[0.016]	-0.025	[0.019]
Thirteen or more completed wells					-0.006	[0.035]	-0.002	[0.039]
One or more construction wells	-0.022***	[0.008]	-0.018**	[0.009]				
One to six construction wells					-0.020**	[0.008]	-0.018**	[0.009]
Seven to twelve construction wells					-0.046	[0.035]	-0.024	[0.038]
Thirteen or more construction wells					-0.099**	[0.046]	-0.064	[0.048]
Ring 2 - between 3501 and 5000 feet								
One or more completed wells	-0.011	[0.008]	-0.005	[0.008]				
One to six completed wells					-0.011	[0.007]	-0.007	[0.008]
Seven to twelve completed wells					-0.009	[0.013]	0.002	[0.015]
Thirteen or more completed wells					0.004	[0.026]	0.019	[0.027]
One or more construction wells	-0.011**	[0.005]	-0.010*	[0.006]				
One to six construction wells					-0.009*	[0.005]	-0.011**	[0.005]
Seven to twelve construction wells					0.004	[0.025]	0.003	[0.028]
Thirteen or more construction wells					0.061	[0.073]	0.066	[0.080]
Ring 3 - between 5001 and 6500 feet								
One or more completed wells	-0.010	[0.007]	-0.001	[0.008]				
One to six completed wells					-0.010	[0.007]	-0.005	[0.007]
Seven to twelve completed wells					0.001	[0.011]	0.016	[0.012]
Thirteen or more completed wells					-0.008	[0.016]	0.018	[0.014]
One or more construction wells	-0.004	[0.006]	-0.004	[0.006]				
One to six construction wells					-0.000	[0.006]	-0.003	[0.006]
Seven to twelve construction wells					-0.031*	[0.019]	-0.019	[0.019]
Thirteen or more construction wells					-0.051	[0.039]	-0.030	[0.035]
Property Characteristic and Amenity Effects								
Number of bedrooms	-0.036***	[0.009]	-0.034***	[0.009]	-0.037***	[0.009]	-0.036***	[0.009]
Number of bathrooms	0.048***	[0.008]	0.049***	[0.008]	0.048***	[0.008]	0.049***	[0.008]
Living area (sqft)	0.035***	[0.002]	0.035***	[0.002]	0.036***	[0.002]	0.035***	[0.002]
Swimming pool	0.110***	[0.009]	0.110***	[0.009]	0.109***	[0.009]	0.109***	[0.009]
Land area (acres)	0.144***	[0.012]	0.144***	[0.012]	0.145***	[0.012]	0.143***	[0.012]
Central Heating	0.110**	[0.044]	0.118***	[0.041]	0.109**	[0.045]	0.118***	[0.042]
Central Air-conditioning	0.167***	[0.031]	0.162***	[0.031]	0.170***	[0.032]	0.164***	[0.032]
Garage, 1 car	0.134***	[0.017]	0.133***	[0.017]	0.134***	[0.017]	0.134***	[0.017]
Garage, 2 car	0.291***	[0.022]	0.290***	[0.023]	0.292***	[0.022]	0.291***	[0.023]
Garage, 3 or more cars	0.375***	[0.021]	0.374***	[0.022]	0.375***	[0.021]	0.374***	[0.022]
Distance from city center (miles)	-0.000	[0.009]	-0.001	[0.009]	-0.001	[0.009]	-0.002	[0.009]
Within 1/2 mile of a major lake	0.103**	[0.043]	0.105**	[0.043]	0.105**	[0.043]	0.106**	[0.044]
Within 1/2 mile of a railroad	-0.033**	[0.016]	-0.034**	[0.016]	-0.034**	[0.016]	-0.034**	[0.016]
Within 1/2 mile of a major highway	-0.016	[0.014]	-0.017	[0.014]	-0.016	[0.014]	-0.017	[0.014]
Within 1/2 mile of a major river	0.065***	[0.021]	0.064***	[0.021]	0.066***	[0.021]	0.065***	[0.021]
Age of house at time of sale	-0.005***	[0.001]	-0.005***	[0.001]	-0.005***	[0.001]	-0.005***	[0.001]
Structure count	0.083	[0.081]	0.104	[0.070]	0.075	[0.083]	0.097	[0.072]
Constant	10.771***	[0.166]	14.035***	[3.055]	10.778***	[0.163]	10.502***	[0.161]
Quarter fixed effects	Yes		Yes		Yes		Yes	
Zip Code fixed effects	Yes		Yes		Yes		Yes	
Zip Code*Quarter fixed effects	No		Yes		No		Yes	
N	124003		124003		124003		124003	
R^2	0.838		0.846		0.836		0.845	

Notes: This table differs from Table 2 in that the wells were defined as both completed and under construction. Standard errors are clustered at the zip code level. *, **, *** denotes significance at the 0.10, 0.05, 0.01 level, respectively.

Table 6. Repeat sales method.

Dependent variable = $\ln(\text{Sales Price}_{t+\tau}/\text{Sales Price}_t)$								
Specification:	(1)		(2)		(3)		(4)	
	Coeff.	Std. Err.	Coeff.	Std. Err.	Coeff.	Std. Err.	Coeff.	Std. Err.
Hydraulic Fracturing Effects								
Ring 1 - within 3500 feet								
One or more wells	-0.029***	[0.009]	-0.014	[0.009]	-0.019**	[0.009]		
One to six wells							-0.019**	[0.009]
Seven to twelve wells							-0.011	[0.017]
Thirteen or more wells							-0.036	[0.029]
Ring 2 - between 3501 and 5000 feet								
One or more wells	-0.027***	[0.007]	-0.014*	[0.007]	-0.016**	[0.008]		
One to six wells							-0.013*	[0.008]
Seven to twelve wells							-0.008	[0.013]
Thirteen or more wells							-0.012	[0.025]
Ring 3 - between 5001 and 6500 feet								
One or more wells	-0.012	[0.008]	0.000	[0.007]	0.003	[0.008]		
One to six wells							-0.001	[0.009]
Seven to twelve wells							0.018	[0.014]
Thirteen or more wells							-0.026	[0.024]
Local price index level	Tarrant County		School District		City		City	
N	15,403		15,403		15,403		15,403	
R^2	0.118		0.231		0.256		0.257	

Notes: The local price index is calculated by including the standard indicator matrix for sales date; the largest level and starting point is the entire county then to the school district level (18 districts) and finally working down to the city level (43 cities). Mininum days between sales is 180 days. Repeat sales with appreciation rates higher than 10 percent per quarter and sold within two years are removed. Repeat sales with appreciation rates higher than 8 percent per quarter and with hold times greater than 2 years are removed. Standard errors are clustered at the census tract level. *, **, *** denotes significance at the 0.10, 0.05, 0.01 level, respectively.