The Housing Market Impacts of Shale Gas Development

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Abstract

Using data from Pennsylvania and New York and an array of empirical techniques to control for confounding factors, we recover hedonic estimates of property value impacts from shale gas development that vary with geographic scale, water source, well productivity, and visibility. Results indicate large negative impacts on nearby groundwater-dependent homes, while piped-water-dependent homes exhibit smaller positive impacts, suggesting benefits from lease payments. At a broader geographic scale, we find that new wellbores increase property values, but these effects diminish over time. Undrilled permits cause property values to decrease. Results have implications for the debate over regulation of shale gas development.

JEL Classification Numbers: Q32, Q33, Q50, Q53

Keywords: shale gas, groundwater, property values, hedonic models, nearest neighbor matching, differences-in-differences, triple differences

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1 Introduction

Technological improvements in the extraction of oil and natural gas from unconventional sources have transformed communities and landscapes and brought debate and controversy in the policy arena. Shale gas plays underlying the populated northeastern United States were thought to be uneconomical less than 10 years ago, but now contribute a major share of US gas supply.[1] Natural gas has been hailed as a bridge to energy independence and a clean future because of its domestic sourcing and, compared with coal and petroleum derivatives, its smaller carbon footprint and reduced emissions of other pollutants (e.g., particulates, sulfur dioxide, carbon monoxide, and nitrous oxides). Furthermore, proponents note that jobs associated with shale gas development will boost local economic growth.[2] Yet opposition to unconventional methods of natural gas extraction has emerged, citing the potential for damages from methane leakage (Howarth et al., 2011; Hultman et al., 2011; Burnham et al., 2011), water contamination (Osborn et al., 2011; US Environmental Protection Agency, 2011; Olmstead et al., 2013), local air pollution (Kargbo et al., 2010; Schmidt, 2011; Howarth et al., 2011), and increased congestion from truck traffic (Bailey, 2010; Considine et al., 2011).

Economic and environmental impacts may also arise from the "boom town" phenomenon, where local areas facing shale development see increases in population, employment, business activity, and government revenues (Lillydahl et al., 1982; Wynveen, 2011). However, boom towns may also suffer from negative social, economic, and environmental consequences such as increased crime rates, housing rental costs, and air pollution (Lovejoy, 1977; Albrecht, 1978; Freudenburg, 1982). Furthermore, the "boom" may be followed by a "bust" if benefits from shale gas development are only temporary. Local public goods might be expanded during boom times at considerable cost only to be left underutilized when wells are capped or abandoned.

Properties within a boom town may experience growth or decline in value depending on whether the benefits of the boom outweigh the costs. Moreover, benefits and costs may be heterogeneous across housing types. For example, properties that rely on

[1] In 2000, shale gas accounted for 1.6 percent of total US natural gas production; this rose to 4.1 percent in 2005, and by 2010, it had reached 23.1 percent (Wang and Krupnick, 2013). Natural gas from the Marcellus formation currently accounts for the majority of this production (Rahm et al., 2013) and can be attributed to advances in hydraulic fracturing, horizontal drilling, and 3-D seismic imaging.

[2] Weber (2012) estimates an increase of 2.35 jobs per each million dollars in gas production, and Weinstein and Partridge (2011) find that 20,000 jobs were created in Pennsylvania from 2004 to 2010 due to the shale gas industry expansion (though they argue that this number is much lower than the industry's claims of job increases).

private water may suffer greater reductions in value when confronted with shale gas development if there is a risk of losing their water source. Access to a safe, reliable source of drinking water is an important determinant of a property's value. Even a perceived threat to that access can have detrimental effects on housing prices. This is very important, as the potential for shale gas development to contaminate groundwater has been hotly debated.[3] Perceptions of the risks and benefits from drilling can vary with a variety of factors, including the density of drilling activity, environmental activism, economic activity, unemployment levels, and urban density (Theodori, 2009; Wynveen, 2011; Brasier et al., 2011). While there are valid arguments on both sides of the debate surrounding shale gas development, the question of whether the benefits outweigh the costs has not yet been answered. This paper is a first step in understanding these costs and benefits.

Hedonic analysis describes how a home buyer chooses a house based on the characteristics of the property and its location (see Section 2 for a deeper discussion of the hedonic method as it applies to this paper). Measuring the impacts of shale gas activity on property values is therefore one way to quantify its effects (either real or perceived). There has been limited prior research into how local gas drilling affects property values. A few notable exceptions include Boxall et al. (2005), who focused on sour gas wells in Alberta, and Klaiber and Gopalakrishnan (2012), who measured the temporal impact of shale gas wells in Washington County, Pennsylvania. Most closely related to the present paper is our earlier work (Muehlenbachs et al., 2013), which also used data from Washington County to measure the impact of shale gas proximity on groundwater homes.

This paper extends our earlier analysis to include areas comprising most of the shale gas development in Pennsylvania as well as areas not experiencing development in Pennsylvania and New York. Looking beyond a single county, we are also able to control for more potential sources of estimation bias, and to explore the broader economic impacts of shale gas development. In particular, we measure several impact categories. We label these as *adjacency effects*, *groundwater contamination risk*, and *vicinity effects*. The first refers to the combined impacts (both positive and negative) from being in close proximity to shale gas development aside from groundwater contamination risk (e.g., air, noise, and light pollution; landscape alteration; and the receipt

[3] An example from Dimock, Pennsylvania, can be seen in these headlines: "Water Test Results Prove Fracking Contamination in Dimock," Riverkeeper.org, March 22, 2012, and on the other hand, "Just Like We've Been Saying—Clean Water in Dimock," eidmarcellus.org, August 3, 2012. Under ambiguity aversion, such a debate would decrease the value of groundwater-dependent properties.

of lease payments), the second refers to the *additional* effect of adjacency specific *only* to groundwater-dependent households, and the third refers to impacts associated with the boom town phenomenon along with negative externalities that occur on a broad geographic scale (e.g., air pollution, increased truck traffic, and wastewater disposal).

A major obstacle to accurately estimating the impact of shale gas development on surrounding homes is the presence of correlated unobservables that may confound identification. For example, shale gas wells are not located randomly but are placed in areas that facilitate the drilling process, such as near a road; unobservable property and neighborhood attributes may therefore be correlated both with proximity and with the property value. Methodologically, we utilize a combination of fixed effects along with difference-in-differences nearest-neighbor matching (DDNNM), triple-difference (DDD), and treatment boundary techniques in order to eliminate unobservables that may be correlated with adjacency or vicinity to shale gas wells or water source and thus lead to biased estimates.

Using data from Pennsylvania, both off and on the Marcellus shale, along with bordering counties in New York (where a moratorium has prevented hydraulic fracturing to this point), we are able to identify vicinity effects, as well as control for macroeconomic effects due to the Great Recession and other economic factors that affected the region more broadly. Furthermore, our panel of properties sold in Pennsylvania and New York between January 1995 and April 2012 creates a solid baseline prior to shale gas wells being drilled, more accurately captures time trends, and includes properties that were sold several years after drilling began in the state.

Our results demonstrate that groundwater-dependent homes are, in fact, negatively affected by nearby shale gas development. Similarly proximate homes dependent on piped water, on the other hand, appear to receive small benefits from that development. At a broader geographic scale, we find that drilling increases property values, likely through the boost to the local economy of increased activity. However, undrilled well permits, particularly those that have been permitted for more than a year, can offset these benefits. This is likely due to undrilled permits creating an aesthetic disamenity (e.g., through the clearing of land), but could also be from the loss of the option value of signing a more favorable mineral lease in the future.

Our paper proceeds as follows. Section 2 discusses the hedonic method, which provides the backdrop for our analysis. Section 3 describes our methodology, Section 4 details our data, and Section 5 reports our empirical models and main results, with a summary of different property value impacts in Section 6. Section 7 concludes.

Finally, We provide an appendix for online publication analyzing the impact of shale gas development on community sociodemographics, the frequency of sales, and new construction.

2 Hedonic Method

Rosen (1974) established the connection between individual preferences and the hedonic price function, allowing the researcher to interpret the hedonic gradient as the marginal willingness to pay for an incremental change in a non-marketed house or neighborhood attribute. In the context of our application, $P(W)$ represents the hedonic price relationship describing how prices vary with exposure to increasing numbers of wells, *ceteris paribus*. Rosen describes how the hedonic price function is formed by the equilibrium of buyers and sellers sorting to one another in the marketplace. In Figure 1, buyers A and B are represented by indifference curves (U_1^A, U_1^B, U_2^A, U_2^B); each represents combinations of price and shale gas well exposure that yield a constant level of utility. Sellers X and Y are described by offer curves (O_0^X, O_1^X, O_0^Y, O_1^Y), each of which represents combinations of price and well exposure that yield a constant level of profit. The hedonic price function is formed by the envelope of these indifference and offer curves.

Individuals choose a house that maximizes utility. For individual A, who neither likes paying a lot for a house nor (for the purposes of this discussion) wants exposure to shale gas wells, this is accomplished by reaching the indifference curve lying farthest to the southwest. Considering the constraint formed by the hedonic price function, utility is maximized at point A^*, where that individual achieves utility U_1^A. Individual B similarly maximizes utility at B^*. The fundamental insight of the hedonic method is that, at A^* and B^*, the slope of the price function is equal to the slope of each individual's indifference curve at that point. That slope describes the individual's willingness to give up consumption of other goods in exchange for a marginal reduction in exposure to nearby wells. This is how the literature typically defines marginal willingness to pay (MWTP); we will do the same.[4]

Of course, the value of MWTP defined by the slope of the price function at the level

[4]Other measures of value used in the literature include compensating and equivalent variations in income. CV or EV can be calculated both in a partial equilibrium context, where individuals' housing choices and equilibrium prices are not updated, and in a general equilibrium context, where they are updated to reflect re-optimization and subsequent market re-equilibration.

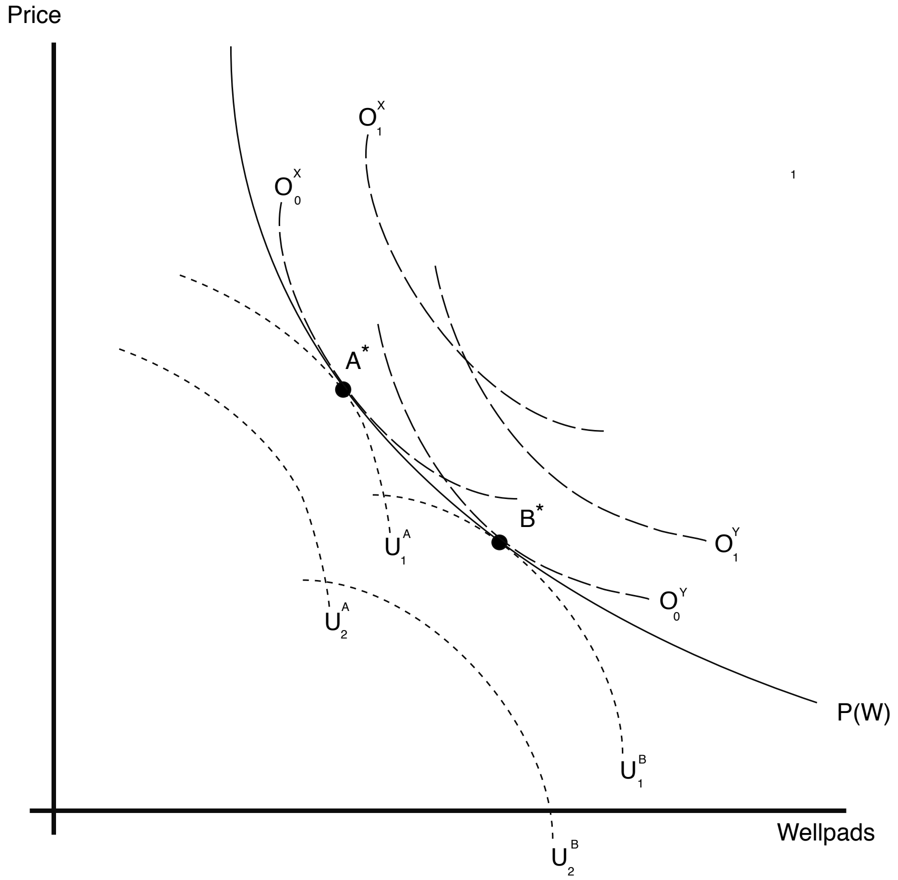

Figure 1: Formation of the Hedonic Price Function

of well exposure chosen by the individual represents just one point on the individual's indifference curve. If we were to trace out each individual's MWTP at each point on a particular indifference curve, we would end up with functions for each individual like those shown in Figure 2.

With cross-sectional data, the hedonic gradient (i.e., the slope of the hedonic price function) therefore only identifies one point on each MWTP function. This is the crux of the identification problems detailed by Brown and Rosen (1982) and Mendelsohn (1985). Endogeneity problems also arise in the effort to econometrically recover these functions; for a discussion, see Bartik (1987) and Epple (1987). More recent literature dealing with the recovery of MWTP functions includes Ekeland et al. (2004), Bajari

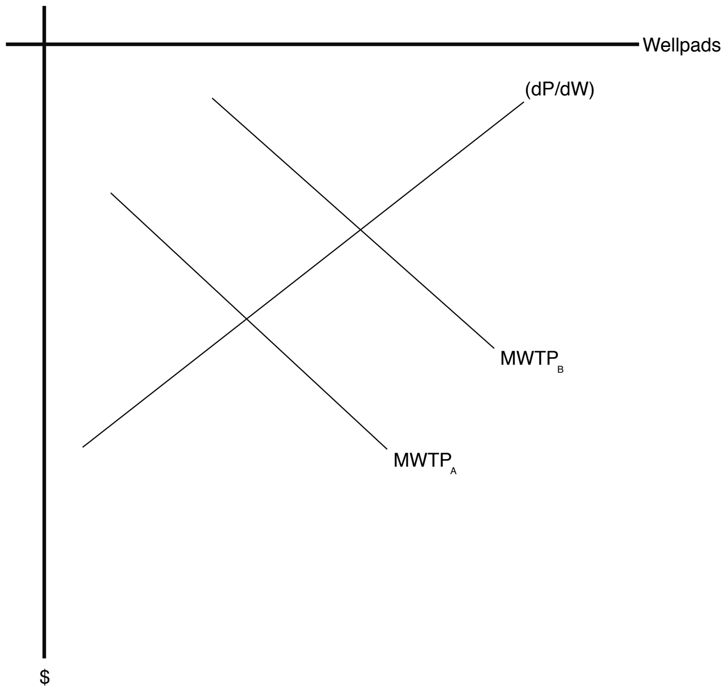

Figure 2: Marginal Willingness to Pay

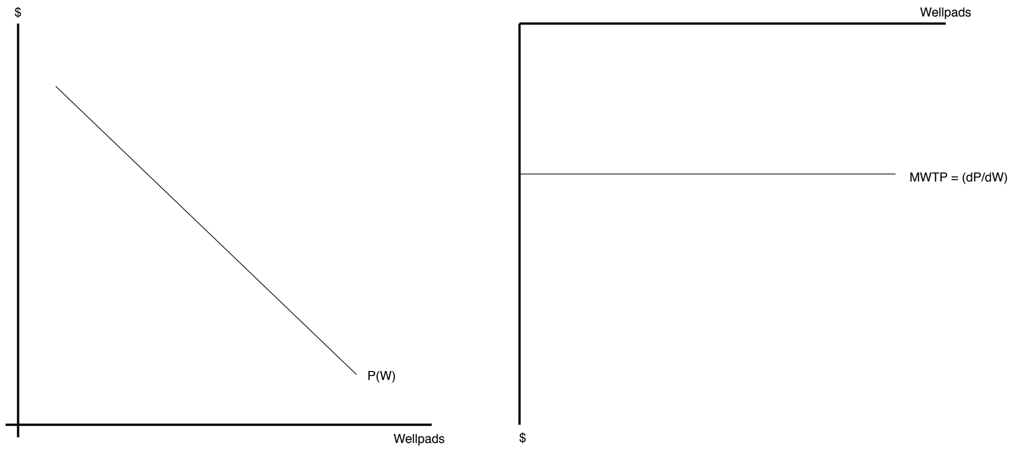

Figure 3: Marginal Willingness to Pay—Simplification

and Benkard (2005), Heckman et al. (2010), and Bishop and Timmins (2012).

With few exceptions, the applied hedonic literature has not estimated heterogeneous MWTP functions, but has instead relied on a strong assumption to simplify the problem—in particular, that the hedonic price function is linear and that preferences are homogenous (so that the hedonic gradient is a horizontal line that represents the MWTP function for all individuals).

This avoids the difficulties associated with recovering estimates of MWTP discussed above, and allows attention to be focused instead on recovering unbiased estimates of the hedonic price function. This literature is vast and includes applications dealing with air quality (Chay and Greenstone, 2005; Bajari et al., 2010; Bui and Mayer, 2003; Smith and Huang, 1995; Harrison Jr and Rubinfeld, 1978; Ridker and Henning, 1967), water quality (Walsh et al., 2011; Poor et al., 2007; Leggett and Bockstael, 2000), school quality (Black, 1999), crime (Linden and Rockoff, 2008; Pope, 2008b), and airport noise (Andersson et al., 2010; Pope, 2008a). Our application is most similar in spirit to papers that have examined locally undesirable land uses (LULUs): Superfund sites (Greenberg and Hughes, 1992; Kiel and Williams, 2007; Greenstone and Gallagher, 2008; Gamper-Rabindran and Timmins, 2011), brownfield redevelopment (Haninger et al., 2012; Linn, 2013), commercial hog farms (Palmquist et al., 1997), underground storage tanks (Zabel and Guignet, 2012), cancer clusters (Davis, 2004), and electric power plants (Davis, 2011). Our estimation strategy described below will draw upon insights from many of these papers.

Of particular importance for our analysis is the discussion in Kuminoff and Pope (forthcoming). They highlight the fact that the change in price over time (which allows for the use of differencing strategies to control for time-invariant unobservables) will only yield a measure of the willingness to pay for the corresponding change in the attribute being considered under a strong set of assumptions. These assumptions include those described above (i.e., linear hedonic price function, common MWTP function). In addition, the hedonic price function must not move over the time period accompanying the change in the attribute. If it does, as in Figure 4, the change in the price accompanying the change in the attribute may provide a poor approximation of the slope of the hedonic price function.

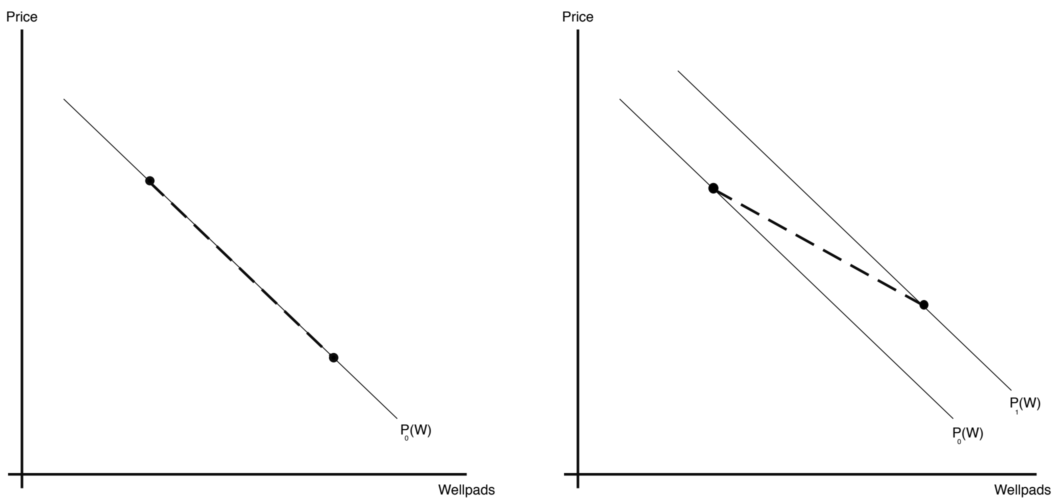

Figure 4: Time-Varying $P(W)$

Determining whether or not the hedonic price function has moved over time is difficult; in particular, it requires having some way of recovering an unbiased estimate of the hedonic price function without exploiting time variation. We provide one strategy for recovering the impact of groundwater contamination risk (double-difference nearest neighbor matching) that avoids using time variation. In the appendix, we also provide an indication of how much of a problem shifting gradients present for our double- and triple-difference strategies by looking at the extent to which neighborhood sociodemographics change because of fracking. If they change a lot, preferences of the local population will likely be altered as well, and caution would be advised when interpreting our results as measures of welfare rather than simple capitalization effects. We note here, however, that the changes we find attributable to shale gas development are quite small.

3 Methodology

Our goal is to recover estimates of the non-marketed costs and benefits of shale gas wells by measuring their capitalization into housing prices. Housing market impacts occur at different levels defined by proximity to wells and by water source—i.e., houses dependent upon private groundwater wells as a source of drinking water (GW) and houses in public water service areas with access to piped water (PWSA). This paper works to identify these impacts and understand how they differ by drinking water source.

3.1 Impact Categories

We categorize the impacts of shale gas exploration and development on housing values as follows. (1) *Adjacency Effects*; this category refers to all of the costs and benefits associated with close proximity to a shale gas well that are incurred regardless of water source. Costs in this category may include noise and light pollution, local air pollution (including methane, hydrogen sulfide, VOCs, and other conventional pollutants), alteration of the local landscape, and visual disamenities associated with drilling equipment and cleared land.[5] The most obvious benefit would be royalties and lease payments

[5]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, 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 a binding agreement between neighbors, each homeowner has a private incentive to lease their mineral rights to the gas companies.

paid to the property owner for the extraction of the natural gas beneath their land.[6] (2) *Groundwater Contamination Risk* (GWCR); this category represents the additional cost capitalized into adjacent properties that are dependent upon groundwater. Our identification strategy assumes that this is the only additional impact of adjacency associated with reliance on groundwater.[7] (3) *Vicinity Effects*; this category refers to impacts on houses within a broadly defined area (e.g., 20km) surrounding wells. These impacts may include increased traffic congestion and road damage from trucks delivering fresh water to wells and hauling away wastewater, wastewater disposal (to the extent that is done locally), and increased local employment and demand for goods and services.

In addition to these three direct impacts of shale gas activities on housing prices, there is a fourth category of housing market impacts that are common to areas with and without shale gas extraction—(4) *Macro Effects*. Given the time period that we study, this impact category includes the housing bubble, the subsequent housing bust and national recession, impacts of globalization and jobs moving overseas, and other regional economic impacts.

[6]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.

[7]As noted earlier, we emphasize that data on groundwater contamination resulting from shale gas activities in Pennsylvania are not generally available to researchers or homeowners because there was no widespread testing of groundwater prior to the start of drilling. What we are measuring is therefore the cost associated with the *risk* of contamination *perceived* by homeowners.

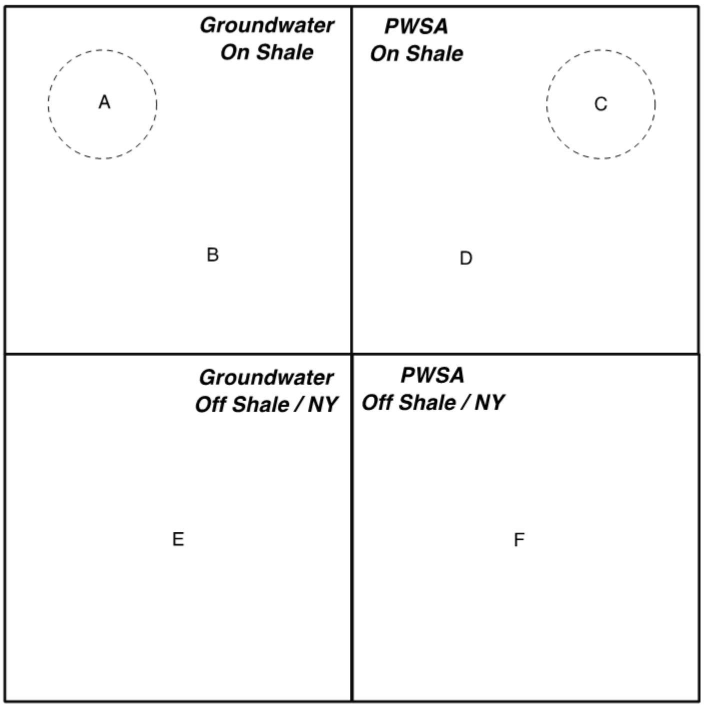

Figure 5: Types of Areas Examined

Figure 5 is useful in describing our identification strategy, and we will refer to it in more detail in Section 5.1.1. Area A represents a buffer drawn around a well pad that defines adjacency; we discuss the difference between wellbores and well pads in Section 4, and provide more information on how the size of the buffer is determined below. That buffer is located in an area dependent upon groundwater (GW)—i.e., outside the public water service area (PWSA). The remainder of that area, which is not adjacent to a well pad but is in the vicinity of one, and which is located in Pennsylvania where drilling is allowed and can occur due to the presence of the Marcellus shale formation, is labeled as area B.[8] Similarly defined regions of the PWSA area are labeled by C and D, respectively. Areas E and F represent regions (GW and PWSA, respectively) that are not exposed to hydraulic fracturing, either because they do not lie on the shale in Pennsylvania, or because they are in New York where a moratorium prohibits the

[8] Area B could also include homes in NY or in PA but off the shale that are within 20km.

practice.[9]

3.2 Defining the Adjacency Buffer

Our analysis focuses on how proximity to shale gas wells affects property values; we focus first on houses in close proximity to shale gas wells—an effect we refer to as *adjacency*. In order to define an adjacency "buffer" (i.e., what is "close" in terms of proximity), we draw on an empirical strategy similar to that employed by Linden and Rockoff (2008), which determines the point where a localized (dis)amenity no longer has localized impacts. In particular, this method compares the prices of properties sold after the drilling of a well to the prices of properties sold prior to drilling, and identifies the distance beyond which that well no longer has an effect that is different from that experienced elsewhere in the area. We then define our adjacency treatment group as properties having a well pad within this distance.

In order to conduct this 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 10km.[10] We begin by estimating two price functions based on distance to a well pad—one for property sales that occurred prior to a well pad being drilled and one for property sales after drilling began, controlling for property characteristics (X), census tract characteristics (Z), and county $\times$ year fixed effects, ν_{it}:[11]

$$\ln P_{it} = X'_{it}\alpha_1 + Z'_{it}\alpha_2 + \sum_{j=1}^{7}(\beta_j D_{ij}) + \nu_{it} + \epsilon_{it} \tag{1}$$

[9]We include homes located in areas E and F in our vicinity regressions to test the robustness of the baseline for estimating our vicinity treatment effect. We find that including or excluding these properties does not significantly affect our coefficients (See Section 5.2). For adjacency impacts, comparing across homes in areas A and B (and areas C and D) allows us to eliminate the common macro impacts without having to rely on homes in areas E and F.

[10]For this exercise, we choose to only look at homes that have one well pad within 10km, as the impact of multiple well pads 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 pad before and after the well pad is drilled if the home was already being impacted by another well pad drilled nearby. Restricting the sample to properties with only one well within a larger distance than 10km would reduce our sample size but we think it is a reasonable assumption that vicinity impacts that are felt at more than 10km will likely be felt in the same way as at 10km.

[11]Property characteristics are square feet, lot size, lot size squared, year built, and distance to nearest MSA. Other characteristics such as number of rooms, number of bathrooms, and number of stories were not reported for all properties and therefore to increase our sample size we did not include these characteristics. Census tract characteristics include percent of 25-year-olds with high school, percent black, percent Hispanic, percent unemployed, and mean income.

$\ln P_{it}$ is the natural logarithm of the transaction price for house i in year t. D_{ij} are indicators for whether a home is within a certain distance to a well as defined by 1.5km bins: (0, 1.5km], (1.5, 3km], and so on. Excluding an indicator for a home more than 9km from a well as our reference category, we have seven indicators. Equation (1) is estimated for each water source two times: once using the sample of properties that are eventually within 10km of a well pad (but not at the time of sale), and once using the sample of properties that are within 10km of a well pad at the time of sale. We plot the β_j's for each of the different distance intervals. We also plot the 95^{th} percentile confidence bands for the coefficients. The point at which the confidence intervals of the coefficients before and after a well pad is drilled intersect is the distance at which property values are no longer affected by adjacency. For groundwater homes, we see a sharp decline in property values after wells are drilled nearby; however, the difference between the before and after graphs goes away outside 1.5km. For PWSA houses, the distance functions are statistically indistinguishable before and after drilling. These figures demonstrate that adjacency impacts differ by drinking water source within 1.5km of a well.

Although the relative effect on groundwater houses (as demonstrated by the difference in the impact before and after a shale gas well is drilled at 1.5km) is statistically significant and negative, it does have a large confidence interval, ranging from just below zero to roughly -5. We don't rely on these numbers to identify our estimate of adjacency because it is a special sample (specifically, homes within 10km of only one shale gas well), and this technique does not control for many unobservable attributes associated with location. Instead we use this figure to motivate our selection of buffer distances below.

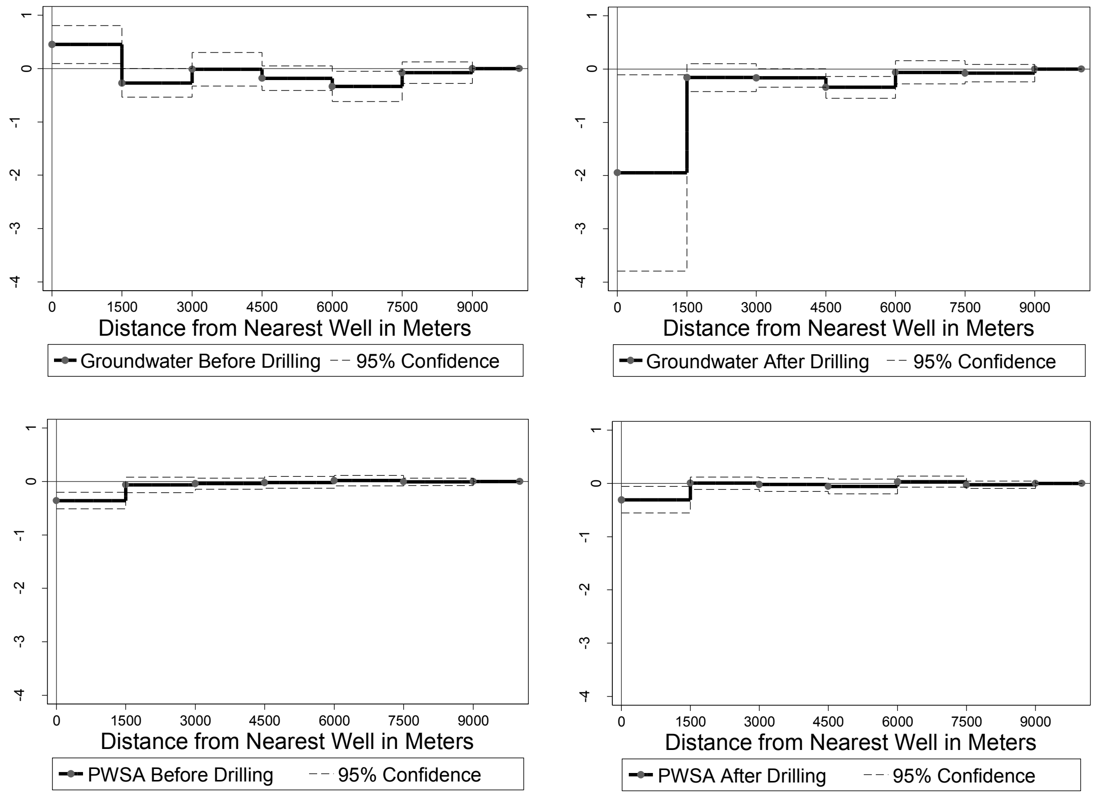

Figure 6: Coefficients from Equation (1) by Drinking Water Source and Timing of Drilling

4 Data

We obtained transaction records of all properties sold in 36 counties in Pennsylvania and seven border counties in New York between January 1995 and April 2012 from CoreLogic, a national real estate data provider. The data contain information on the transaction price, exact street address, parcel boundaries, square footage, year built, lot size, number of rooms, number of bathrooms, and number of stories. We start with 1.38 million unique observations of sales that have information on the location of the property. After excluding properties without a listed price, a price in the top or bottom 1% of all prices, and properties sold more than once in a single year, we are left with 1.20 million sales observations. Of these, there are 1.12 million sales of properties designated as a single family residence, rural home site, duplex, or townhouse; our main specifications only include these properties in order to estimate the impact on (likely) owner-occupied homes, rather than properties that are more likely transient or rented.[12] Furthermore, we want to include in our main specification only homes that were sold from one person to another (i.e., excluding made-to-order homes), thus we drop approximately 8,000 properties that were sold in the year built.[13] After eliminating new homes, of the remaining 1.04 million sales, 473,605 are repeat sales—a necessary condition for including property fixed effects. For specifications that instead rely on observed housing attributes, not all properties report a full slate of housing characteristics; out of our 1.04 million sale sample, only 799,767 have information on all property characteristics.

Figure 7 depicts the location of the Marcellus shale formation as well as the properties sold in Pennsylvania and bordering counties in New York (where hydraulic fracturing has been prohibited throughout our sample period). We also calculate the distance of each property's exact location to the population-weighted centroid of the nearest Metropolitan Statistical Area (MSA) in order to measure the property's rural character.

To determine the date that wells are drilled, we use the Pennsylvania Department of Environmental Protection (PADEP) Spud Data as well as the Department of Conservation and Natural Resources (DCNR) Well Information System (the Pennsylvania

[12]Though CoreLogic provides an indicator for whether the property is owner-occupied, this variable is not consistently reported by all counties. We exclude properties listed as a hotel, motel, residence hall, or transient lodging.

[13]Results are similar if these homes are included. We return to the question of new home construction in response to shale gas development in Appendix Section A.3.

Internet Record Imaging System/Wells Information System [PA*IRIS/WIS]). Combining these two datasets provides us with the most 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.[14]

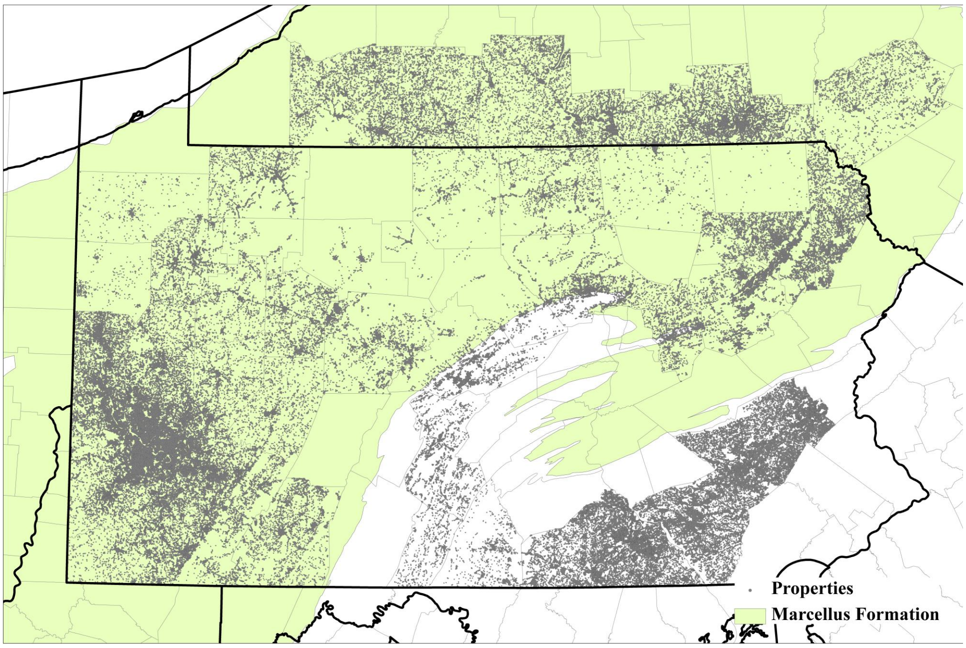

Figure 7: The Marcellus Shale Formation and Property Sales in Pennsylvania and New York

Because operators are able to drill horizontally underground, they can locate the tops of several wellbores close together at the surface, and radiate out the horizontal portion of the wellbore beneath the surface. Therefore, multiple wellbores can be drilled within meters of one another on the same "well pad," concentrating the surface disruption to a smaller space. Though the data do not group wells into well pads, we believe this is important to consider when estimating the effect of shale gas wells on nearby properties, as the impact from an additional wellbore is likely different than the impact of an additional well pad. We therefore assume that any wellbore within a

[14]Risk of improper well casing or cementing would be present in both vertical and horizontal wells.

short distance of another wellbore is located on the same pad (specifically, any wellbore that is closer than 63m, or the length of an acre, to any other wellbore in a well pad).[15] We start with 6,260 wellbores, which we group into 3,167 well pads (with an average of 2 wellbores per pad and a maximum of 12). Using the geographic information system (GIS) location of the wells and the properties, we calculate counts of the number of well pads that have been drilled, within certain distances, at the time of the property sale. The PADEP also provides information on the GIS location of all permitted wells, which we use to count the number of wells that have been permitted but have not yet been drilled (only about 60% of the wells that have been permitted have been drilled). We can also use the date that the well was permitted to determine how long a permit has remained undrilled. And finally, we obtain the volume of natural gas produced for each wellbore from the PADEP's Oil & Gas Reporting Website.[16]

Pennsylvania has many hilly and mountainous areas as well as plateaus. Therefore, depending on where the property is located, a homeowner may or may not be able to see all the wells within a 2km distance. Following the methodology in Walls et al. (2013), who examine the property value of natural landscape views, we count the number of wells that are in view and not in view at the time of sale. To do so we use ArcGIS's Viewshed tool and an elevation map from the National Elevation Dataset (at a 30 meter resolution) to predict how far a 5-foot tall observer can see from all directions around the property centroid. From this we make a count of the visible wells within different radii (1, 1.5, and 2km).

To identify properties that do not have access to piped drinking water, we utilize data on public water service areas. We obtained the GIS boundaries of the public water supplier's service area in Pennsylvania from the PADEP, and the GIS locations of parcel centroids that have access to public water in New York from the New York State Department of Taxation and Finance (NYDTF).[17] In the case of Pennsylvania,

[15]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).

[16]The data are reported as annual quantities until 2009 and then biannual from 2010 to 2012.

[17]In order to designate a PWSA/GW indication for New York properties, we utilize GIS to determine whether each CoreLogic parcel boundary intersects one of the NYDTF parcels. However, not all property locations geocoded in the NYDTF data fall within the parcel boundaries of the CoreLogic properties. For these unmatched CoreLogic properties, we create 250m buffer areas around each NYDTF parcel indicated as having access to public water. The unmatched CoreLogic properties that fall within this buffer are designated as having public water. If these properties fall outside the buffer, we assume they are groundwater dependent.

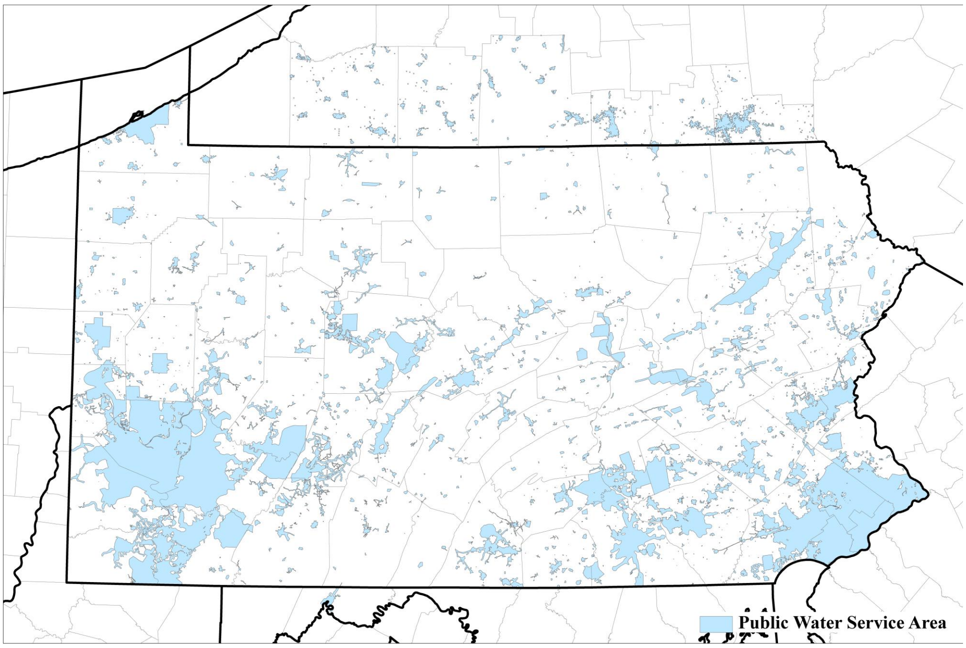

Figure 8: Public Water Service Areas in Pennsylvania and Bordering Counties in New York

any property that was outside the PWSA was assumed to be groundwater dependent.[18]

Table 1 shows that there exist observable differences between PWSA and GW homes, in terms of lot size, property values, age, ruralness, and well proximity, demonstrating the importance of controlling for property-level unobservables with property fixed effects. Furthermore, differences in observables across the two types of water sources suggest there may be unobservable, time-varying differences across PWSA and GW homes that could confound the estimates of impacts of proximity to shale gas wells on property values. We deal with this issue by focusing on GW homes that are near PWSA homes, in order to minimize the unobservable differences in location across the two water source homes; see Section 5.1.2 for a more in depth discussion of how we utilize the GW boundary to minimize these unobservables. Figure 8 shows the PWSA areas for Pennsylvania and New York, where the unshaded areas are assumed to depend on private groundwater wells as a drinking water source. This figure demonstrates that the PWSAs are scattered throughout both states, further illustrating the

[18]There is not much financial assistance to households that wish to extend the piped water area to their location, and this is a costly endeavor according to personal communication with the development manager at the Washington County Planning Commission, April 24, 2012.

importance of estimating the impacts of shale development on groundwater homes. Figure 9 demonstrates the PWSA boundary sample for an example county, Armstrong County, Pennsylvania.

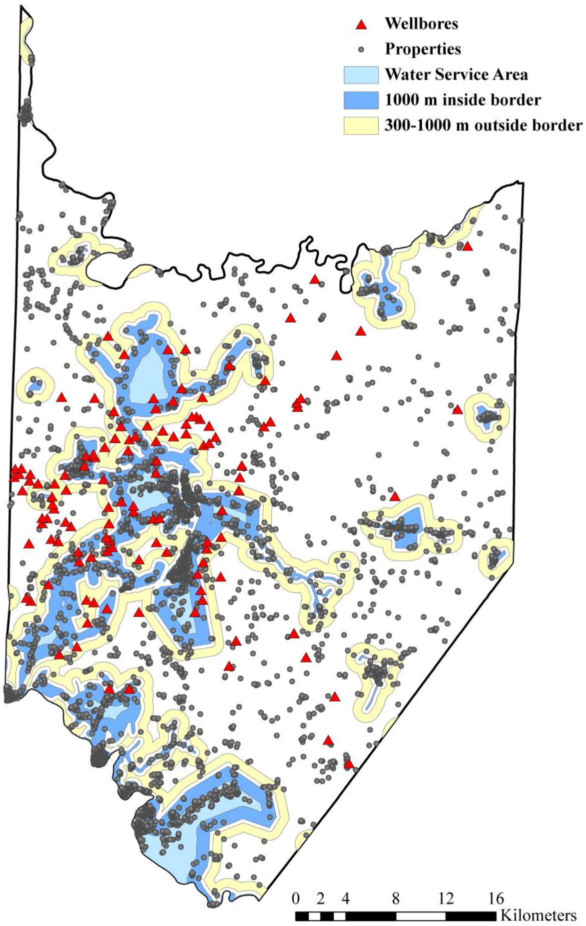

Figure 9: Example Indicating the 1000m Boundary Inside and 300-1000m Boundary Outside of Public Water Service Areas in Armstrong County, Pennsylvania

To obtain information on neighborhood attributes, we merge in census tract data compiled by SimplyMap, a national data mapping software tool.[19] SimplyMap combines information from decennial censuses, the American Community Survey Public Use Microdata Samples, the Annual Demographic Survey, Current Population Reports, numerous special Census reports, and information from the US Postal Service to create estimates for key sociodemographic variables at the census tract level. Data are available in 2010 census tract geographies for 2000, 2010, 2011, and 2012.

[19]http://geographicresearch.com/simplymap/

Table 1: Summary Statistics by Sample

	GW Means(SD)	**PWSA** Means(SD)	**PA/On** Means(SD)	**PA/Off** Means(SD)	**NY** Means(SD)
Transaction Price (k 2012 Dollars)	174	147	128	165	100
	(106)	(95.4)	(98.4)	(95.7)	(77.7)
GW	1	0	.116	.212	.378
	(0)	(0)	(.321)	(.409)	(.485)
Age	41.5	52.2	56.8	50.5	63.5
	(38.7)	(33.9)	(32.3)	(39.5)	(37.1)
Total Living Area (1000 sqft)	1.77	1.65	1.59	1.7	1.66
	(.739)	(.66)	(.82)	(.666)	(.665)
No. Bathrooms	1.92	1.88	1.79	1.9	1.75
	(.851)	(.857)	(.877)	(.857)	(.761)
No. Bedrooms	3.09	3.08	2.97	3.2	3.17
	(.818)	(.843)	(.961)	(.889)	(1.01)
Lot Size (acres)	3.47	1.52	.87	3.23	4.07
	(11.5)	(233)	(5.97)	(352)	(16.7)
Distance to nearest MSA (km)	22.3	18.1	22.8	15.4	19.8
	(11.1)	(10.5)	(12.6)	(7.84)	(13.5)
% Age 25 w/High School	42.3	36	37.5	39.3	35.2
	(7.92)	(10.5)	(11.5)	(8.42)	(8.65)
% Black	1.16	5.83	6.56	5.17	2.15
	(1.94)	(10.8)	(13.7)	(7.17)	(2.22)
% Hispanic	.457	1.5	.59	3.16	.699
	(.697)	(3.77)	(2.04)	(5.74)	(1.16)
% Unemployed	3.69	4.26	4.1	4.78	4.5
	(1.34)	(2.37)	(2.07)	(3.03)	(2.11)
Mean Income (k Dollars)	68.7	66.3	64.5	63.7	59.3
	(15.7)	(26)	(27.4)	(19.2)	(14.9)
Marcellus Indicator	.466	.634	1	0	1
	(.499)	(.482)	(0)	(0)	(0)
Distance to Closest Well Pad (km)	10.3	12.3	11.2	16.1	15.3
	(5.62)	(5.12)	(5.4)	(2.49)	(3)
Pads in 1km	.00224	.000701	.004	0	0
	(.0618)	(.0366)	(.0928)	(0)	(0)
Pads in 1.5km	.00575	.00205	.0107	0	0
	(.123)	(.0738)	(.19)	(0)	(0)
Pads in 2km	.0115	.00462	.0219	0	.000032
	(.2)	(.127)	(.328)	(0)	(.0073)
Pads in View in 1km	.00042	.000116	.00063	0	0
	(.0249)	(.0132)	(.0298)	(0)	(0)
Pads in View in 1.5km	.000709	.000306	.00145	0	0
	(.0327)	(.0218)	(.0498)	(0)	(0)
Pads in View in 2km	.00106	.0005	.00232	0	0
	(.0415)	(.0304)	(.0721)	(0)	(0)
Annual Prod. in 1.5km (MMcf)	.655	.176	.891	0	0
	(41)	(25)	(57.6)	(0)	(0)
Annual Prod. in 1km (MMcf)	1.55	.533	2.3	0	0
	(79.7)	(48.2)	(102)	(0)	(0)
Annual Prod. in 2km (MMcf)	3.44	1.18	4.79	0	0
	(137)	(80.5)	(163)	(0)	(0)
Wellbores in 20km	2.55	3.77	7.25	.0313	1.2
	(21.3)	(21.8)	(32.5)	(.868)	(7.73)
Undrilled Permits in 20km	1.62	2.68	4.85	.00753	.777
	(13.5)	(15.7)	(21.9)	(.222)	(5.23)
Annual Prod. in 20km (MMcf)	482	670	1,359	3.04	144
	(6,071)	(5,396)	(9,407)	(184)	(1,249)
Observations	121,352	656,010	581,198	397,275	93,845

Notes: GW refers to properties without access to piped water. PWSA refers to properties in a public water service area. PA/On refers to properties on the Marcellus shale in PA. PA/Off refers to properties off the Marcellus shale in PA. NY refers to properties in New York (all of which are on the Marcellus shale).

5 Empirical Strategy and Results

5.1 Adjacency Effects and Groundwater Contamination Risk

In this section, we estimate the impacts of close proximity (adjacency) to shale gas wells on property values. These effects can be positive, such as in the case that the property owner receives royalty or other lease payments from the gas company for the natural gas extracted under their property, or negative, given perceived impacts of groundwater contamination or the alteration of the local landscape. As the siting of shale gas wells can be strategic on the part of gas companies, it is important to account for a wide range of unobservable attributes that may be correlated with proximity to both the property and the shale well. Thus, we employ two different empirical approaches—a difference-in-differences technique combined with a nearest-neighbor matching algorithm and a triple-difference technique that makes use of a PWSA boundary sample (described in more detail in Section 5.1.2) in order to eliminate unobservables and thus more accurately capture the impact of adjacency.

5.1.1 Difference-in-Differences Nearest Neighbor Matching (DDNNM)

To begin, we are interested in measuring the GWCR—i.e., the effect of well pad adjacency on groundwater-dependent homes. The standard problem in recovering a treatment effect is that we are unable to observe the counterfactual for a treated observation; in the current setting, we fail to observe the price of a house located in close proximity to a well pad if that same house were instead located farther away ("same," in this context, is in terms of both house and neighborhood attributes, both time invariant and those that vary over time). Parametric hedonic regression functions are used to address this problem by specifying a functional relationship with which the counterfactual value can be imputed. This assumes that unobserved determinants of house value are not correlated with observed determinants.[20]

Matching estimators impute counterfactual observations by pairing treated houses with similar houses from a control group.[21] The effect of treatment is then found by averaging across the price differences for matched pairs. More detail on the techniques

[20]A number of quasi-experimental approaches have been developed to deal with the case when this assumption does not hold (Parmeter and Pope, 2009); we utilize several of these ideas in subsequent sections.

[21]For more background on the advantages of matching compared to parametric hedonic methods, see Cochran and Rubin (1973), Rubin (1974), Rosenbaum and Rubin (1983), Rubin and Thomas (1992), and Heckman et al. (1998).

involved in matching estimators can be found in Abadie and Imbens (2002), Abadie and Imbens (2006), Abadie and Imbens (2011), and Abbott and Klaiber (2011); our main specification uses the nearest neighbor matching technique.

The key to the success of this type of matching estimator is to structure the problem so that unobservable house and neighborhood attributes are not correlated with treatment status. We do so here by limiting the control sample in certain dimensions and by requiring exact matches in other dimensions. In particular, the nearest neighbor matching estimator allows us to require exact matches in the geographic dimension (i.e., census tract) to control for neighborhood unobservables, and in the temporal dimension (i.e., transaction year) to control for time-varying unobservables. We require exact matches in these dimensions to help control for various forms of unobservables that might otherwise bias our results. Moreover, we limit the sample to include only houses that we expect to be in a relatively homogenous neighborhood within each census tract. Thus, we (1) limit our analysis to only houses that are within 6km of a well pad (defining the treatment buffer to be 1, 1.5, or 2km given evidence of a small adjacency buffer found in Section 3.2, (2) require exact matches by census tract, (3) require exact matches by year of sale, and (4) perform the analysis separately for groundwater and PWSA houses. The idea behind these restrictions is that houses within 6km of a well pad in the same census tract that rely on the same water source will be located in similar neighborhoods, thereby reducing both the time-varying and time-invariant unobservables that may be correlated with the location of the property. Requiring exact matching by year of sale will further eliminate differences in unobservables that vary from year to year at this level of the neighborhood.

The nearest neighbor matching algorithm is used to recover an estimate of the average treatment effect on the treated (ATT), or the impact on price from moving a non-adjacent house inside the adjacency buffer. In Figure 5, this corresponds to a move from B to A for groundwater houses, and from D to C for PWSA houses. We now show that, by differencing these ATT estimates, we are able to recover an estimate of GWCR. Using the areas defined in Figure 5, we can refer to the price of housing in each area as being composed of a number of constituent parts:

$$
\begin{aligned}
P_A &= \text{GWCR} + \text{Adjacency} + \text{Vicinity} + \text{Macro} \\
P_B &= \text{Vicinity} + \text{Macro} \\
P_C &= \text{Adjacency} + \text{Vicinity} + \text{Macro} \\
P_D &= \text{Vicinity} + \text{Macro} \\
P_E &= \text{Macro} \\
P_F &= \text{Macro}
\end{aligned}
$$

Our nearest neighbor matching algorithm applied to groundwater houses yields an estimate of the GWCR combined with the adjacency effect: $P_A - P_B = GWCR + Adjacency$. Applied to PWSA houses, it yields an estimate of the adjacency effect alone: $P_C - P_D = Adjacency$. Differencing these two estimates leaves us with an estimate of the GWCR:

$$\text{GWCR}_{\text{DDNNM}} = (P_A - P_B) - (P_C - P_D)$$

The results of the nearest neighbor matching procedure are reported in Table 2. The first two rows report the point estimates and 90% confidence intervals for PWSA houses using 1, 1.5, and 2km treatment buffers. The next two rows report comparable figures for groundwater houses.

In all cases, the difference-in-differences estimate of the GWCR effect based on these estimates is negative. In the case of the 1.5km treatment buffer, the DD estimate is large (-16.7%) and significant at the 10% level.

An advantage of the DDNNM estimator is that, unlike the DDD estimator that we describe below, it does not rely on variation in exposure to shale gas development over time; the concerns about shifting hedonic price gradients raised by Kuminoff and Pope (forthcoming), as discussed in Section 2, are therefore not relevant.

Table 2: Log Sale Price on Groundwater Contamination Risk of Well Pads from a Matching Estimator

	Treatment Buffer		
Sample	1km	1.5km	2km
PWSA (*n=9,517*)	-0.0064	0.039	0.006
	(-0.080, 0.073)	(-0.014, 0.092)	(-0.036, 0.047)
GW (*n=1,980*)	-0.0834	-0.128	-0.088
	(-0.187, 0.020)	(-0.211, -0.044)	(-0.163, -0.013)
DD Estimate	-0.077	-0.167	-0.094
Bias Adjustment Variables			
-House Attributes	Yes	Yes	Yes
-Year Fixed Effects	Yes	Yes	Yes
-County Fixed Effects	Yes	Yes	Yes

Notes: Sample comprising all houses within 6km of a well pad. Each house in the treatment buffer is matched with 4 houses in the control sample. Exact match required on year of sale and census tract. Matching also based on house attributes (lot size, square footage, number of bedrooms, number of bathrooms, and year built). Treatment buffer size varies between 1 and 2km. Bias adjustment equation contains all matching variables and census tract fixed effects. 90% confidence intervals reported in parentheses.

5.1.2 Triple-Difference Estimator (DDD)

A second approach is used to identify *both* adjacency and vicinity effects jointly. Unlike the previous approach, however, it does exploit variation in house prices over time. Considering the impact categories defined above, we begin with the change in a *particular* property's value over time (ΔP) in each area:

$$\begin{aligned}
\Delta P_A &= \Delta \text{GWCR} + \Delta \text{Adjacency} + \Delta \text{Vicinity} \; + \Delta \text{Macro} \\
\Delta P_B &= \Delta \text{Vicinity} + \Delta \text{Macro} \\
\Delta P_C &= \Delta \text{Adjacency} + \Delta \text{Vicinity} + \Delta \text{Macro} \\
\Delta P_D &= \Delta \text{Vicinity} + \Delta \text{Macro} \\
\Delta P_E &= \Delta \text{ Macro} \\
\Delta P_F &= \Delta \text{Macro}
\end{aligned}$$

Our strategy for identifying adjacency effects uses a difference-in-differences (DD) estimator:

$$\Delta \text{Adjacency}_{\text{DD}} = [\Delta P_C - \Delta P_D]$$

$$\Delta \text{Adjacency}_{\text{DD}} + \Delta \text{GWCR}_{\text{DD}} = [\Delta P_A - \Delta P_B]$$

where the first difference, "Δ," reflects the change in price of a particular house (e.g., accompanying the addition of a new well pad). The second difference compares the change in prices for PWSA properties adjacent to shale gas development to the change in prices of PWSA properties not adjacent to development. For the PWSA homes, this differences away vicinity and macro effects that are common across C and D; the corresponding equation for GW homes results in both adjacency and groundwater contamination risk. Finally, to estimate the effect of perceived groundwater contamination risk, we take the third difference, between the effects in PWSA and GW areas in a triple-difference (DDD) estimator defined by:

$$\Delta \text{GWCR}_{\text{DDD}} = [\Delta P_A - \Delta P_B] - [\Delta P_C - \Delta P_D]$$

In this expression, the first difference, Δ reflects the change in the price of a particular house accompanying the addition of a new well pad. The second difference (i.e., $[\Delta P_A - \Delta P_B]$ and $[\Delta P_C - \Delta P_D]$) compares the change in prices inside each adjacency buffer to the change in prices in the area outside of that buffer. This differences away relevant vicinity and macro effects, which should be the same on both sides of the adjacency buffer boundary, leaving only GWCR and adjacency effects. The third (and final) difference differences those double-differences, eliminating adjacency effects and leaving only GWCR.

In order to conduct this test in an empirical framework, we define our impact variable given the results of our adjacency test in Section 3.2. Specifically, we look at well pads rather than wellbores for adjacency effects. We choose to look at pads in order to identify GWCR because we are capturing perceptions of contamination risk. When the pad is cleared and drilling begins, it is unlikely that the second bore will have the same impact on property values as the initial pad. Essentially, here we assume that the perception that groundwater will be contaminated will be the same regardless of the number of wellbores.[22] Therefore, we look at the impact of different counts of well pads within 1, 1.5, or 2km of property i at time t of sale (i.e., $pads_{it}$ in Equation 2). Our first regression specification takes the following form:

$$\ln P_{it} = \theta pads_{it} + \lambda(GW \times pads)_{it} + \nu_{it} + \mu_i + \epsilon_{it} \tag{2}$$

We include controls for county × year, ν_{it}, and property, μ_i, fixed effects. Importantly,

[22] We test this by running the regressions on bores rather than pads and find that bores do not significantly affect GWCR.

we restrict the sample to only houses that are at some point in time inside a treatment buffer (i.e., area A or C). θ therefore measures ΔP_C and $\lambda+\theta$ measures ΔP_A; $\Delta P_A - \Delta P_C$ is thus defined by λ, the coefficient on the interaction term between *pads* and GW. Assuming $\Delta P_B = \Delta P_D$, λ will provide an estimate of the capitalization effect of groundwater contamination risk. Of course, there is no reason to expect *a priori* that $\Delta P_B = \Delta P_D$; however, a simple F-test demonstrates that this is indeed the case.[23] Therefore, only using properties that are at some point in time within an adjacency buffer (areas A and C), allows us to conduct an implicit triple difference, where the macro and vicinity effects are canceled out; i.e., $\lambda = [\Delta P_A - \Delta P_B] - [\Delta P_C - \Delta P_D]$. This allows us to estimate the GWCR and adjacency effects without having to control explicitly for vicinity impacts.

As mentioned earlier, unobservables can affect the estimated impact of proximity to shale gas wells on property values. We utilize several strategies including difference-in-differences and triple differences to control for many of these unobservables. We also use property fixed effects to control for any time invariant unobservables at the house level and county $\times$ year fixed effects to control for time-varying unobservables at the county level.

In addition to these controls, we implement a sample restriction designed to minimize differences in time-varying unobservables across the GW and PWSA subsamples. In particular, we limit our sample to only properties located in a narrow band around the PWSA boundary—1000m on either side, ignoring houses on the GW side within 300m (to avoid potential miscodes of PWSA houses as GW houses).[24] GW and PWSA houses can be very different on average (see Table 1 for summary statistics); these structural differences are, however, captured by property fixed effects. Time-varying unobservable differences in GW and PWSA houses are, conversely, more likely to result from changing neighborhood attributes. In particular, we would expect neighborhood attributes to be very different across GW and PWSA houses located far from the boundary—some of the GW houses are in very rural areas while some of the PWSA

[23] Vicinity effects, estimated using wellbores, are described below. We re-estimate those vicinity regressions using well pads, adding interactions between all variables and the groundwater dummy. We then conduct an F-test of the joint significance of the interactions between groundwater and the well pad count variables. That F-test reveals that these interactions are not jointly statistically significant ($Prob > F = 0.4805$), demonstrating that the vicinity effects do not differ across drinking water sources.

[24] Our final results are robust to removing 300m on the PWSA side as well; doing so, we find an even larger decrease in values of GW-dependent homes and a statistically significant increase in PWSA homes.

houses are in urban areas. By limiting our DDD analysis to houses along the PWSA boundary, we still allow for variation in water source while geographically restricting neighborhoods to be more homogenous.[25]

We provide simple evidence that restricting our sample to the band surrounding the PWSA boundary functions as intended. In particular, using data from years prior to the onset of hydraulic fracturing, we estimate the following regression equation:

$$\ln P_{it} = year'_{it}\gamma + (GW \times year)'_{it}\delta + \mu_i + \epsilon_{it}$$

$\ln P_{it}$ is the log of the transaction price of the property in year t, $year'_{it}$ are indicators for the year the property was sold, GW is an indicator for whether the property is groundwater dependent, μ_i are property fixed effects, and ϵ_{it} is a time-varying error term.

We estimate this regression equation first using the full sample and then using only properties in the band surrounding the PWSA boundary. If the band is able to successfully control for time-varying differences between GW and PWSA houses, we would expect to see δ become insignificant using the boundary sample.

Figure 10 describes the 95% confidence interval for estimates of δ derived from the full sample and the PWSA band for each year of our data prior to the onset of hydraulic fracturing (i.e., 1996 to 2005). While δ derived from the full sample is significant in every year except 1998 and 2003, δ derived from the PWSA band is insignificant in every year except 2004. This demonstrates that utilizing only the sample within 1000m of the PWSA band eliminates (most) time-varying unobservables that may confound our estimates of shale gas impacts on property values.

As we have now defined the PWSA boundary, we restrict our attention to those homes located within this region in order to clearly identify the GWCR in our triple-difference estimation. Using this sample, results show that the GWCR effect is negative, large, and statistically significant.

[25] In our matching technique described in Section 5.1.1 the definition of our control group and requirement of exact matching on year and census tract do this job.

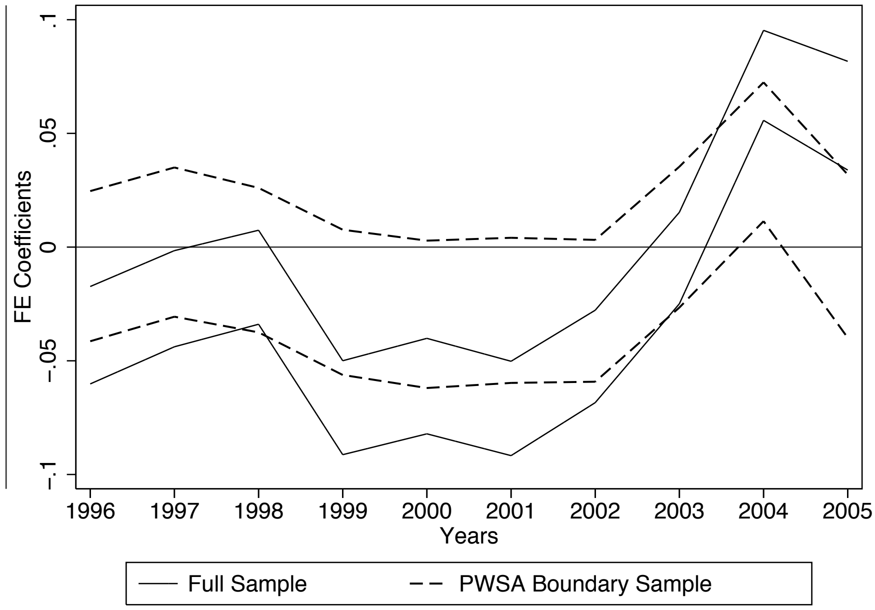

Figure 10: 95% Confidence Bands on Groundwater × Year Fixed Effect Interaction—Full Sample vs. PWSA Boundary Band

Table 3: Groundwater Contamination Risk

	Using $K \leq 1$km		Using $K \leq 1.5$km		Using $K \leq 2$km	
	Full	Boundary	Full	Boundary	Full	Boundary
	(1)	(2)	(3)	(4)	(5)	(6)
	ln(price)	ln(price)	ln(price)	ln(price)	ln(price)	ln(price)
Pads in Kkm	.046	.057	.047**	.066**	.016*	.031***
	(.040)	(.042)	(.020)	(.030)	(.010)	(.010)
(Pads in Kkm)*GW	-.003	-.224***	-.005	-.100**	.021	.031
	(.062)	(.051)	(.028)	(.046)	(.018)	(.069)
County-Year Effects	Yes	Yes	Yes	Yes	Yes	Yes
Property Effects	Yes	Yes	Yes	Yes	Yes	Yes
n	1,961	942	3,885	1,835	6,608	3,090

Notes: Dependent variable is log sale price in 2012 dollars. Sample includes only properties that at some point in time (future or present) are within Kkm of a well pad. *Boundary* restricts sample to a buffer around the border of the public water service area. Regressors include counts of well pads drilled within Kkm before the sale date. Robust standard errors are clustered by census tract. *** Statistically significant at the 1% level; ** 5% level; * 10% level.

One thing to note is that the *overall* impact of adding a well pad within 1km is not just the GWCR, but must also take into account the positive (although sometimes statistically insignificant) adjacency effect. The results from Table 3 imply that adding an extra well within 1.5km causes groundwater homes to depreciate by 3.4%, with -10%

being due to the risk of groundwater contamination, and +6.6% due to the positive impact of lease payments and other adjacency impacts. However, it is interesting to see how the effects differ as we change the size of the adjacency buffer. Very near the well (within 1km), we see much larger negative impacts and insignificant positive impacts. This may be due jointly to the increased perception of groundwater contamination along with increased negative impacts (such as noise and light pollution associated with drilling) that dampen the positive impacts of lease payments. Moving farther from the well (from 1km to 1.5km) reduces the negative impact on PWSA homes (perhaps by decreasing the localized pollution impacts) and allows for a positive impact to emerge; the negative impact on GW homes also diminishes. Finally, farthest from the shale gas well, at 2km, there are no longer significant negative impacts of proximity for GW homes; this is intuitive, as we would expect that being located farther from a well would decrease the perception of groundwater contamination risk. For PWSA homes, on the other hand, the *net* positive benefits decrease at 2km relative to 1.5km; this is likely the result of fewer homes at this distance receiving lease payments.[26]

To examine the effect of adjacency to shale gas wells in more detail, we next focus only on properties that have access to piped water (i.e., any property located in areas C and D). This allows us to identify the adjacency effect in the absence of any concerns over GWCR, via a difference-in-difference estimation. Table 4 displays how the impacts of shale gas development depend on characteristics of that development, using different distances (1km, 1.5km, and 2km) as adjacency buffers.

[26]Although electronic records of the location of the horizontal segment of the wellbores are not available, anecdotal evidence suggests that wellbores are typically between 3,000 (.9km) and 5,000 feet (1.5km) (US Energy Information Administration, 2013), but could be up to 9,000 feet (2.7km) (Horizontal Well Drillers, 2012).

Table 4: Adjacency Effects

	K=1km	K=1.5km	K=2km
	(1)	(2)	(3)
	ln(price)	ln(price)	ln(price)
A. Log Sale Price on Well Pads in View			
Not-Visible Well Pads in Kkm	.023	.012*	.032**
	(.028)	(.006)	(.013)
Visible Well Pads in Kkm	-.006	.014	-.027
	(.071)	(.037)	(.059)
B. Log Sale Price on Production			
Annual Production in Kkm (MMcf)	2.1e-05	2.2e-05**	9.0e-06*
	(1.9e-05)	(8.8e-06)	(5.2e-06)
C. Log Sale Price on Timing of Wellbores			
New Bores (drilled $\leq$ 365 days)	.015	.020**	.009**
	(.018)	(.010)	(.004)
Old Bores (drilled > 365 days)	-.008	-.012	-.003
	(.029)	(.013)	(.008)
New Undrilled Permits	.052**	.020	.010
	(.025)	(.014)	(.011)
Old Undrilled Permits	.040*	.006	.006
	(.023)	(.013)	(.008)
County-Year Effects	Yes	Yes	Yes
Property Effects	Yes	Yes	Yes
n	507,023	507,023	507,023

Notes: Dependent variable is log sale price in 2012 dollars and each panel and column represents a separate regression. Regressors are the count of wells (or annual natural gas production) within Kkm, depending on the column. Sample includes only properties that are in piped water service areas, in Pennsylvania, on the Marcellus Shale. Robust standard errors are clustered by census tract. *** Statistically significant at the 1% level; ** 5% level; * 10% level.

First, since the topography of Pennsylvania varies across the state, we have variation in the number of wells that are visible to a 5ft individual looking 360 degrees around a property. Panel A of Table 4 shows that that the positive impact of being adjacent to a well is driven by those wells that are not in view of the property. The positive effects from lease payments appear to be offset when the wells are in view, as the coefficient on wells in view is statistically insignificant.

We next examine whether the positive results are indeed driven by royalties from the gas production by including as a regressor total production from nearby wells. We do find evidence to support this; in Panel B we find that the amount of natural gas produced by the wells (as measured as total natural gas production in the year of sale) increases property values. This result is intuitive, as the level of production would result in higher royalty payments to the homeowner.[27]

Our final specification in Panel C explores the timing of the well drilling: in particular, we estimate whether newly drilled bores (i.e., bores drilled within a year prior to the sale of the home) affect property values more than older bores. Results show that newly drilled bores positively impact property values for homes within 1.5km and 2km, while old bores have an insignificant, negative impact. At a very close distance, 1km, there is no positive effect felt from newly drilled wells, however there is a positive effect from permits implying that expectations for drilling have positive implications for property values in close proximity. Newly drilled bores tend to produce more natural gas than old bores; therefore, the number of new bores may be acting as a proxy for production.

5.2 Vicinity

We next estimate the effect of shale gas development on housing prices in the broader geographical area, which we refer to as vicinity effects. These impacts may include increased traffic congestion and road damage from trucks delivering fresh water to wells and hauling away wastewater, local wastewater disposal, and increased local employment and demand for goods and services, for example.

In measuring vicinity effects, we consider the impact on property values of the number of wellbores within 20km of each house, thus estimating the broader economic impacts of a shale boom.[28] We do this by regressing the natural logarithm of the transaction price for house i in year t ($\ln P_{it}$) on a variety of different regressors. Our simplest specification includes the counts of wellbores that have been drilled prior to the time of sale within 20km, $bores20_{it}$.

$$\ln P_{it} = \zeta \, bores20_{it} + \nu_{it} + \mu_i + \epsilon_{it} \quad (3)$$

We use a vector of county $\times$ year fixed effects, ν_{it}, to control for macro effects, and

[27] In another specification, not shown, we found that the positive result is only driven by wells that have produced some natural gas; in the data, 42% of wells that have been drilled have not produced anything as of 2012.

[28] We choose to use counts of wellbores rather than well pads because wellbores are a more direct measure of productivity; the more wellbores there are, the more natural gas can be extracted. We expect the broader impacts on housing prices to be driven by immigration of natural gas workers and associated economic activity; thus we choose a measure more closely related to productivity at a broader scale—wellbores. Results using well pads rather than wellbores are qualitatively similar; given high levels of correlation between bores and pads, we are unable to include both in our regressions.

either census tract fixed effects or property fixed effects, labeled here as μ_i, to control for time invariant unobservables at the property or neighborhood level.[29] Further regressions explore the impact of undrilled permits, production data, and the timing of the drilling on property values.

Table 5: Vicinity Effects from Wellbores

	Using On	Using On/Off	Using On/NY	Using On	Using On/Off	Using On/NY
	(1)	(2)	(3)	(4)	(5)	(6)
	ln(price)	ln(price)	ln(price)	ln(price)	ln(price)	ln(price)
A. Log Sale Price on Cumulative Wellbores in 20km						
Bores	2.2e-04	2.6e-04*	2.3e-04*	-1.1e-04	-1.1e-04	-8.0e-05
	(1.4e-04)	(1.5e-04)	(1.4e-04)	(1.5e-04)	(1.5e-04)	(1.4e-04)
B. Log Sale Price on Wellbores and Permits in 20km						
Bores	7.1e-04***	7.2e-04***	6.1e-04***	1.3e-04	1.1e-04	1.3e-04
	(1.5e-04)	(1.5e-04)	(1.4e-04)	(1.6e-04)	(1.6e-04)	(1.6e-04)
Undrilled Permits	-.0017***	-.0016***	-.0012***	-8.4e-04**	-8.1e-04**	-7.6e-04**
	(4.1e-04)	(4.1e-04)	(3.7e-04)	(3.7e-04)	(3.6e-04)	(3.4e-04)
C. Log Sale Price on Production in 20km						
Annual Production (MMcf)	1.9e-06***	2.0e-06***	2.0e-06***	3.0e-07	3.0e-07	3.8e-07
	(4.3e-07)	(4.5e-07)	(4.4e-07)	(4.2e-07)	(4.2e-07)	(4.1e-07)
D. Log Sale Price on Timing of Drilling						
New Bores ($\leq$ 365 days)	.0018***	.0018***	.0015***	8.6e-04**	8.1e-04**	8.8e-04**
	(3.8e-04)	(3.8e-04)	(3.7e-04)	(4.0e-04)	(3.9e-04)	(3.9e-04)
Old Bores (> 365 days)	5.9e-04***	6.2e-04***	5.9e-04***	9.3e-05	7.9e-05	9.0e-05
	(2.3e-04)	(2.3e-04)	(2.2e-04)	(2.6e-04)	(2.5e-04)	(2.5e-04)
New Undrilled Permits	-.0013***	-.0012***	-8.8e-04**	-3.5e-04	-3.3e-04	-3.1e-04
	(4.3e-04)	(4.2e-04)	(3.7e-04)	(4.3e-04)	(4.2e-04)	(3.8e-04)
Old Undrilled Permits	-.003***	-.003***	-.0026***	-.002***	-.0019***	-.0019***
	(7.0e-04)	(6.7e-04)	(6.5e-04)	(6.4e-04)	(6.2e-04)	(6.2e-04)
Property Effects	No	No	No	Yes	Yes	Yes
Census Tract Effects	Yes	Yes	Yes	No	No	No
County-Year Effects	Yes	Yes	Yes	Yes	Yes	Yes
n	378,518	743,529	466,062	226,775	425,342	268,807

Notes: Dependent variable is log sale price in 2012 dollars. Each column represents a different sample. All columns include properties that are on the Marcellus shale in Pennsylvania, excluding those that at some point in time are within 2km of a wellbore. Columns (2) and (5) also include properties that are off the Marcellus shale and in Pennsylvania. Columns (3) and (6) include properties on the Marcellus shale as well as properties in New York. Robust standard errors are clustered by census tract. *** Statistically significant at the 1% level; ** 5% level; * 10% level.

[29] Our choice of using either property or census tract FE is discussed in more detail below.

Results are reported in Table 5. This table includes three different samples. The first sample only includes properties that are located on the Marcellus shale. This initial specification implies that identification is based on the timing of when drilling in the vicinity occurred, given that the control group has positive and rational expectations of future drilling. The second sample adds to the control group homes in Pennsylvania that are off the shale. This identifies the vicinity effect based on the timing of drilling but also in comparison to areas that would never have any shale gas development due to geological constraints. The third sample instead adds to the control group homes in New York, where the current drilling moratorium may be lifted; thus, the control group has some rational expectation that drilling may occur in the (distant) future. Each of these three samples excludes homes that at any point in time of our sample period are within 2km of a shale gas well (i.e., inside areas A and C), in order to avoid confounding the vicinity and adjacency impacts.

The first three columns include census tract fixed effects with property characteristics while the following three columns instead utilize property fixed effects. We therefore control for time-invariant unobservables through different fixed effects. Utilizing census tract fixed effects assumes that the unobservables that are correlated with vicinity are at the neighborhood level. Alternatively, using property fixed effects assumes that there is something unobservable about the house that affects the number of wells within 20km. While the property fixed effects are essential to use in the adjacency and GWCR regressions, it is reasonable to assume that they are less important in the vicinity regressions, where it is unlikely that an unobservable property attribute would be associated with the number of wells within 20km. Instead, it is more likely that census tract attributes could affect the number of wells in the vicinity; for example, a census tract with lots of hills may be less amenable to high levels of development than a flat census tract area (which would require less land clearing). Furthermore, when comparing the variation in the number of wells drilled and total natural gas production *within* property sales to the variation *across* property sales there is much more within-property variation in the adjacency regressions than the vicinity regressions (about twice as much). Our preferred specifications are therefore those in the first three columns.

Examining the specification in Panel A, we find insignificant effects of increased exposure to wellbores within 20km, with weakly significant and positive impacts in columns 2 and 3. This provides some weak evidence that development increases property values in the vicinity.

In Panel B we introduce as an extra regressor the count of wellbores that have been permitted but are not yet drilled at the time of sale. Results show that undrilled permits have a negative impact on property values, regardless of the fixed effect or sample utilized. This is likely due to the fact that locations with undrilled permits are areas that have begun to be cleared for a well pad but have not stimulated economic activity through natural gas production. Thus, they only cause disamenities (which are then capitalized into the price of the home) without producing natural gas, which can be a source of wealth for those in the community. Moreover, areas with many undrilled permits could experience deflated expectations—i.e., they are areas that were expected to be highly profitable but have yet to deliver or have been shown to be unprofitable.[30] In this specification, we also find that the number of bores positively impacts properties (further strengthening the evidence found in Panel A), but this result only holds when we use census-tract fixed effects.

We next test whether having productive wells in the vicinity affects property values. In Panel C our regressor "Annual Production" is the total amount of natural gas produced by the wellbores within 20km of a property. We find that annual production positively impacts property values, although the coefficient is only significant when we include census-tract fixed effects.[31] The loss of significance when moving to property fixed effects may be due to the fact that property fixed effects soak up too much of the variation in prices; utilizing census-tract fixed effects instead allows for more of the variation in values given different levels of shale gas development.

We next separate out the wellbores based on the timing of the drilling. Panel D demonstrates that new bores (i.e., those that were drilled within a year before the time of sale) positively impact property values, presumably from increased economic activity in the region. However, wells drilled more than a year earlier only appear to have any economic impacts when using census tract fixed effects. Furthermore, undrilled permits have a negative economic impact, although the property fixed effects results only show significant negative impacts of old undrilled permits. These undrilled permits may be associated with the bust portion of the boom-bust cycle of development.

These results suggest that the broad economic impacts of shale gas development are felt when new wellbores are being drilled in the vicinity—drilling requires an influx of workers, which can boost the local economy. We find some evidence that production

[30] "Pa. fracking boom goes bust," *Philadelphia Daily News*, September 12, 2013.

[31] In this regression, areas that have wells within 20km but have no production are treated the same as areas with zero wells, and hence, zero production.

may lead to extra economic activity. However, leaving an area cleared without actually drilling on it or an un-fulfillment of expectations, as indicated by undrilled permits can produce a disamenity that is felt in the broader region. Thus, benefits from shale gas development appear to come quickly with the influx of drilling activity, and then fade once the drilling is done, providing some evidence of a boom-bust cycle.

6 Summary of Impacts

Our various difference-in-differences, nearest neighbor matching, and triple-difference specifications demonstrate that groundwater-dependent homes are negatively affected by shale gas development. These negative impacts are large in the 1-1.5km range, suggesting that the perception of groundwater contamination risk for homes that are located very close to shale gas wells can have substantial negative capitalization impacts on property values. Although data are not available to measure the impact of actual groundwater contamination, the perception of these risks is large, causing important, negative impacts on groundwater-dependent properties near wells.

While it is clear that the perceived risk of groundwater contamination is negatively impacting property values, homes that have piped water may in fact benefit from being adjacent to drilled and producing wells. These results appear to be driven by royalty payments (or expectations of royalties) from productive wells. However, it is evident from how the results change when we use different sized adjacency buffers that the positive impacts from being close to a well diminish as the property gets too close to a well. The overall positive impacts are in fact a net impact of being near a well; i.e., net of any negative environmental externality (such as light and noise pollution from drilling) that is common to all properties regardless of drinking water source. Thus, even homes with piped water are better off being slightly farther from a well, as long as they are able (i.e., not too far) to capitalize on lease payments. Consistent with the increase in property values being due to royalties and lease payments, we find that the property values increase with the quantity of natural gas produced by the adjacent wells. We also find that this positive finding is driven by wells that were drilled within a year prior to the sale, most likely because the highest production levels occur in the first year of a well's life. Coinciding with the visual disamenity of a shale gas well, we only find these positive effects for wells that are not visible from the property.

Similarly, for groundwater-dependent homes, the negative impacts of adjacency are large when the property is very close (1.5km or closer) to a shale gas well, and become more negative the closer a home gets to a shale gas well. We find that the costs of groundwater contamination risk are large and significant (ranging from -10% to -22.4%), suggesting that there could be large gains to the housing market from regulations that reduce the risk. In the most recent year of our data (April 2011 to April 2012) the average annual loss for groundwater-dependent homes within 1.5km of a well was $33,214.[32] The average annual loss for GW properties is larger than the average annual gain for piped-water properties within 1.5km of a shale gas well ($8,954).[33] These losses, when multiplied by the number of affected houses, may be quite important in terms of property tax revenues for local governments, which could potentially justify costly regulation to diminish groundwater contamination risk. Furthermore, it is important to keep in mind that our estimates do not fully capture the total costs associated with groundwater contamination risk. Owners of groundwater-dependent homes may purchase expensive water filters to clean their drinking water when faced with a shale gas well nearby; whole home filters can cost thousands of dollars. Since we do not capture adaptation costs, our estimates are therefore a lower bound of the actual costs incurred by homeowners located near shale gas wells, implying that contamination risk reduction can have very large benefits to nearby homes.

The use of the properties in the band surrounding the PWSA boundary (relative to using the full sample of homes) demonstrates that failing to control for unobservable attributes that vary with location can lead one to understate the negative impacts on groundwater homes. This is intuitive: very rural groundwater-dependent neighborhoods may be different in unobservable but important ways when compared with more urban PWSA neighborhoods, and these differences might vary over time. Using a sample containing both PWSA and GW homes, but specifically limited to be within the PWSA boundary, helps to reduce the potential for these unobserved neighborhood differences to bias our results while still permitting comparison based on water source.[34]

[32]This value is calculated using all groundwater-dependent properties that are within 1.5km of a well and sold between April 2011 and April 2012. For these properties, the number of well pads in 1km and between 1 and 1.5km are combined with the coefficients from our boundary sample (columns 2 and 4, Table 3).

[33]This is calculated using properties that have access to piped water, are within 1.5km of a well, and are sold in the most recent year of our data. If we also include properties within 2km of a well and include coefficients from column 6 for properties within 1.5km and 2km of a well, the groundwater losses are larger on average but have a smaller total loss (i.e., the average loss for GW homes within 2km of a well is $15,774 compared to gains for PWSA homes on average of $8,940).

[34]Of course, any two houses in the PWSA boundary sample are not necessarily near one another as the boundary extends throughout the state.

We also find that all homes, regardless of water source, are affected by shale gas development at the vicinity level. There are positive impacts from having drilling in a property's vicinity, but these effects are larger for wells drilled within a year of the property sale; wells that were drilled more than a year earlier have little to no effect on property values, while wells that have been permitted but have not been drilled negatively affect homes in the vicinity. Undrilled permits have a particularly large effect if the permits were issued more than a year before the property sale. This implies that shale gas development causes a temporary boom in the economy, likely through increased in-migration and increased employment and economic activity caused by drilling activities. However, after a year has gone by, the boom diminishes and permitted pads that were never drilled can have detrimental impacts on property values. These results hold regardless of whether we include properties that have the potential for shale gas development, because they are located on top of the Marcellus shale, or properties that do not, because they are in New York or are off the Marcellus shale.

7 Conclusion

Shale gas development has become increasingly widespread due to advances in technology that allow for the inexpensive extraction of natural gas from shale rock. This rapid expansion in development has generated ample discussion about whether any benefits from a cleaner, domestic fuel and the accompanying economic development outweigh the potential local negative impacts associated with extraction. This paper addresses many of these questions by measuring the net capitalization of benefits and costs of shale gas development at various levels of proximity.

Shale gas development's ability to impact nearby groundwater sources has been a major point of discussion. We estimate the local impacts on groundwater-dependent homes to be large and negative, which is not surprising given the attention the media has been placing on this potential risk. As groundwater contamination can cause severe economic hardship on homes without access to piped water, the perception that a nearby shale gas well will cause irreversible harm to an aquifer can drop property values by affecting buyers' willingness to pay for proximity to shale gas wells. Moreover, we demonstrate that our estimates can be interpreted with some confidence as measures of marginal willingness to pay, as neighborhood characteristics are not found to have changed in an economically significant manner with the introduction of shale gas.

The potential for exposure to shale gas development to hurt property values is not just an econometric curiosity; rather, it is beginning to show up in the way housing markets on shale plays operate. In particular, there has been recent evidence that major national mortgage lenders are refusing to make loans for properties in close proximity to shale gas wells, and that insurance providers are refusing to issue policies on those houses.[35]

Shale gas development can bring positive impacts to small towns, for example, through increased employment opportunities and economic expansion. The growth of a boom town may be positively capitalized by the homes in the area, while lease payments can provide a great source of income for many homeowners (and these royalties may be spent locally, helping to boost the economy). However, negative externalities associated with shale gas development can extend beyond the immediate proximity surrounding a well. Netting out these different impacts, we find statistically significant evidence of boom town positive impacts in the general vicinity of shale gas development, as evidenced by property value increases from wells drilled within one year of sale. However, the long-term impacts of wells older than a year or never drilled are cause for concern, as the boom is short-lived.

In conclusion, our estimates suggest that there are localized benefits to homes that are adjacent to producing wells, once the drilling stage is complete. However, there are also localized costs of shale gas development borne particularly by groundwater-dependent homes. Benefits to the broader housing market from prominent drilling in the vicinity appear to be focused in areas with a lot of contemporaneous drilling, while areas without will likely see drops in property values. Wells that have been permitted in the vicinity but have remained undrilled for more than a year have a negative effect on property values. Hence, we would anticipate that long-term benefits from shale gas development are most likely to be realized nationally through increased energy security and low fuel costs.

[35] For example, "How the Fracking Boom Could Lead to a Housing Bust," *The Atlantic: Cities*, August 19, 2013.

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A Appendix (For Online Publication)

A.1 Effects on Sociodemographics

In this subsection, we examine the effect of shale gas development on sociodemographic attributes at the vicinity level. As described in Section 2, if the hedonic price function moves over time, the change in price accompanying a change in exposure to shale gas may provide a poor approximation of the slope of the hedonic price function. Kuminoff and Pope (forthcoming) discuss a number of conditions that must hold in order for this not to be a concern. One important requirement is that the preferences of local residents for exposure to wells do not change over time. If preferences are a function of residents' attributes, a simple check can be performed by examining how tract-level sociodemographics change with changes in exposure. Table 6 describes the results of this analysis. In particular, we regress the change in 33 tract-level attributes, X, over the period 2000 to 2012 on the change in the number of cumulative wellbores within 20km of the centroid of the census tract in 2012.[36]

$$(X_{i,2012} - X_{i,2000}) = \rho \, bores20_{i,2012} + \epsilon_i$$

The first column reports the variable name, and the second column reports the mean of that variable in 2012. The third column reports the coefficient on wellbores, ρ, and the fourth column reports the percent change in the variable in question over the period 2000 to 2012 attributable to the average change in the number of wells in the corresponding vicinity of each census tract.

Out of the 33 variables that we consider, 23 have statistically significant wellbore effects. While statistical significance may be a cause for concern, very few of these effects are *economically* significant. In particular, considering the actual change in well exposure in each census tract over this period, the average of the resulting changes in tract attributes was no larger than 1% for any variable. Changes in neighborhood composition induced by shale gas development are, therefore, quite small. While this is not sufficient to rule out shifts in the hedonic price function over time, it is evidence in favor of a MWTP, as opposed to a simple capitalization effect, interpretation of our DDD results.

[36]Recall that cumulative wellbores is everywhere equal to zero in 2000.

Table 6: Change in Sociodemographic Characteristics, 2000-2012

Variable	Mean in 2012	Coefficient on Wellbores	Average % Δ from Wells
Household Income per Capita	30,080.30	-2.45E0	-0.154
Household Median Vehicles	1.803	1.30E-4***	0.071
Median Age	39.09	5.83E-3***	0.156
Median Age (Female)	40.294	5.19E-3***	0.135
Median Age (Male)	37.706	6.87E-3***	0.189
Population	3,964.24	-6.05E-1***	-0.291
% Asian	0.059	-6.25E-5***	-0.009
% Associate Degree	0.055	3.10E-5***	0.000
% Bachelor's Degree	0.122	-2.24E-6	0.000
% Black	0.155	-6.62E-6	0.000
% Family	0.784	-1.59E-5	0.000
% Female	0.515	-2.39E-5***	0.000
% High School	0.211	2.74E-5***	0.000
% Hispanic	0.131	-9.98E-5***	-0.004
% In Group Quarters	0.034	6.69E-6	0.001
% Less Than High School	0.093	-3.46E-5***	0.000
% Male	0.485	2.39E-5***	0.000
% Married, Female	0.202	-2.91E-5***	0.000
% Married, Male	0.204	-3.52E-5***	0.000
% Non-Family	0.182	9.22E-6	0.000
% Occupation, Construction	0.034	-1.05E-5**	0.000
% Occupation, Farming	0.002	-1.17E-6	0.000
% Occupation, Management	0.068	-1.07E-5	0.000
% Occupation, Production	0.054	-9.87E-6*	0.000
% Occupation, Professional	0.107	8.36E-7	0.000
% Occupation, Sales and Office	0.111	1.11E-5	0.000
% Occupation, Service	0.092	-1.81E-5**	0.000
% Other Race	0.052	5.56E-5***	0.013
% Some College	0.115	2.43E-5***	0.000
% Speaks English	0.728	1.16E-4***	0.000
% Urban	0.835	-9.92E-6***	0.000
% White	0.701	7.68E-5***	0.000
% White, Non-Hispanic	0.643	1.33E-4***	0.000

Note: % Δ from Wells is calculated as the average across census tracts of (Δ Wellbores*Coefficient on Wellbores)/(Mean in 2012)*100.

A.2 Effects on Likelihood of Transaction

Here we investigate whether shale gas development within 20km affects the number of properties that are sold in a census tract. The concern is that drilling activity may affect the likelihood of a transaction, so that our sample of observed sales will be selected based upon the drilling exposure treatment. Using aggregated CoreLogic data, we regress the log of the annual number of transactions in each census tract on exposure to shale gas development within 20km of the tract centroid, including year and census tract fixed effects. We find that the effect of cumulative well pads is small and statistically insignificant for the number of properties sold (Table 7). We therefore do not worry about sample selection in our housing transactions data induced by the well exposure treatment.

Table 7: Log Number of Sales on Drilling Activity

	Using Full Sample
	(1)
	ln(# Sales)
Cumulative Wellbores	1.88e-04
	(1.55e-04)
County-Year Effects	Yes
Census Tract Effects	Yes
n	28,564

Notes: Dependent variable is the log annual number of properties sold in a census tract, calculated using the property sales data. Standard errors are clustered by census tract. Regressor is the count of wellbores within 20km of the centroid of the census tract in the year of observation.

A.3 Effects on Likelihood of New Construction

In this section, we perform two tests to investigate whether new construction associated with shale gas development may be driving down the size of the positive vicinity effect we find during the period around drilling. In particular, a strong increase in new housing supply may result in a failure to find any increase in prices in spite of a positive vicinity effect. Using CoreLogic data, we check first to see if the likelihood of a transaction for a newly constructed property is a function of exposure to cumulative wellbores within 20km at the time of sale.[37] In particular, we run a regression at the property level, where the dependent variable is equal to one if the sale refers to a newly constructed house, and zero otherwise; the regression includes census tract and year fixed effects. Results are reported in Column (1) in Table 8—we find that cumulative wellbores are weakly *negatively* correlated with the likelihood of a transaction being a new construction.

Table 8: New Construction on Drilling Activity

	Using All Property Sale Data	Using 2012 Census Tract Data
	(1)	(2)
	Indicator (New=1)	% Built 2005 or later
Cumulative Wellbores	-2.16e-04*	2.24e-04
	(1.14e-04)	(7.56e-04)
Census Tract Effects	Yes	No
County-Year Effects	Yes	No
County Fixed Effects	No	Yes
n	1,133,013	8,137

Notes: In the first column, the sample includes all properties sold in the property sales data; dependent variable equals 1 if the property was a new building, zero otherwise. Cumulative Wellbores is the count of wellbores that have been drilled within 20km of the property at the time of sale. In the second column, the sample includes 2012 census tract data from SimplyMap on the % of housing built 2005 or later. In the case of the census tract sample, Cumulative Wellbores is the count of wells within 20km of the centroid of the census tract in 2012.

In our second test, we use data from SimplyMap describing the percentage of houses in each census tract in 2012 that were built in 2005 or later. We regress this percentage on

[37]Whereas we had dropped new construction homes from our previous analyses, we reintroduce them to the dataset here. If we were to include newly constructed homes in our previous analyses, our findings would not change.

cumulative wellbores in 2012, using county fixed effects to help control for unobservables. This effect is statistically insignificant, providing further evidence that a positive supply response is not responsible for our failure to find any positive effects of drilling at the vicinity level.