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# Shale Gas Development and the Costs of Groundwater Contamination Risk

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## Abstract

While shale gas development can result in rapid local economic development, negative externalities associated with the process may adversely affect the prices of nearby homes. We utilize a difference-in-differences estimator with additional controls for house fixed effects and the boundary of the public water service area in Washington County, Pennsylvania to identify the capitalization of groundwater contamination risk in property values, differentiating it from other externalities, lease payments to homeowners, and local economic development. We find that proximity to wells increases property values. However, groundwater contamination concerns fully offset those gains by reducing property values up to 26 percent.

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A recent increase in the extraction of natural gas and oil using unconventional methods has transformed communities and landscapes. This paper focuses on shale gas extraction in Pennsylvania, which has grown rapidly in recent years thanks to developments in hydraulic fracturing and horizontal drilling. Natural gas provides an attractive source of energy; when burned, it emits fewer pollutants (e.g., carbon dioxide, sulfur dioxide, nitrogen oxides, carbon monoxide, and particulate matter) than other fossil-fuel energy sources per unit of heat produced, and it comes from reliable domestic sources. The extraction of natural gas from shale, which had hitherto been economically unrecoverable, has resulted in greatly expanded supply. Moreover, it can produce high resource rents for many landowners who lease the hydrocarbons beneath their land.<sup>1</sup> Furthermore, there is also evidence that natural gas development creates jobs and generates income for local residents (see Weber (2011); Marchand (2012)). These benefits may be positively capitalized into property values, which can increase local property tax revenues.

In contrast to these benefits, concerns have frequently been raised about the environmental impacts associated with shale gas development.<sup>2</sup> As part of the high-volume, slick-water hydraulic fracturing process, fracturing fluid is pumped at high pressure through perforations in the well, fracturing the shale rock and allowing the gas to escape. Some of the chemicals used in the fracturing fluids, although small in proportion to the quantity of fresh-water used, would be harmful to human health if ingested (Colborn et al.,

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<sup>1</sup>Upon signing their mineral rights to a gas company, landowners may receive two dollars to thousands of dollars per acre as an upfront “bonus” payment, and then a 12.5 percent to 21 percent royalty per unit of gas extracted. Natural Gas Forum for Landowners: Natural Gas Lease Offer Tracker, available at <http://www.naturalgasforums.com/natgasSubs/naturalGasLeaseOfferTracker.php>.

<sup>2</sup>There are many different pathways that could potentially lead to impacts on, for example, air quality (McKenzie et al., 2012) or water quality (Entrekin et al., 2011). For a risk matrix of many other potential pathways, see [http://www.rff.org/centers/energy\\_economics\\_and\\_policy/Pages/Shale-Matrices.aspx](http://www.rff.org/centers/energy_economics_and_policy/Pages/Shale-Matrices.aspx).

2011), inciting public concerns of chemicals contaminating groundwater.<sup>3</sup> Even if shale gas operations do not contaminate groundwater in the short run, the stigma from the possibility of future groundwater contamination may be capitalized negatively into property values, resulting in important long-term consequences for homeowners. Important for housing markets and local tax revenues, the environmental impact of shale gas development and the perception of the risks associated with these processes, as well as increased truck traffic or the visual burden of a well pad, could depress property values.<sup>4</sup>

Given that property values could be negatively affected by proximity to a shale gas well, one might wonder why a homeowner would be willing to lease their mineral rights to the gas company. In many cases refusing to lease out the mineral rights under one's property might not prevent a company from drilling on a neighbor's land, which would still expose the holdout-homeowner to development nearby. Therefore, since the signing of the lease can be very lucrative in the short run for the homeowner (given large signing bonuses), leasing out the mineral rights will result in higher payoffs than holding out and still being exposed to the impacts of shale development. Furthermore, horizontal drilling requires having the rights to drill under a large contiguous area, which implies that a critical mass of homeowners need to lease their mineral rights before drilling occurs. In this case, if all homeowners in a neighborhood refuse to sign and thus prevent development, a single homeowner can reap the benefits of the bonus payment without being exposed to nearby shale gas wells. Unless there is

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<sup>3</sup>One of the concerns frequently raised by the public is that the fractures might reach a drinking-water aquifer, bringing methane, contaminants that are naturally occurring in the formation, or the fracturing fluids into shallow groundwater aquifers. Typically, there are many thousands of feet between a shale gas formation and an aquifer used for drinking water; this exposure pathway has therefore been hotly debated among different interest groups. In the current literature, this pathway is a concern if hydraulic fracturing occurs too close to a drinking water aquifer (EPA, 2011) or if there are naturally occurring hydraulic pathways between the formation and the drinking water aquifer (Warner et al., 2012; Myers, 2012). A potential pathway with more consensus across different interest groups is that of faulty well casings or cement in the vertical portion of a wellbore (SEAB, 2011; Osborn et al., 2011), which can cause contaminants to leak into groundwater aquifers

<sup>4</sup>The potential for reduction of property values is important given the current housing crisis; in severe cases, it could cause homeowners to fall "underwater" in terms of mortgage repayment, potentially increasing the risk of loan default and foreclosure.

a binding agreement between neighbors, each homeowner has a private incentive to lease their mineral rights to the gas companies.<sup>5</sup>

There is anecdotal evidence that property values are negatively affected by possible shale gas activity,<sup>6</sup> but there has been little research into how the presence of a natural gas well affects property values overall.<sup>7</sup> In this paper, we use a difference-in-differences (DID) estimator, applied to properties that border the public water service area (PWSA), to measure the housing market effect of groundwater water contamination risk from shale gas development. Understanding both the positive and negative impacts of shale gas exploration can help the government choose between policies such as regulating fracking fluids or extending the reach of the PWSA to homes located near shale gas wells. These policies could protect groundwater-dependent homeowners from the negative effects of shale gas development while allowing for the benefits associated with increased local economic growth, lease payments, and a cleaner source of fossil-fuel energy. State regulators are currently debating such rules and regulations.

In this paper, we estimate the differential effect of shale gas development for groundwater-dependent properties relative to those properties with access to piped water, giving us valuable insights into the capitalization of groundwater contamination risk.<sup>8</sup> The key to estimating housing market impacts of the concern for groundwater contamination is controlling for correlated unobservables that may bias estimates (e.g., unattractive attributes of properties and neighborhoods that may be correlated with exposure to drilling activity, and beneficial factors like lease payments and increased economic development). Even in the best datasets, these factors may be hard to measure and can lead to omitted variables bias. We take several steps to overcome this bias. The intuition proceeds as follows. First, we use property fixed effects, comparing changes in the price of a particular property over time, controlling non-parametrically for anything about that

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<sup>5</sup>This decision will depend on the size of one's lot: if a homeowner has a large enough lot, development may not depend on the signing decision of the neighbors.

<sup>6</sup>"Gas Drilling Jitters Unsettle Catskills Sales," *New York Times*, 30 September 2012.

<sup>7</sup>Two notable exceptions are Boxall, Chan and McMillan (2005) and Klaiber and Gopalakrishnan (2012).

<sup>8</sup>Our estimation strategy will control for the possibility that groundwater in Pennsylvania had been contaminated prior to drilling (Swistock, Sharpe and Robillard, 1993) by using information on sales of the same property before and after drilling.

property that remains the same. Next, we see how those price changes differ depending upon whether the property is located in a treatment or control area, defined according to well proximity. We follow Linden and Rockoff (2008)’s threshold test to identify the distance at which a home is within a treatment or control area. Finally, we observe how the differences in the change in price across proximity-based treatment and control groups differ depending upon the water source (i.e., groundwater versus piped water). In addition to controlling for any time-invariant unobserved heterogeneity of the properties, our approach will also control for two sources of potential time-varying unobservable heterogeneity—(i) anything common to our proximity-based treatment and control groups (e.g., increased economic activity); and (ii) anything within the proximity based treatment group that is common to both groundwater and PWSA households (e.g., lease payments). Furthermore, we also geographically restrict some of the specifications in our analysis to the smallest available neighborhood that will allow us to observe differences across water source: a 1000-meter buffer drawn on both sides of the PWSA boundary. This reduces the burden on our differencing strategy, as homes located within a few blocks of one another are presumably affected by similar time-varying unobservables. This regression discontinuity design is similar to that employed by Black (1999) who uses home prices on either side of school district boundaries to identify WTP for school improvements. Our quasi-experimental strategy is also similar to that employed by (Pope, 2008*a*) analyzing property value impacts of sex offenders and (Davis, 2011) measuring the impact of proximity to power plants.

While our identification strategy provides an estimate of the impact of proximity to shale gas wells, this impact is *relative* to the overall changes in housing prices occurring in the county. For example if shale gas development changes property values throughout the county from increased in-migration or jobs, we would identify only the change in property values for homes near shale gas wells relative to this increase (or decrease). Using this identification strategy along with data on property sales in Washington County, Pennsylvania from 2004 to 2009, we find that properties are positively affected by the drilling of a nearby shale gas well—relative to the overall change in economic activity within the county—unless the property

depends on groundwater, in which case the risk to groundwater (whether real or perceived) more than fully offsets these gains.

## 1 Application of the Hedonic Model for Non-Market Valuation

In the hedonic model (formalized by Rosen (1974)), the price of a differentiated product is a function of its attributes. In a market that offers a choice from amongst a continuous array of attributes, the marginal rate of substitution between the attribute level and the numeraire good (i.e., the willingness to pay for that attribute) is equal to the attribute's implicit (hedonic) price. The slope of the hedonic price function with respect to the attribute at the level of the attribute chosen by the individual is therefore equal to the individual's marginal willingness to pay for the attribute; thus, the hedonic price function is the envelope of the bid functions of all individuals in the market. This implies that we can estimate the average willingness to pay for an attribute (i.e., exposure to groundwater risk from hydraulic fracturing) by looking at how the price of the product (i.e., housing) varies with that attribute.

A vast body of research has examined the housing price effects of locally undesirable land uses, such as hog operations (Palmquist, Roka and Vukina, 1997), underground storage tanks (Guignet, 2012), and hazardous waste sites (Gamper-Rabindran and Timmins, 2011) to name a few. These estimates are then used to measure the disamenity value of the land use (or willingness to pay to avoid it). Furthermore, nearby pollution levels have been found to affect housing prices: see Smith and Huang (1995) for a meta-analysis of how property values are affected by air pollution, and Leggett and Bockstael (2000), who demonstrate that property values are negatively affected by nearby water pollution. This paper also uses hedonic methods to model the effect of proximity to a shale gas well on property

values.<sup>9</sup> In particular, we use variation in the market price of housing with respect to changes in the proximity of shale gas operations to measure the implicit value of a shale well to nearby homeowners, depending upon water source. As such, it should be able to pick up the direct effect of environmental risks—in particular, risk of water contamination and consequences of spills and other accidents—while differentiating those risks from other negative externalities (e.g., noise, lights, and increased truck traffic) and the beneficial effects of increased economic activity and lease payments. The latter is analogous to the effect of a wind turbine (Heintzelman and Tuttle, 2012), where the undesirable land use is also accompanied by a payment to the property on which it is located. In this paper, we focus on the hedonic impact of groundwater contamination risk on property values, as it is generally considered to be one of the most significant risks from shale gas development (Krupnick, Gordon and Olmstead, 2012).

The academic literature describing the costs of proximity to oil and gas drilling operations is small. See, for example, Boxall, Chan and McMillan (2005), who examine the property value impacts of exposure to sour gas wells and flaring oil batteries in central Alberta, Canada. The authors find significant evidence of substantial (i.e., 3-4 percent) reductions in property values associated with proximity to a well. Klaiber and Gopalakrishnan (2012) also examine the effect of shale gas wells in Washington County, PA, using data from 2008 to 2010. They examine the temporal dimension of capitalization due to exposure to wells, focusing on sales during a short window (e.g., 6 months) after well permitting and using school district fixed effects to control for unobserved heterogeneity. Like Boxall, Chan and McMillan, Klaiber and Gopalakrishnan also find that wells have a small negative impact on property values. We find evidence of much larger effects on property values. The difference in our estimates may be due to several different factors. First, we utilize two different government datasets on the locations of wells in PA (see Section 3) and incorporate both verti-

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<sup>9</sup>Assuming that the housing supply is fixed in the short run, any additional shale gas well in the vicinity is assumed to be completely capitalized into price and not in the quantity of housing supplied. Given that the advent of shale gas drilling is relatively recent, we would expect to still be in the “short run.” As more time passes, researchers will be able to study whether shale gas development has had a discernable impact on new development.

cal and horizontal wells; Klaiber and Gopalakrishnan only use one of these. Second, we group our wells into well pads, while Klaiber and Gopalakrishnan consider each well as having a separate impact on property values. Multiple wells can be drilled from the same well pad, reducing the surface area used per well (see figure 2), and we therefore expect that an additional well would not have the same effect as an additional well pad. Third, our dataset spans a longer time frame which allows us to create a baseline prior to any wells being developed in the area; Klaiber and Gopalakrishnan use only two years of data after all well activities began. Finally, our estimation technique allows us to control for both time-invariant and time-varying unobservables that may affect the results whereas Klaiber and Gopalakrishnan only use school district fixed effects to control for unobservables. Given these methodological and data differences, it is understandable that we would produce different point estimates.

Because the hedonic price function is the envelope of individual bid functions, it will depend upon the distributions of characteristics of both home buyers and the housing stock. This means that if few of the neighborhoods in our sample are affected by increased traffic and noise, then a lower premium will be placed on quiet neighborhood location. However, if shale development is widespread and results in most neighborhoods being affected by heavy truck traffic, then the houses located in the relatively few quiet neighborhoods would receive a high premium. In the case of a widespread change in the distribution of a particular attribute in the housing stock, it is possible that the entire hedonic price function might change, so that even the price of properties far from shale wells will be affected. Furthermore, the hedonic price function is dependent on the distribution of tastes. If the mix of home buyer attributes changes dramatically over time, that could also lead to a shift in the hedonic price function. Bartik (1988) shows that, if there is a discrete, non-marginal change that affects a large area, the hedonic price function may shift, which can hinder one's ability to interpret hedonic estimates as measures of willingness to pay. Rather, the estimates may simply describe capitalization effects (Kuminoff and Pope, 2012). This would be a conservative interpretation of our results. Whereas a willingness-to-pay interpretation is useful for the cost-benefit analysis of alternative regulations and standards that might be imposed on drillers, a

focus on the capitalization effect is relevant for policy if we are interested in whether shale gas wells increase the risk of mortgage default. It is also important for local fiscal policy, as drilling may have important implications for property tax revenues.

## 2 Method

Implementation of the hedonic method is complicated by the presence of property and neighborhood attributes that are unobserved by the researcher but correlated with the attribute of interest (in our case, proximity to shale gas wells). We utilize a difference-in-differences (DID) estimator that uses detailed geographic information about well proximity and the placement of the piped water network to define several overlapping treatment and control groups. We briefly review the econometric theory behind this approach below.

### 2.1 Difference-in-Differences (DID)

Our estimation technique allows us to control for two types of unobservables that can bias our results: property level and time-varying unobservables. The first of these unobservables is very important, as properties near shale wells might differ systematically in unobservable ways from those that are not near wells. If properties farther from wells are associated with more desirable unobserved characteristics, then this would create an elevated baseline to which the properties near wells would be compared, inflating the estimated negative effect of proximity to a well. Utilizing property-level fixed effects allows us to difference away the unobservable attributes associated with a particular property, or with the property's location.

While property-level fixed effects account for time-invariant unobserved property and location attributes, they are not able to control for time-varying sources of unobservable heterogeneity. This is a concern, as shale gas production could be associated with a boom to the local economy and with valuable payments for mineral rights at the property level, both of which can be hard to quantify but also may be correlated with well proximity. As Table 1 demonstrates, average distance to the nearest well decreases

Table 1: Shale Gas Activity over Time in Washington County, PA

Year	No. Wells	No. Permitted	Dist. to Nearest Well (m)	Dist. to Nearest Permit (m)
2005	5	13	11,952.9	11,952.9
2006	30	45	11,879.4	11,883.6
2007	110	161	9,370.8	7,806.5
2008	298	382	7,336.6	7,329.3
2009	486	650	6,326.3	6,323.6

*Note:* Counts are of cumulative well pads drilled (there may be multiple wellbores on each well pad).

over time as more wells are drilled. In fact, the average distance to a well decreased by almost 50 percent over the time period. If the economic boom associated with increased in-migration and employment due to drilling activity increases property values over time, then this increased capitalization will appear to be caused by closer proximity to shale gas wells. If we do not take this underlying trend into account, then we will underestimate the negative impact of the well. Failure to account for payments for mineral rights can have a similar effect. This warrants going beyond a simple fixed-effects specification and conducting a quasi-experimental procedure that removes the underlying time trends and better estimates the impact of proximity to shale gas wells on property values. We employ a linear DID technique, which is described in more detail below. There, we define a pair of overlapping treatment and control groups of properties by exploiting a property’s proximity to wells and whether or not it is part of the public water service area (PWSA). This results in our main specification equation:

$$\begin{aligned} \text{Log}(\text{price})_{it} = & \beta_0 + \beta_1 \text{WELLTREAT}_{it} + \beta_2 \text{GWTREAT}_{it} + \\ & \beta_3 \text{GWTREAT}_{it} * \text{WELLTREAT}_{it} + \theta_t + \mu_i + \nu_{it} \quad (1) \end{aligned}$$

where  $\text{WELLTREAT}_{it}$  indicates whether house  $i$  is treated by shale gas development at the time  $t$  of sale; in the following section we describe how we choose the treatment group.  $\text{GWTREAT}$  is an indicator for whether property  $i$  relies on groundwater and we describe in section 2.1.2 how we define this second treatment group. This specification therefore has two treatment groups: proximity to shale gas wells and groundwater depen-

dence.  $\theta_t$  is a year fixed effect to capture trends over time and  $\mu_i$  is a property fixed effect. Since *GWTREAT* does not change over time in our sample, this variable is absorbed by the property fixed effects. Having an interaction between the groundwater and well treatments captures the difference in the impact of proximity to shale gas wells by the property's water source.

### **2.1.1 Determining the Well Proximity Treatment Group**

In order to identify the properties treated by exposure to shale gas wells, we exploit the fact that the effects of a well are localized, in that many of the disamenities associated with development (such as noise and truck traffic along with the risk of groundwater contamination) will not affect properties farther from a well. At some distance far enough away from the well site, drilling may not influence property values at all. This appears to be the case based on work by Boxall, Chan and McMillan (2005) on sour gas wells in Alberta, Canada.

In order to identify the correct treatment distance from a well, we conduct an econometric test to see at which point a well no longer impacts the property values of nearby homes. The test we employ follows the strategy of Linden and Rockoff (2008). This method compares properties sold after a well has been drilled (within certain distances) to properties sold prior to a well being drilled (within the same distance), and identifies at which distance the drilling of a well stops impacting property values. We then define our first treatment group as properties having a well within this distance.

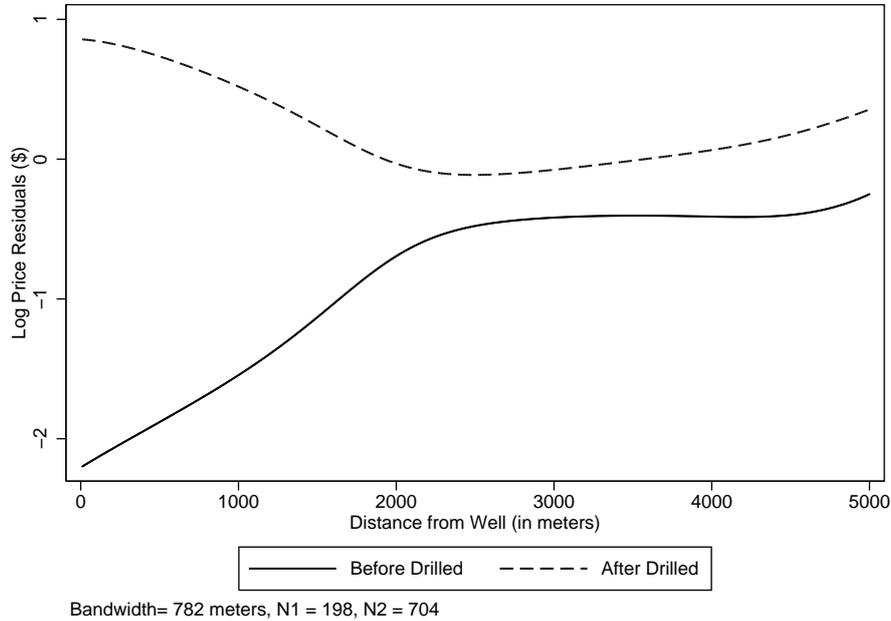


Figure 1: Sales Price Gradient from Local Polynomial Regressions on Distance from Current/Future Well

In order to conduct the Linden and Rockoff (2008) test, we create a subsample of properties that have, at some point in time (either before the property is sold or after), only one well pad located within 5000 meters. We begin by estimating two price gradients based on distance to a well: one for property sales that occurred prior to a well being drilled and one for property sales after drilling began. The distance at which the difference in these two price gradients becomes insignificant is the distance at which we can define the first treatment group.

We choose to only look at homes that have one wellpad within a certain distance as the impact of multiple wells on a home's value may be multiplicative instead of additive, which could confound this threshold test. Furthermore, it would be difficult to separate the impact of the nearest well before and after the well is drilled if the home was already being impacted by another drilled well nearby.

We also chose to look only at homes affected by one well within 5000 meters because the larger the band, the more likely a house would have more than one well drilled in the band, and we would not be able to use the

house in our test. Restricting the neighborhood to 5000 meters allows us to maintain needed sample sizes to conduct the local polynomial regressions, while still including distances with little expectation for an effect. We also assume that larger county-wide impacts that are felt at more than 5 km will likely be felt in the same way at distances less than 5 km.

Figure 1 shows these price gradients estimated by local polynomial regressions, controlling for property and census tract characteristics. For properties that are located more than 2000 meters from a well, the gradients are similar both before and after the well is drilled. However, properties located closer than 2000 meters to a well are sold for more on average after the well is drilled than before the well is drilled, which would correspond to properties receiving, or properties we might expect to be receiving, lease payments.<sup>10</sup> The solid line in the graph demonstrates that sale prices for properties sold prior to a well being drilled within 2000 meters are lower the closer they are to a well, implying that wells are being located in areas with negative unobservable attributes.<sup>11</sup> Thus, we use a distance of 2000 meters from a well to measure the treatment, where any property located farther than 2000 meters is assumed to not be affected by well drilling. Importantly, we expect the effects of a boom to the local economy to be similar across that 2000-meter threshold. This defines our first treatment-control group: treated homes are those located within 2000 meters' distance of a shale gas well, and the control homes are those located outside this 2000-meter band. Specifically, we use the count of well pads within 2000 meters of the home as one of our treatment variables. This allows us to control for the unobserved time-varying factors that are correlated with shale gas development by looking at homes sold inside and outside of a 2000-meter boundary around shale gas wells (the latter having a count of zero), as both these groups will likely be affected in similar ways by a regional economic boom. Finally, given evidence that wells are located in less desirable areas, we control for these unobserved area attributes with property fixed effects.

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<sup>10</sup>A horizontal well might extend over a mile (1609 meters), and therefore it is possible for a property within 2000 meters of a well to be receiving payments.

<sup>11</sup>Creating this figure after excluding properties that have permitted, but not drilled, wells nearby excludes only 11 observations and results in a figure similar to Figure 1. This provides further evidence that the upward sloping portion of the “before drilled” line reflects negative unobservables correlated with proximity rather than expectations of future drilling.

We note that properties near shale gas wells are not more likely to be sold; the average turnover rate for homes that have a well within 2000 meters is statistically identical to the turnover rate for homes that are farther from a well.

### 2.1.2 Private Water Wells vs. Piped Water

Much of the concern surrounding shale gas development arises from the risk of groundwater contamination. Properties that utilize water wells may be affected if the surface casing of a gas well cracks and methane or other contaminants migrate into the groundwater (SEAB, 2011; Osborn et al., 2011) or if fractures connecting the shale formation reach the aquifer (Warner et al., 2012; Myers, 2012). Properties that receive drinking water from water service utilities, on the other hand, are less likely to face this risk.<sup>12</sup> We hypothesize that this risk may be capitalized into the value of the property; in particular, households using water wells may be more adversely affected by proximity to shale gas wells relative to households relying on piped water, and therefore would face a lower transaction value when “treated” by proximity to a well. In order to capture this difference across properties, we define an additional treatment group by designating properties depending upon whether they rely on groundwater or piped water. Specifically, we use GIS data on the location of the PWSA and map the properties into their respective groups. This allows us to interact the shale gas treatment effect with a groundwater indicator in our estimation in order to find the different impact of proximity to wells for groundwater versus piped water homes. Any differences (unobservable and observable) between groundwater and piped water dependent properties that were present before the well is put in place are accounted for at a very detailed level by property

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<sup>12</sup>While shale gas development has been shown to have impacts on surface water (Olmstead et al., 2013), impacts on tap water, treated to meet drinking water standards have not been studied. The city is tasked with providing clean water to its constituents, so the risk of receiving contaminated water through piped water lines is much lower than an unregulated well managed by a homeowner. This implies that, though the control group may also face some drinking water risk, the impact of proximity to shale gas wells on property values for homes outside of the PWSA captures a perceived risk that is likely higher than that of homes within the PWSA. Furthermore, since municipal water is distributed throughout the county, contamination in the PWSA will not depend on proximity to shale gas wells, and therefore will not bias our results.

fixed effects. While properties within 2000 meters of a shale gas well are equally likely to receive benefits from lease payments regardless of water source, those properties dependent upon groundwater are more likely to capitalize the negative consequences of increased contamination risk. This defines our second treatment-control group: by looking at the difference across groundwater dependence (and within 2000 meters of a shale gas well), we are essentially controlling for the unobserved lease payments that are common to both these groups, while allowing the first treatment effect (proximity to shale gas wells) to vary by drinking water source.

### 3 Data

Our main dataset is used under an agreement between the Duke University Department of Economics and Dataquick Information Services, a national real estate data company. These property data include information on all properties sold in Washington County, Pennsylvania from 2004 to 2009. We chose to utilize data from only this county given that Duke University's access to PA transactions data was quite limited; Washington County had the necessary intersection of a long enough panel of transactions as well as a large number of wells drilled.<sup>13</sup> Including very small samples of transactions from other counties in PA would not allow us to create a valid baseline to compare the changes within Washington County. Unfortunately, having access to only one county (all of which was exposed to fracking in the broadest sense) does not allow us to identify overall impacts on property values due to economic shifts associated with shale gas development at the county level. However, even with our data limitations, we are still able to identify the impact of groundwater contamination risk on property values from proximity to shale gas wells. Many other papers in the hedonics literature have also utilized only one or two small counties in their analysis and have given important insights into how property values change with proximity to (dis)amenities (for example, Davis (2004); Linden and Rockoff (2008); Pope (2008*b*)). Even with limited data, our paper provides valuable under-

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<sup>13</sup>After Bradford and Tioga counties, Washington County has had the most shale gas wells drilled in Pennsylvania; Bradford and Tioga are not available in Duke University's license for Dataquick.

standing of the benefits and costs associated with proximity to shale gas development. The comparison of census tract characteristics in Washington County, and other counties in Pennsylvania is found in the Appendix (Table 5). Other than mean income and race, the average characteristics in Washington County are very similar to the rest of Pennsylvania, and would still be similar if we excluded urban areas.

The Dataquick dataset provides the names of the buyers and sellers, along with the transaction price, exact street address, square footage, year built, lot size, number of rooms, number of bathrooms, number of units in building, and many other characteristics. We begin with 41,266 observations in Washington County and remove observations that do not list a transaction price or have a zero transaction price,<sup>14</sup> do not have a latitude/longitude coordinate, were sold prior to a “major improvement,”<sup>15</sup> are described as only a land sale (a transaction without a house), or claim to be a zero square footage house. The final cleaned dataset has 19,055 observations. Summary statistics comparing the full sample and final sample show that they are similar in all respects except for the transaction price (Table 2).<sup>16</sup> Unfortunately, we do not have information concerning the boundary of the properties nor whether a home has leased their mineral rights to the gas company. This implies that we cannot know whether a home has a well on its property, nor can we fully capture how much of the capitalization is due to the ongoing lease and royalty payments to the homeowner. However, at a given distance from a well, properties in our control and treatment group are equally likely to be receiving royalty payments, and therefore this should not bias our results.

In order to control for neighborhood amenities, we match each property’s location with census tract information, including demographics and other characteristics. The census tract data come from the American Community Survey, which provides a tract-level moving average of observations recorded between the years 2005 and 2009. Using these data we have to

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<sup>14</sup>12,327 observations are removed after deleting transactions with a price of zero.

<sup>15</sup>We delete sales prior to major improvements because Dataquick data only report property characteristics at the time of the last recorded sale. If the property was altered between the last sale and earlier sales, we would have no record of how it had changed. Nonetheless, this only removes 4 observations.

<sup>16</sup>We only calculated location variables (such as distance to Pittsburgh, groundwater dependency, and well proximity) for the final cleaned sample.

Table 2: Summary Statistics

	Final Sample		Full Sample	
	Mean	Std. Dev.	Mean	Std. Dev.
<b>Property Characteristics:</b>				
Transaction Price (Dollars)	127,233	135,002	119,797	448,706
Groundwater	0.09	0.286		
Age	54.6	39.7	53.5	40.1
Total Living Area (1000 sqft)	1.8	0.877	1.78	.877
No. Bathrooms	1.69	1.01	1.62	1.02
No. Bedrooms	2.73	1.12	2.65	1.15
Sold in Year Built	0.118	0.322	.0608	.239
Lot Size (100,000 sqft)	0.244	0.766	0.262	1.3
Distance to Pittsburgh (km)	35.8	7.04		
<b>Census Tract Characteristics:</b>				
Mean Income	65,655	23,778	66,130	23,473
% Under 19 Years Old	23.9	4.19	23.8	4.14
% Black	3.78	5.87	3.61	5.74
% Hispanic	0.426	0.72	0.428	0.713
% Age 25 w/High School	39.2	10.5	39.2	10.4
% Age 25 w/Bachelor's	16.7	7.51	16.9	7.51
% Same House 1 Year	88.6	6.75	88.8	6.64
% Unemployed	6.19	2.84	6.11	2.82
% Poverty	7.63	6.93	7.38	6.86
% Public Assistance	2.21	2.13	2.11	2.1
% over 65 Years Old	17.7	4.92	17.8	4.89
% Female Household Head	10	5.6	9.85	5.54
<b>Shale Well Proximity:</b>				
Distance to Closest Well (m)	10,109	4,307		
Distance to Closest Permit (Not Drilled) (m)	10,239	4,675		
Number of Well Pads Drilled within 2 km	.0306	.489		
Observations	19,055		41,266	

*Notes:* Transactions in Washington County, 2004 to 2009, of houses in sub-sample used, and all transactions. The number of observations varies depending on whether there are property characteristics.

make the assumption that these characteristics do not change over our sample period. We also calculate the distance of each property's exact location to the population-weighted centroid of Pittsburgh (Washington County's Metropolitan Statistical Area).

We also match geocoded property transactions data to our second main data source—the location of wells in Washington County. We obtained data describing the permitted wells located on the Marcellus shale from the Pennsylvania Department of Environmental Protection. To determine whether the permit has been drilled, we rely on two different datasets. A well is classified as drilled if a “spud” date (i.e., date that drilling commenced) was listed in the Pennsylvania Department of Environmental Protection Spud Data or if a completion date was listed in the Department of Conservation and Natural Resources Well Information System (the Pennsylvania Internet Record Imaging System/Wells Information System [PA\*IRIS/WIS]). Combining these two datasets provides us with the most

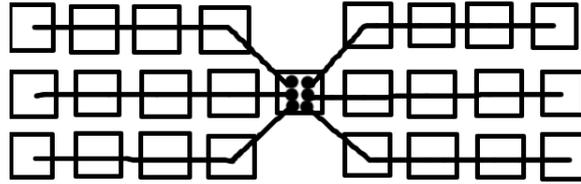


Figure 2: Well Pad with Multiple Wells

comprehensive dataset on wells drilled in Pennsylvania that is available (for example, no other data distributors, such as IHS, would provide more comprehensive data than this). The final dataset includes both vertical and horizontal wells, both of which produce similar disamenities, including risks of groundwater contamination.<sup>17</sup>

Many of these wells are in very close proximity to one another, yet the data do not identify whether these wells are on the same well pad. Well pads are areas where multiple wells are placed close to each other, allowing the gas companies to expand greatly the area of coverage while minimizing surface disturbance. As current shale gas extraction in Pennsylvania typically involves horizontal drilling, a well pad can include many wells in close proximity while maximizing access to shale gas below the surface. Figure 2 demonstrates how six horizontal wells can be placed on a small well pad, minimizing the footprint relative to vertical drilling (which would require 24 wells evenly spaced apart, as indicated by the squares in the figure).

Without identifying well pads, we might overstate the extent of drilling activity confronting a property. For example, a property near the well pad in Figure 2 would be identified as being treated by six wells, though presumably after the first well has been drilled, the additional impact from each additional wellbore would be less than the first. Thus, we create well pads using the distance between the wells, and treat each well pad as a single entity. In order to create well pads, we choose all wellbores that are within one acre (a 63-meter distance) of another wellbore and assign them

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<sup>17</sup>Risk of improper well casing or cementing would be present in both vertical and horizontal wells.

to the same well pad.<sup>18</sup> In our data, of the wellbores that are within one acre of another wellbore, 50 percent are within 11 meters and 75 percent are within 20 meters. Any wellbore within one acre is considered to be on the same well pad, so if more than two wellbores are included, our constructed well pads can cover an area larger than one acre. The average number of wellbores per well pad is 3.7 (max of 12), where 25 percent of the well pads in our data have only 1 wellbore.

We begin by matching property transactions to all wells located within 20km of the property that were either permitted or drilled prior to the transaction date. The transaction price will have been settled prior to the actual transfer date, and it is feasible that a well was drilled nearby after the transaction price was agreed upon and prior to the date of transfer. It is likely that this new well has little to no effect on the transaction price, but since we don't know the date of price settlement, we include all wells drilled up to the sales date, and therefore our results are a lower bound on the impact of proximity on sales prices.

Once these wells are matched, we measure each house's Euclidean distance to the closest well pad that is either permitted or drilled at the time of the transaction, and then count the number of well pads within 2000 meters. These are our main variables of interest, as they identify our first "treatment": how proximity to wells and permitted wells affects property values.

In order to capture the water contamination risks that homeowners may face from shale gas extraction, we utilize data on public water service areas in Washington County and identify properties that do not have access to public piped drinking water. We obtained the GIS boundaries of the public water supplier's service area from the Pennsylvania Department of Environmental Protection. Properties located outside of a PWSA most likely utilize private water wells, since the county does not provide much financial assistance to individuals who wish to extend the piped water area

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<sup>18</sup>During completion, a multi-well pad, access road, and infrastructure are estimated to encompass 7.4 acres in size; after completion and partial reclamation, a multi-well pad averages 4.5 acres in size (New York State Department of Environmental Conservation, 2011).

to their location.<sup>19</sup> This allows us to separate the analysis by water service area into PWSA and “groundwater” areas, and we use this distinction to identify the water contamination risk that may be capitalized into the transaction value. Figure 3 presents a map of Washington County, Pennsylvania, showing the locations of the permitted and drilled (spudded) wells, property transactions, and the water service area. This map describes all wells and transactions in the sample, so some of the wells shown there were not present at the time of a nearby transaction. The large clustering of transactions in the center part of the county corresponds to the two cities in the county: Washington and Canonsburg. These cities fall along the major highway that cuts through the county (I-79, which connects with I-70 in the city of Washington). We hypothesize that properties within these relatively larger cities may face significant changes due to the economic boom associated with shale gas development. Thus, we exclude these cities in certain specifications in order to help isolate the (dis)amenity value associated with proximity to a well from the property value benefits associated with the economic boom.

It is important to note that property transactions are a realization of a sorting equilibrium between the buyer and seller. That is, for homes that were exposed to shale gas activities and then sold, the sellers may have had a higher aversion to fracking proximity, and therefore may have been willing to accept a lower transaction price to avoid this exposure. This would overestimate the negative capitalization for a home randomly exposed to fracking and not being sold. Similarly, the buyer of the exposed home may have very little aversion to fracking proximity, thus willing to pay more than others (or require less of a discount) for this type of home. In this case, we would underestimate the negative capitalization that a random homebuyer would demand for being closer to a shale gas well. This implies that our estimates may be either underestimated or overestimated. However since we are unable to capture the aversions of the parties involved we cannot sign the bias on our estimates.

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<sup>19</sup>Personal communication with the development manager at the Washington County Planning Commission, April 24, 2012.

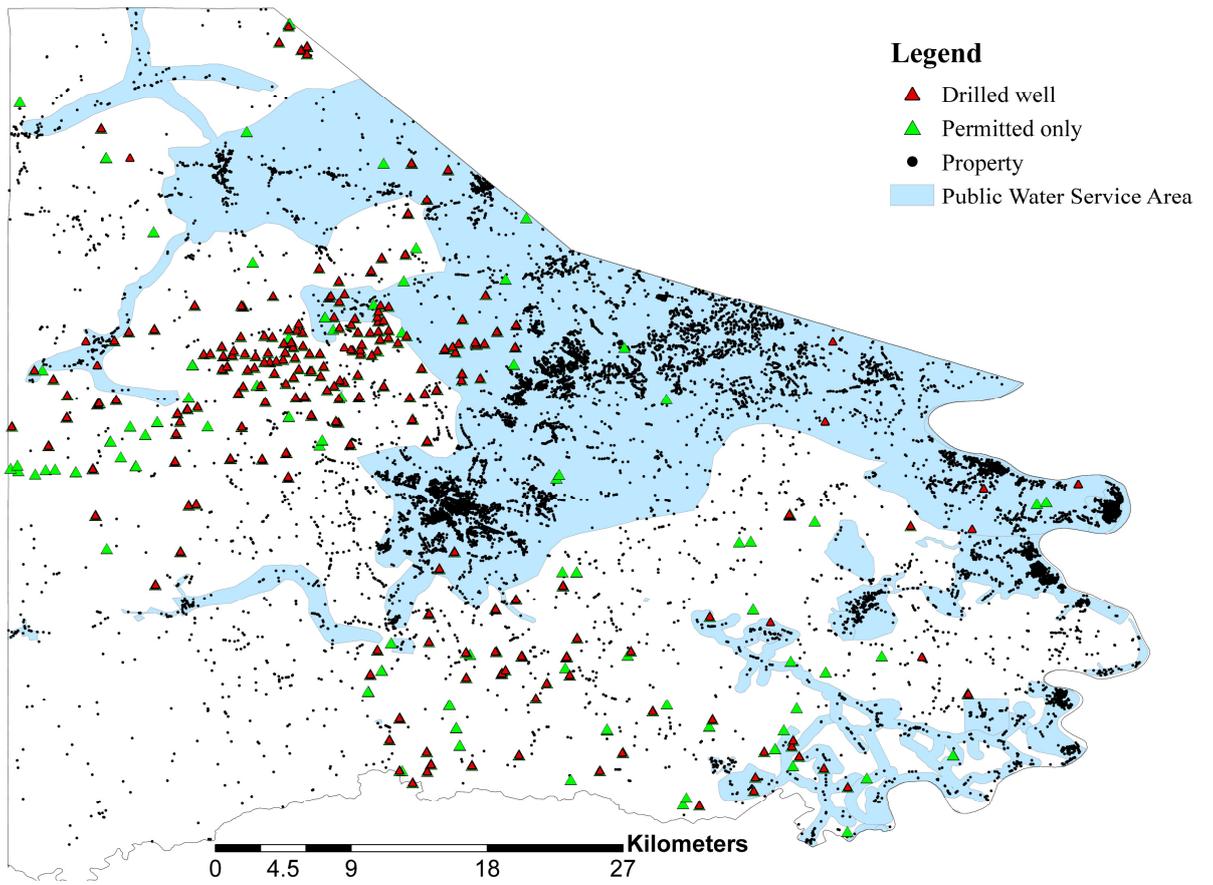


Figure 3: Property Sales in Washington County, 2004–2009

## 4 Results

Though we do not have information on gas lease payments to homeowners,<sup>20</sup> we assume that all properties (conditional upon proximity to a drilled well and other observables such as lot size) have an equal likelihood of receiving lease payments regardless of water service area.<sup>21</sup> Moreover, while both may see their prices go up because of mineral rights and increased economic activity, properties that rely on groundwater may see their values increase by less (or even decrease) given concerns of groundwater contamination from nearby shale gas development. Our overlapping treatment and control groups based on shale gas well proximity and water source provide us with a two-part quasi-experiment with which we can tease out the negative impact of groundwater contamination from the positive impact of the mineral lease payments and economic activity. Given our definitions for treatment groups in section 2.1, we rewrite equation (1) in the following way:

$$\text{Log}(\text{price})_{it} = \beta_0 + \beta_1 N_{2000,it} + \beta_2 \text{Groundwater}_i * N_{2000,it} + \theta_t + \mu_i + \nu_{it} \quad (2)$$

where  $N_{2000,it}$  is a count of the number of well pads within 2000 meters at the time  $t$  of sale. It equals zero if  $t$  is before drilling takes place, or if property  $i$  is more than 2000 meters from the nearest well pad. *Groundwater* is an indicator for whether property  $i$  is outside of the PWSA and thus is assumed to rely on groundwater;  $\theta_t$  is a year fixed effect;  $\mu_i$  is a property fixed effect that absorbs the time-invariant differences between properties that

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<sup>20</sup>Mineral leases are filed at the county courthouse, although not in an electronic format. Some leases have been scanned and are available in pdf format at [www.landex.com](http://www.landex.com). However, this service is geared toward viewing a handful of leases; downloading all leases in a county would be expensive, and matching the leases to properties via an address or tax parcel number would likely be an imprecise endeavor.

<sup>21</sup>It could be the case that, given groundwater safety concerns, individuals in groundwater areas are less likely to sign a mineral lease, in which case we would overestimate the negative impact of a well in a groundwater area if fewer groundwater-dependent homes are receiving lease payments. Our results would thus be interpreted as an upper bound on the negative impact of proximity for groundwater-dependent homes. However, gas exploration and production companies will only drill after obtaining the mineral rights to a sufficiently large area to warrant drilling, implying that holdouts are the minority in areas where wells have been drilled. Furthermore, property owners unwilling to sign based on groundwater contamination concerns are likely rare; if others nearby have granted their mineral rights, groundwater contamination is not prevented by not signing.

eventually have one or more wells within 2000 meters and those that do not,<sup>22</sup> as well as time-invariant differences between groundwater and PWSA properties. The interaction  $Groundwater_i * N_{2000,it}$  measures the treatment effect on groundwater homes relative to PWSA homes, accounting for any time-varying unobservables that similarly affect close and distant properties. This allows us to separately identify the impact of proximity to a well pad (or well pads) for households living in groundwater areas. We expect this coefficient to be negative, as being closer to a well causes a greater risk to households living in groundwater areas.<sup>23</sup> We also include the count of nearby permitted well in order to identify whether there is a different impact from permitted wells relative to drilled wells. This variable is also interacted with a groundwater dummy.

Our first specification is a cross-sectional regression where we include property and census tract characteristics. This specification is problematic because of the fact that it does not account for two different sources of unobservables. The first is the unobservable attributes of the property that may be correlated with proximity to shale gas wells. For example, houses located in close proximity to wells may be of better or worse quality than those located elsewhere in the county. One way to check for this possibility is by comparing observable attributes of properties and neighborhoods located both near and far from shale gas wells. Significant differences in observable attributes suggest a potential for differences in unobservables, which could lead to bias in the estimation (see Table 4 in the Appendix). In order to account for the first type of unobservable, we run a property fixed effects model of this equation. This allows us to capture the fact that wells

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<sup>22</sup>While being located inside the PWSA or groundwater area may not be invariant over time, we only have data on the most recent layout of the PWSA; thus our data on water service are time invariant and we do not include a groundwater dummy in this specification.

<sup>23</sup>The transaction price for a home near a well will differ from a home farther from a well if the impacts of proximity are capitalized into the property value, as is the case for all hedonic studies dependent on property values. Even if the change in property value is due not only to the capitalization of the disamenity of proximity but also to the groundwater dependent seller's risk aversion (and/or the buyer's risk neutrality in the case that proximity is a disamenity), it is unclear whether the results would be biased either way. If the buyer is less risk averse than the seller, he will be willing to pay a larger amount for a home that is near a shale gas well, while the risk-averse seller offers a lower price. It is not clear which of these will dominate in a competitive market, and if this difference is evenly distributed, then it will not bias our results.

are not located randomly throughout the county, but instead are located strategically by the gas companies. Hence, unobservable attributes of the property are important to account for in estimation.

The second is a time varying unobservable such as changes in the terms of mineral leases or economic shocks. We address this type of unobservable by only utilizing properties located within 1000 meters of either side of the border of the PWSA.<sup>24</sup> This represents the smallest (and most homogeneous) geographic area we can use that still contains properties relying on groundwater along with properties in the PWSA. Including homes that are within 1000 meters of the PWSA border allows us to minimize the impact of unobservable time varying shocks, such as occurred with the economic crash in 2008. If homes that are more rural (and hence, more dependent on groundwater) were more affected by the economic crash than urban homes, then it would bias our results away from zero: proximity would appear to have a larger (and more negative) impact on groundwater homes than PWSA homes. It is conceivable that rural homes were more affected by the economic crash than urban homes: sky-rocketing gasoline prices may affect properties that are further from urban centers, as transaction prices decrease with an increase in commuting costs (Sexton, Wu and Zilberman (2012)). Given the impact of gasoline prices increasing at the same time as more shale gas wells were drilled, and hence proximity to these wells increasing, our results might be biased away from zero if we include homes that are very far from the PWSA border. Restricting the sample to homes near the border allows us to minimize the impact of commuting costs on property values, as it is unlikely that homes within a few blocks of each other will be affected in different ways by gasoline prices and economic shocks.

In order to validate our assumption of common time trends across the two groups (PWSA and groundwater) and within the same neighborhood (1000 meters from the border), we regress transaction values on the property characteristics and census tract attributes that are used in our cross-sectional specification, and then calculate the residuals, separately for groundwater-dependent and PWSA homes. We plot the residuals over

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<sup>24</sup>We also include a specification with the entire sample in Washington County to test how the assumption of common trends changes with a larger group.

time, once for the entire sample of homes in Washington County and once for a restricted sample of homes located within 1000 meters of either side of the PWSA border. Figure 4 plots the time trend across the full sample of the two groups, while Figure 5 restricts the sample to homes located within 1000 meters of either side of the PWSA border (note that the first well in Washington County was drilled in June 2005, but the majority were drilled after 2008 – see Table 1). Both price series are highly correlated across the two samples, although the levels are more similar in the restricted sample (which is our final DID sample). This demonstrates that focusing on homes that are closer together helps eliminate differing unobserved variables across the control and treatment group, thereby validating our DID approach with the restricted sample.

We provide additional evidence to validate our assumption that PWSA homes within 1000 meters of the PWSA border are a good control for the groundwater-dependent homes near the other side of the border by inspecting aerial maps of the homes in this region. We find that, for nearly all of our sample, PWSA and groundwater areas are not divided in such a way as might cause neighborhood discontinuity (e.g., such as by a highway, railroad track, etc).<sup>25</sup> This provides further justification for use of homes on the PWSA side of the border as controls for the groundwater-dependent homes in our final sample.

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<sup>25</sup>One exception is displayed in the Appendix (Figure 8), where highway I-70 coincides with the PWSA boundary. Our results are robust to dropping homes located in this area.

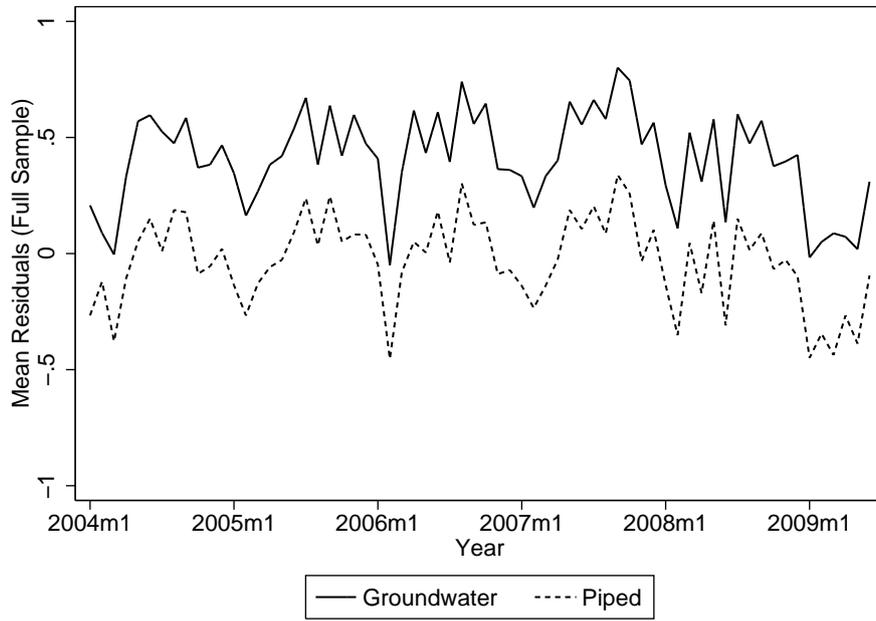


Figure 4: Mean Residuals of Log Transaction Price Using the Full Sample

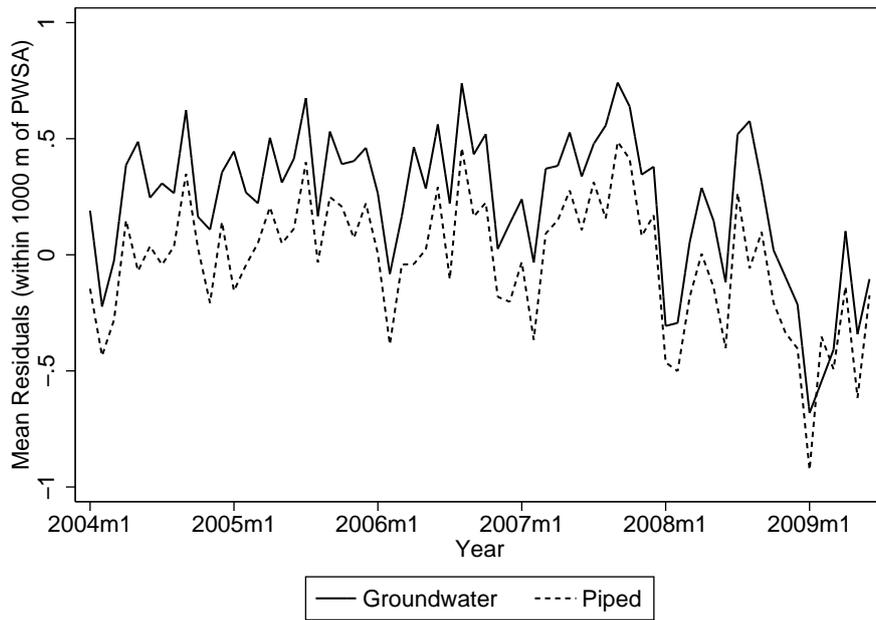


Figure 5: Mean Residuals of Log Transaction Price Using the Properties Located 1000 m from the PWSA Border

In all of our specifications, we control for permitted wells in the vicinity of the home that have not been drilled at the time of sale, in order to capture the expectations of future drilling or lease payments. We interact this count of permitted wells with groundwater in order to test whether groundwater homes react differently to proximate permitted wells.

Table 3: DID Estimates of the Effect of Shale Gas Wells on Log Sale Price by Drinking Water Source

	(1)	(2)	(3)	(4)
	Full	Band	Full	Band
Groundwater	-.143*	-.020		
	(.072)	(.095)		
Well Pads Drilled within 2km	.062***	.054***	.091*	.101**
	(.009)	(.014)	(.053)	(.043)
Well Pads Drilled within 2km*Groundwater	-.094***	-.081*	.011	-.266**
	(.022)	(.044)	(.106)	(.114)
Well Pads Permitted (not drilled) within 2km	-.022	-.032	.177	.005
	(.036)	(.042)	(.119)	(.069)
Well Pads Permitted (not drilled) within 2km*Groundwater	.203**	.139	.002	-.786
	(.079)	(.109)	(.123)	(.471)
Year Effects	Yes	Yes	Yes	Yes
Property Characteristics	Yes	Yes	No	No
Census Tract Characteristics	Yes	Yes	No	No
Property Effects	No	No	Yes	Yes
n	17,688	5,422	17,907	5,522

*Notes:* Robust standard errors clustered at the census tract (102 census tracts). All specifications include year-of-sale. Columns (1) and (2) are cross-sectional regressions with property characteristics (age, square feet, lot size, lot size squared, distance to Pittsburgh), census tract characteristics (mean income, % unemployed, % aged 25 with a Bachelor's, % over 65, % Black, % Hispanic). Columns (3) and (4) include property fixed effects. Columns (2) and (4) only examine properties within a 1000 meter band around the water service area. \*\*\* Statistically significant at the 1% level; \*\* 5% level; \* 10% level.

The first column of Table 3 is our most basic cross-sectional DID estimation, where we include property and census tract characteristics, and include all properties within Washington County. These results suggest that groundwater-dependent homes have lower property values than homes with access to piped water. Overall, having a well pad within 2000 meters increases property values, however, if the property depends on groundwater, there is a decrease in value when a well pad is within 2000 meters. Having permitted well pads nearby is positive and significant for groundwater-dependent homes. The positive sign on the coefficient may be picking up

the fact that proximity to a permitted well implies a likely lease payment.<sup>26</sup> In fact, these lease payments increase with the amount of land leased, and lot sizes in groundwater areas are much larger than in the PWSA areas. Thus, the groundwater-dependent properties may positively capitalize on the permitting of the well before the negative amenities associated with drilling occur.

However, the positive impact of permitted wells on groundwater homes disappears in all other specifications, demonstrating the importance of accounting for unobservables. The results from the second specification (cross-sectional but only using the sample near the PWSA border) are quantitatively similar to the first specification except that some of the coefficients become less significant.<sup>27</sup>

The third column in Table 3 presents the fixed effects estimation result using the full county sample. The positive impact of proximity to shale gas wells increases for non-groundwater homes, though groundwater homes do not appear to be affected by proximity. Furthermore, permitted wells are no longer significant.

Our final, and preferred specification, deals with both types of unobservables—time-varying and time-invariant—that may affect our results.<sup>28</sup> In this specification, we find that PWSA homes positively capitalize proximity to a well pad by 10.1 percent, suggesting that there exist substantial benefits from being near shale gas wells. This is most likely due

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<sup>26</sup>Usually the mineral rights would be part of any property transfer, unless those rights were severed from the title to the property by being retained by the seller during the transfer, or sold to another party prior to the transfer. If mineral rights are sometimes severed, this would simply reduce the size of the price premium we estimate on well proximity. This should not, however, affect our estimates of the capitalization of groundwater contamination risk unless the probability of mineral rights severance is correlated with water source in the area around the groundwater-PWSA boundary. We have no reason to suspect that this is the case.

<sup>27</sup>There are more observations in columns 1 and 2 relative to columns 3 and 4 because of missing values for property characteristics—the fixed-effects specification does not require these variables to be complete for all homes, so we are able to make use of more observations in the fixed-effects regressions than in the OLS regressions.

<sup>28</sup>This specification assumes that the effect of proximity is constant over time, rather than interacting treatment variables with year dummies. Some results from robustness checks with these interactions suggest that the impacts vary over time, but small sample sizes prevent us from estimating these interactions in our preferred specification. Using the full county sample, we see the benefits of proximity decrease over time while the costs associated with groundwater contamination risk increase over time.

to lease payments, which allow properties in the PWSA to increase their values while avoiding the risks (whether real or perceived) of contaminated groundwater. However, groundwater-dependent homes are negatively affected by proximity. In fact, the point estimate of the effect of drilling a well pad within 2000 meters implies a *net* decrease in property values. This net effect is made up of a statistically significant reduction in value of 26.6 percent attributable to groundwater contamination risk, partially offset by the 10.1 percent increase (likely) attributable to lease payments. Their summation (−16.5 percent) is borderline significant in a two-tailed test (the p-value on this test is 0.114 ) and is significant in the corresponding one-tailed test, suggesting that, in contrast to PWSA homes, prices of groundwater-dependent properties certainly do not rise as a result of nearby drilling, and may fall because of groundwater contamination risk.

In moving from the cross sectional estimation to fixed effects, the coefficients on well pads interacted with groundwater changes significantly across the two specifications. This demonstrates that there is an unobservable correlated with both proximity and groundwater-dependence that is being picked up by the house fixed effects. Specifically, the change in coefficients suggests that shale gas wells are being located near homes in groundwater areas that are unobservably better. There is indeed evidence that these groundwater area homes are observably better and have larger lots (see Table 4 for differences across homes located close to shale gas wells). Properties with larger lots—which tend to be located in groundwater areas—would be preferred by gas exploration and production companies, as leasing the same quantity of land would require fewer transactions and potentially lower costs per well. Though we control for lot size in the OLS specification, lot size may be correlated with positive unobservable attributes in groundwater areas, which would explain the shift in the interaction coefficient. However, as evidenced by Figure 1, there appear to be negative unobservables correlated with proximity in PWSA homes, which could drive the increase in the proximity coefficient when moving from OLS

to fixed effects.<sup>29</sup>

The final specification also demonstrates the importance of controlling for unobservables that may vary across Washington County. Since gas wells near both sides of the border are located in relatively similar areas, unobservable neighborhood attributes are less likely to be correlated with well placement. Our final specification demonstrates that not controlling for these neighborhood unobservables can cause groundwater-dependent homes to appear less harmed by proximity to wells than they truly are.

## 5 Conclusion

Our study seeks to understand and quantify the positive and negative impacts of shale gas development on nearby property values. Our goal is to distinguish who benefits and who loses from this unconventional form of natural gas extraction *relative* to the overall change in economic activity throughout the county. Specifically, we focus on the potential for groundwater contamination, one of the most high-profile risks associated with drilling. We demonstrate that those risks lead to a large and significant reduction in property values. Measured relative to property value changes in the broader community, these reductions offset gains to the owners of groundwater-dependent properties from lease payments or improved local economic conditions, and may even lead to a net drop in prices. Unfortunately, due to limitations on lease payment data, we are not able to disentangle the positive effects of nearby drilling on property values from the effects of negative externalities that are not associated with groundwater risks (e.g., increased traffic; noise, air, and light pollution); doing so is the subject of ongoing research. And, given that we only have data on one county, we are not able to estimate the overall increase or decrease in economic activity from shale gas development that may affect property values

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<sup>29</sup>In order to create this figure, we only included homes with *one* wellpad within 5000 meters, which excluded many of the groundwater-dependent properties; the results from this figure are driven mostly by PWSA homes for which, given the upward-sloping solid line, it would appear there are negative unobservables correlated with proximity. Creating a separate figure for groundwater and PWSA properties would have too few observations in each distance bin to be reliable. This does not affect our DID estimation strategy, however, which relies on homes being located near *one or more wells* within 2000 meters.

at the county level. However, with our DID strategy, we are able to provide evidence that concern for groundwater contamination risk significantly decreases the value of homes located near shale gas wells. Furthermore, given that homeowners in our sample not currently exposed to drilling or permitting might still expect to be exposed to drilling sometime in the future, our estimates are lower bounds of how shale gas proximity affects property values. Thus, being able to mitigate risk of water contamination from shale gas development (such as through the extension of the piped water service area) allows properties to benefit from the lease payments and increased economic activity that accompanies drilling without having to bear the cost of groundwater risk.<sup>30</sup> This finding also provides added impetus for regulators to increase regulations to protect groundwater around hydraulic fracturing sites and for industry to increase transparency and voluntary action to reduce water contamination concerns.

To the extent that the *net* effect of drilling on groundwater-dependent properties might even be negative, we could see an increase in the likelihood of foreclosure in areas experiencing rapid growth of hydraulic fracturing. The U.S. government acknowledged the possible negative consequences of allowing leasing on mortgaged land in March 2012 when it began discussing a regulation requiring an environmental review of any property with an oil and gas lease before issuing a mortgage.<sup>31</sup> However, this proposed regulation was rejected within a week.<sup>32</sup> The overall lack of research regarding the impacts on property values from proximity to shale gas wells hinders the ability of the government to regulate optimally, at both the national and local levels. This paper helps to fill that void.

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<sup>30</sup> Unfortunately, extending the piped water service area is very expensive and can cost tens of thousands of dollars per home (Personal communication with the development manager at the Washington County Planning Commission, February 4, 2013).

<sup>31</sup>“Mortgages for Drilling Properties May Face Hurdle,” *New York Times*, 18 March 2012.

<sup>32</sup>“U.S. Rejects Environmental Reviews on Mortgages Linked to Drilling,” *New York Times*, 23 March 2012.

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# Appendix

Table 4: Means (and Standard Deviations) of Property Characteristics by Distance to Nearest Current or Future Well

	<2 km	2–4 km	4–6 km	6–8 km
Transaction Price (Dollars)	120,108 (107,633)	112,262 (103,219)	104,810 (116,334)	104,300 (97,693)
Age	54.58 (39.19)	54.65 (40.3)	57.62 (40.01)	58.66 (40.17)
Total Living Area (1000 sqft)	1.896 (1.004)	1.747 (.8265)	1.642 (.679)	1.682 (.7133)
No. Bathrooms	1.612 (.9343)	1.48 (.9562)	1.482 (.9373)	1.521 (.931)
No. Bedrooms	2.699 (1.067)	2.52 (1.21)	2.452 (1.164)	2.577 (1.151)
Sold in Year Built	.06311 (.2437)	.1222 (.3278)	.1013 (.3019)	.1162 (.3206)
Lot Size (100,000 sqft)	.4076 (.5176)	.2238 (.3906)	.2209 (.4955)	.1864 (.3763)
Distance to Nearest MSA (km)	34.81 (5.76)	34.99 (6.184)	35.74 (7.013)	37.77 (5.631)
Mean Income	68,851 (11,678)	59,431 (12,038)	59,431 (12,749)	58,681 (16,620)
% Under 19 Years Old	24.67 (4.066)	23.66 (4.523)	23.01 (3.095)	23.67 (4.566)
% Black	1.846 (3.082)	4.277 (4.529)	3.393 (3.62)	5.518 (7.88)
% Hispanic	.6519 (.9262)	.681 (1.026)	.2979 (.4401)	.4773 (.7651)
% Age 25 w/High School	43.52 (4.766)	43 (5.573)	41.26 (7.712)	41.82 (7.977)
% Age 25 w/Bachelor's	13.98 (3.421)	14.03 (3.838)	14.98 (5.9)	14.83 (6.393)
% Same House 1 Year	89.99 (3.055)	88.81 (3.96)	87.99 (4.838)	87.02 (7.504)
% Unemployed	6.243 (1.648)	7.028 (2.269)	5.979 (2.46)	6.859 (3.09)
% Poverty	4.764 (3.366)	6.286 (4.513)	7.019 (4.633)	8.53 (7.882)
% Public Assistance	1.991 (1.025)	1.962 (1.574)	2.126 (1.763)	2.526 (2.576)
% over 65 Years Old	17.3 (3.711)	18.13 (4.46)	18.08 (4.674)	17.67 (5.233)
% Female Household Head	9.577 (3.349)	11.62 (4.727)	10.59 (4.205)	12.19 (5.438)
Groundwater	.4396 (.4975)	.1639 (.3704)	.09304 (.2906)	.06808 (.2519)
Observations	207	775	1623	2130

*Note:* Summary statistics based on the distance to the closest well drilled at time of sale or at some time in the future.

Table 5: Census Tract Characteristics in Washington County and the Rest of Pennsylvania

	Washington		Rest of PA	
	Mean	Std. Dev.	Mean	Std. Dev.
Mean Income	65,913	31,485	57,197	17,720
% under 19 Years Old	24.94	7.092	23.16	3.328
% Black	11.94	22.55	4.402	6.84
% Hispanic	1.342	3.13	.3926	.7905
% Age 25 w/High School	37.86	12.06	42.77	9.434
% Age 25 w/Bachelor's	15.91	9.313	14.38	6.763
% Same House 1 Year	87.05	9.647	87.19	9.203
% Unemployed	4.772	2.813	4.459	1.987
% Poverty	10.05	11.03	9.113	7.228
% Public Assistance	3.531	4.351	3.098	2.665
% over 65 Years Old	15.57	6.219	17.48	4.527
% Female Household Head	12.31	8.578	11.14	5.158
Observations	3155		54	

Notes: Average census tract data from the American Community Survey, between 2005 and 2009.

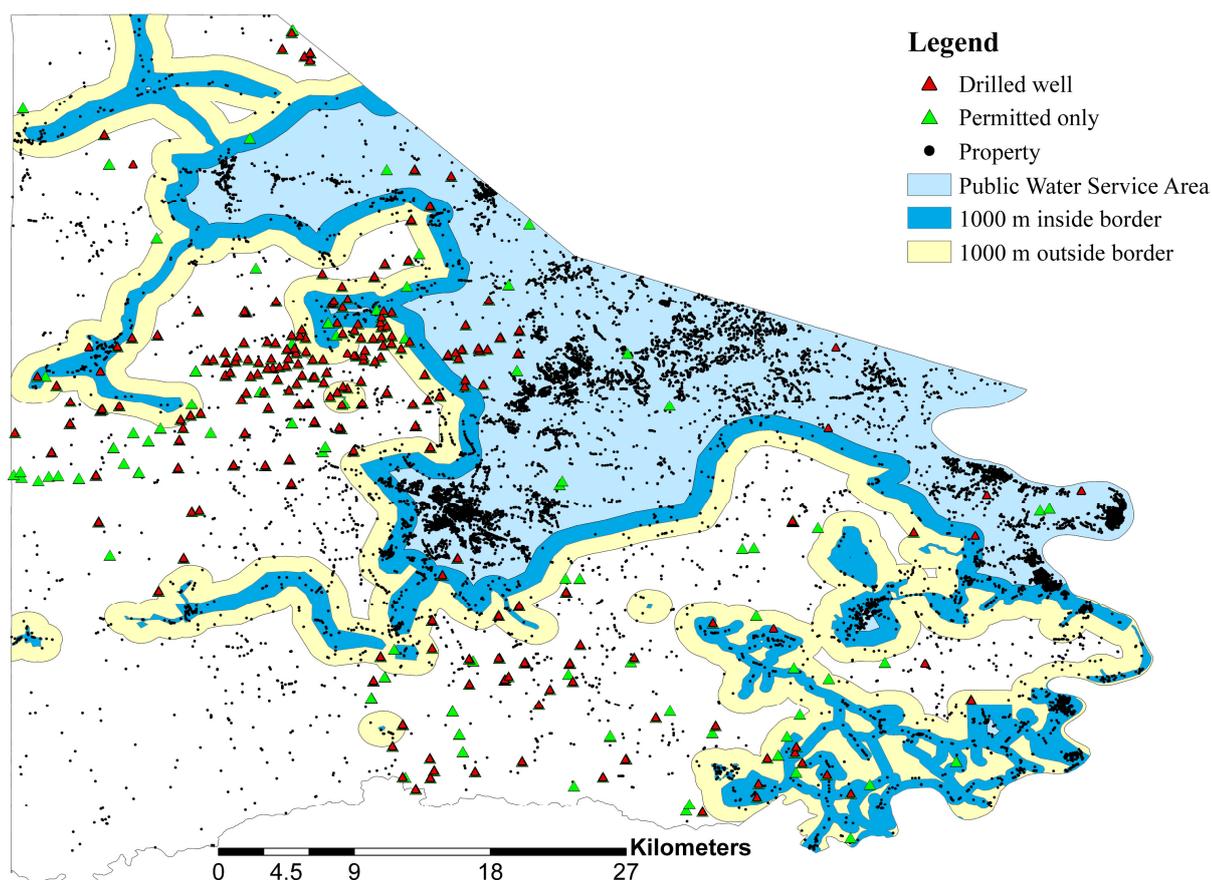


Figure 6: Property Sales and Permitted and Drilled Wells in Washington County, 2004–2009. Indicates 1000-meter Band Inside and Outside of Public Water Service Areas. 36

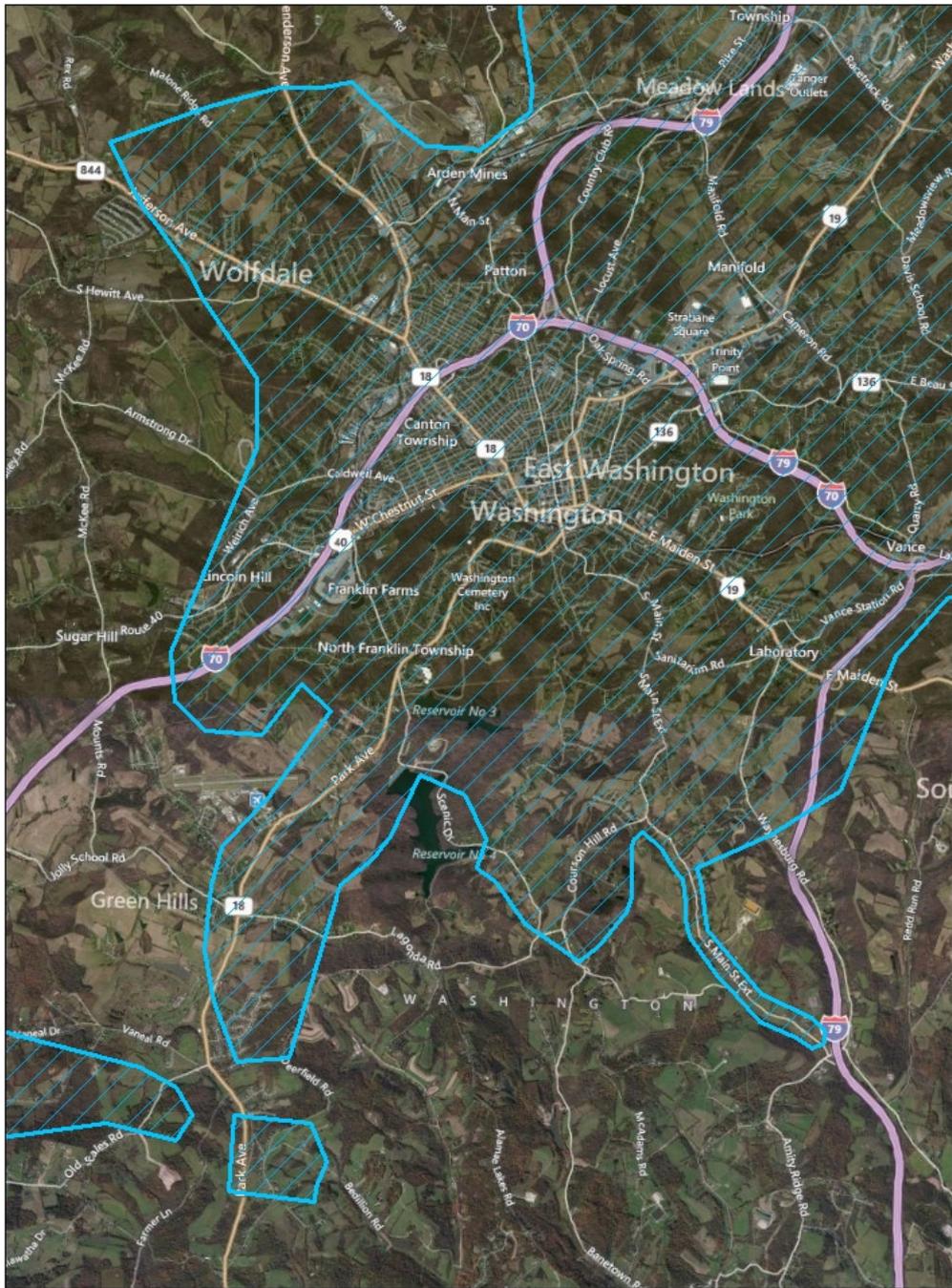


Figure 7: Example of No Artificial Boundaries: Close-up of Washington City.

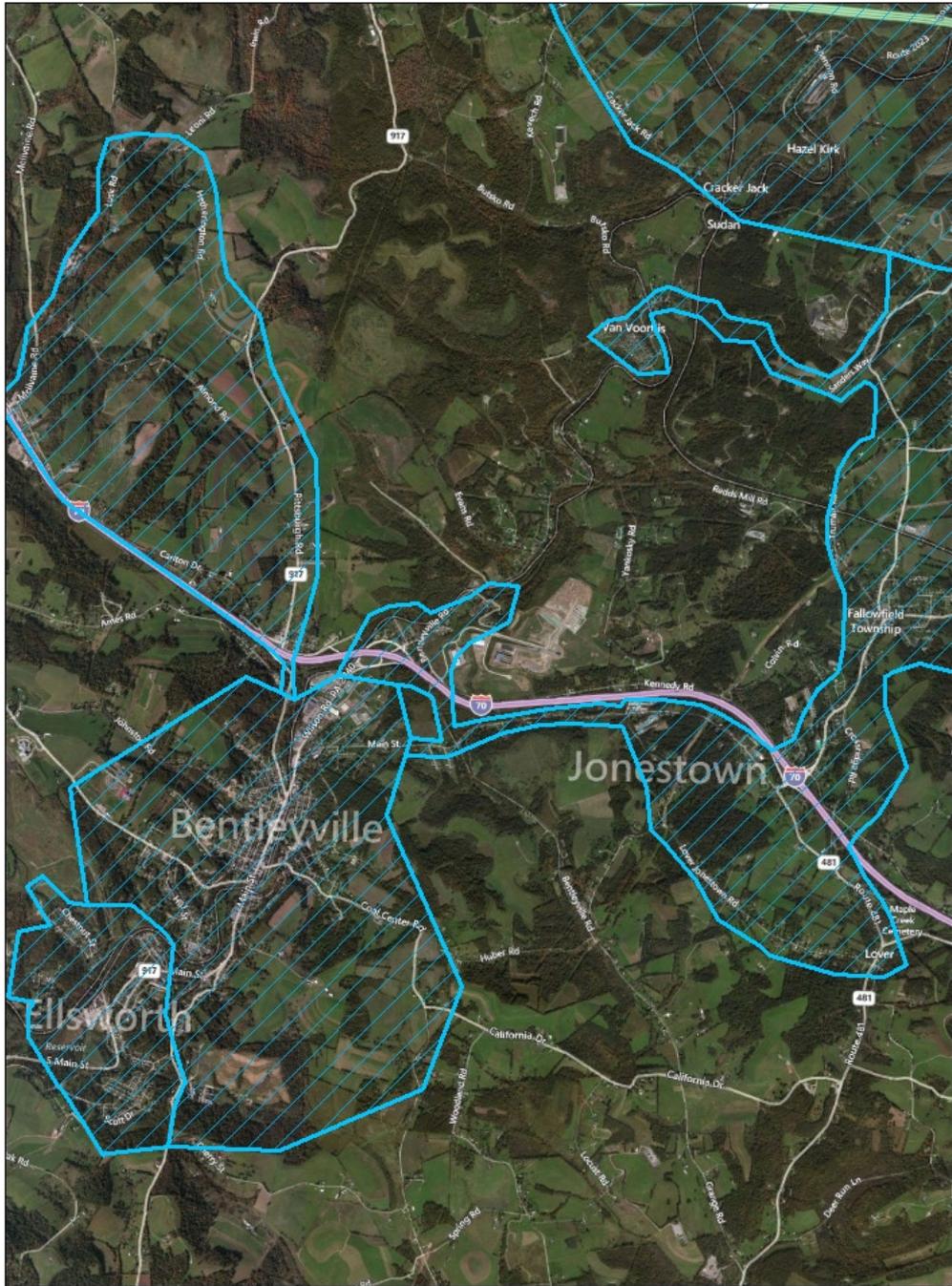


Figure 8: One exception Where a Highway Coincides with the PWSA Boundary; Our Results are Robust to Dropping this Area.