The Housing Market Impacts of Shale Gas Development

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Abstract

Using data from New York and Pennsylvania 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 and water source. Results indicate large negative impacts on nearby groundwater-dependent homes, while piped water-dependent homes are positively impacted by proximity (although by a smaller amount), suggesting an impact of lease payments. At a broader geographic scale, we find evidence that new well bores can increase property values, but these effects diminish over time. Undrilled permits, conversely, may cause property values to decrease.

JEL Classification Numbers: 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 U.S. 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 when burned, its lower 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 externalities such as methane leakage (Howarth and Ingraffea, 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 and Gallon, 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; Freudenberg, 1982). Furthermore, the "boom" may be followed by a "bust," such that any benefits from shale gas development are only temporary. Local public goods might therefore be ex-

[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 (2011) 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 2004-2010 due to the shale gas industry expansion (though they argue that this number is much lower than the industry's claims of job increases).

panded 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 are rented (such as apartments) may experience greater increases in value than properties that are owner-occupied because of the increased demand for short-term housing. Groundwater-dependent properties may suffer greater reductions in value if they face a greater risk of losing their water source. Perceptions of the competing issues 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 fracking debate, the question of whether the benefits of shale gas development outweigh the costs has not yet been answered. Our goal in this paper is to quantify many of 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: *vicinity effects*, *adjacency effects*, and *groundwater contamination risk*.

The first 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 waste water disposal). The second 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 alternation, and the receipt of lease payments), and the third refers to the *additional* effect of adjacency specific *only* to groundwater-dependent households. 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]

A major obstacle to accurately estimate 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-difference 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 cause bias in the results.

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 the macroeconomic effects due to the Great Recession and other economic factors that affected the region more broadly. Furthermore, our panel data of properties sold in Pennsylvania and New

[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.

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. 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 drilled and producing wells can increase property values, likely through the boost to the local economy of abundant natural gas production. However, when these wells remain undrilled or nonproducing, property values can in fact decrease. This is likely due to the fact that undrilled or nonproducing wells still create a disamenity, for example, through the clearing of land.

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 examines the impact of shale gas development on community sociodemographics.[4] Finally, Section 8 concludes.

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

[4] We also provide an appendix analyzing the impact of shale gas development on the frequency of sales and new construction.

curves (O_1^X, O_2^X, O_1^Y, O_2^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.

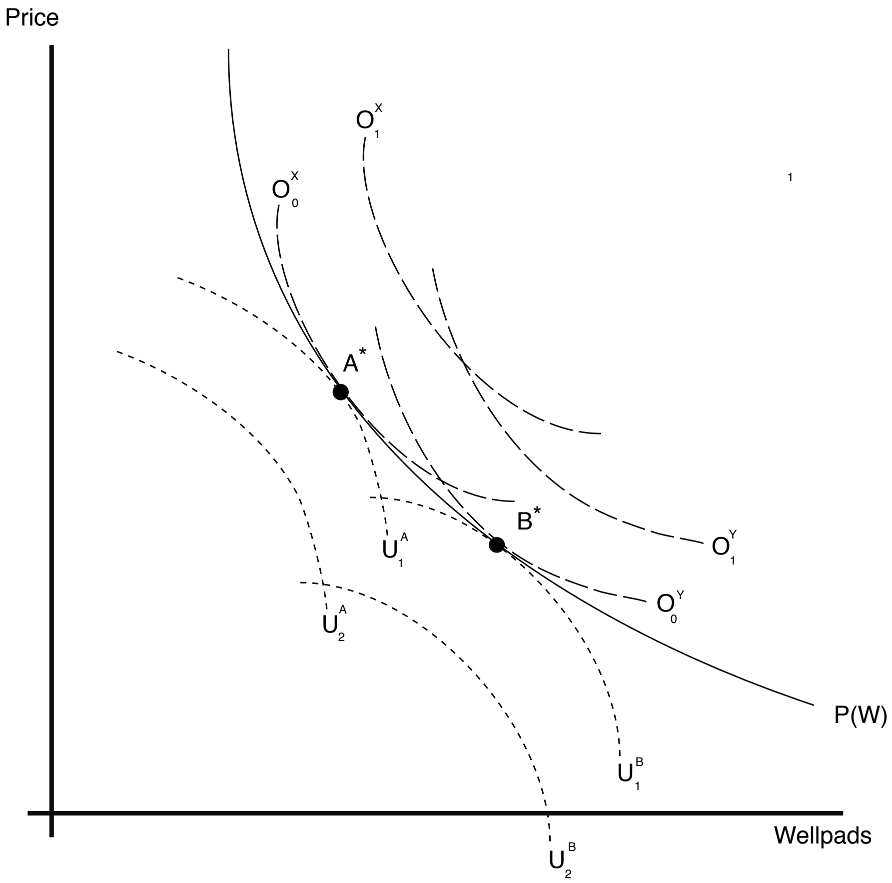

Figure 1: Formation of the Hedonic Price Function

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) well exposure, this is accomplished by reaching the indifference curve lying furthest 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.[5]

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

[5]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.

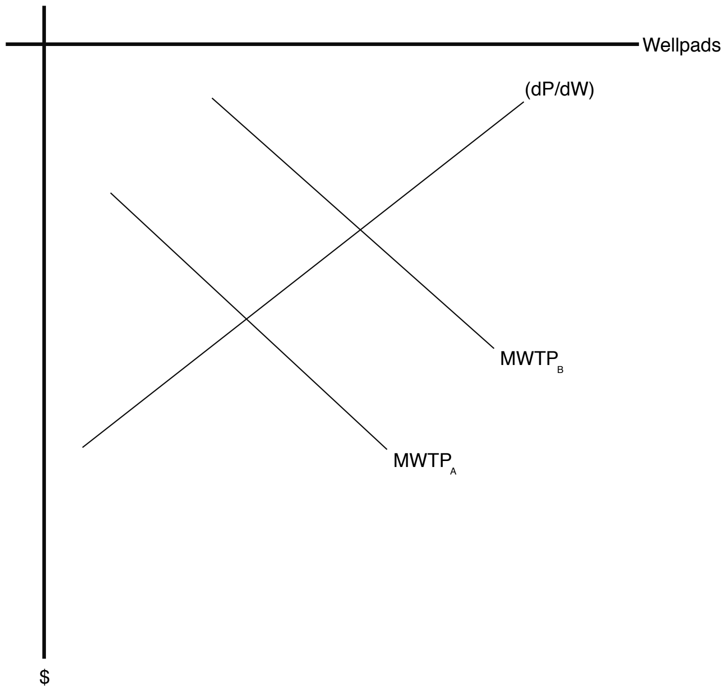

Figure 2: Marginal Willingness to Pay

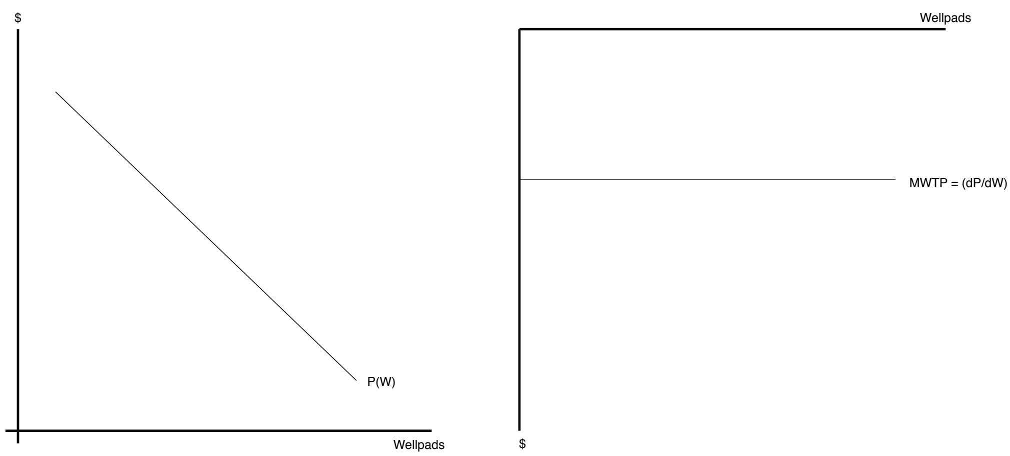

Figure 3: Marginal Willingness to Pay–Simplification

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 (LULU's) - 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 (2012). 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.

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. 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 different, and caution would be advised when interpreting our results as measures of welfare rather than simple capitalization effects. We address this question in more detail in sub-section 7, and note here that we find changes attributable to shale gas development that are quite small.

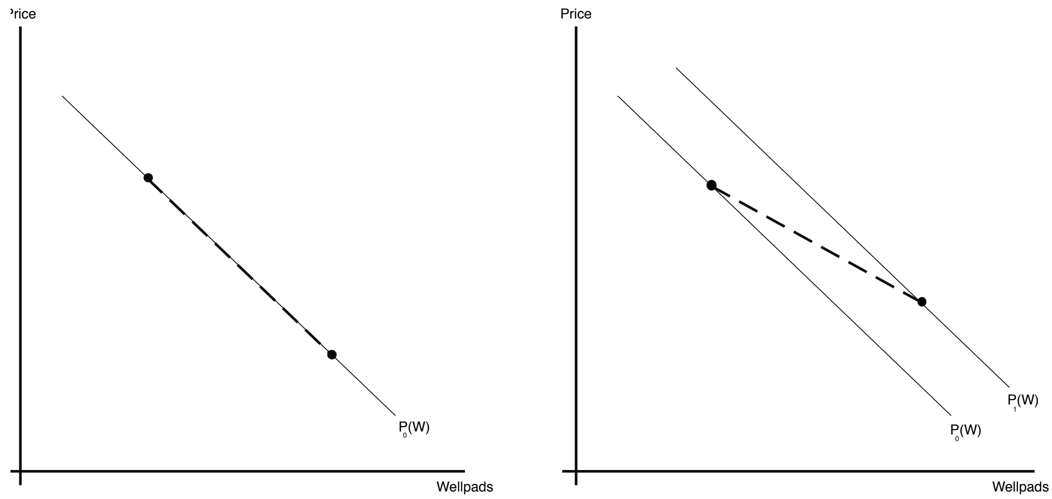

Figure 4: Time Varying $P(W)$

3 Methodology

Our goal is to recover estimates of the non-marketed costs and benefits of shale gas development 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) *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. (2) *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, VOC's, and other conventional pollutants), alteration of the local landscape and visual disamenities associated with drilling equipment and cleared land. The most obvious benefit would be royalty and lease payments. (3) *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.[6]

[6] 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.

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.

Figure 5 is useful in describing our identification strategy, and we will refer to it in more detail in Section 5.2.2. 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. 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 practice.

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 placement of a well pad to the prices of properties sold prior to that placement, and identifies the distance beyond which that placement 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

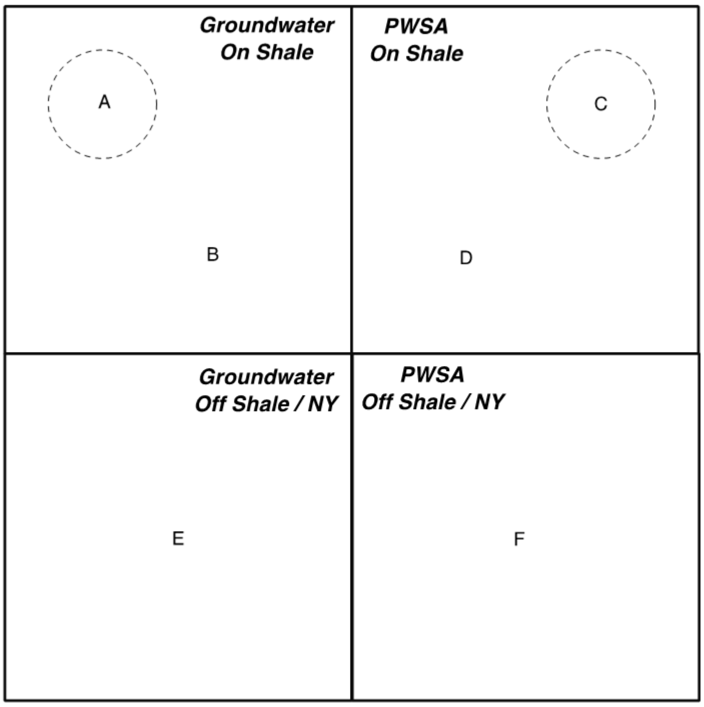

Figure 5: Types of Areas Examined

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.[7] 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 × year fixed effects, ν_{it}:[8]

[7]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.

[8]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 character-

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

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 greater 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; we use this to motivate our selection of buffer distance below.

istics include percent of 25 year olds with high school, percent black, percent Hispanic, percent unemployed, and mean income.

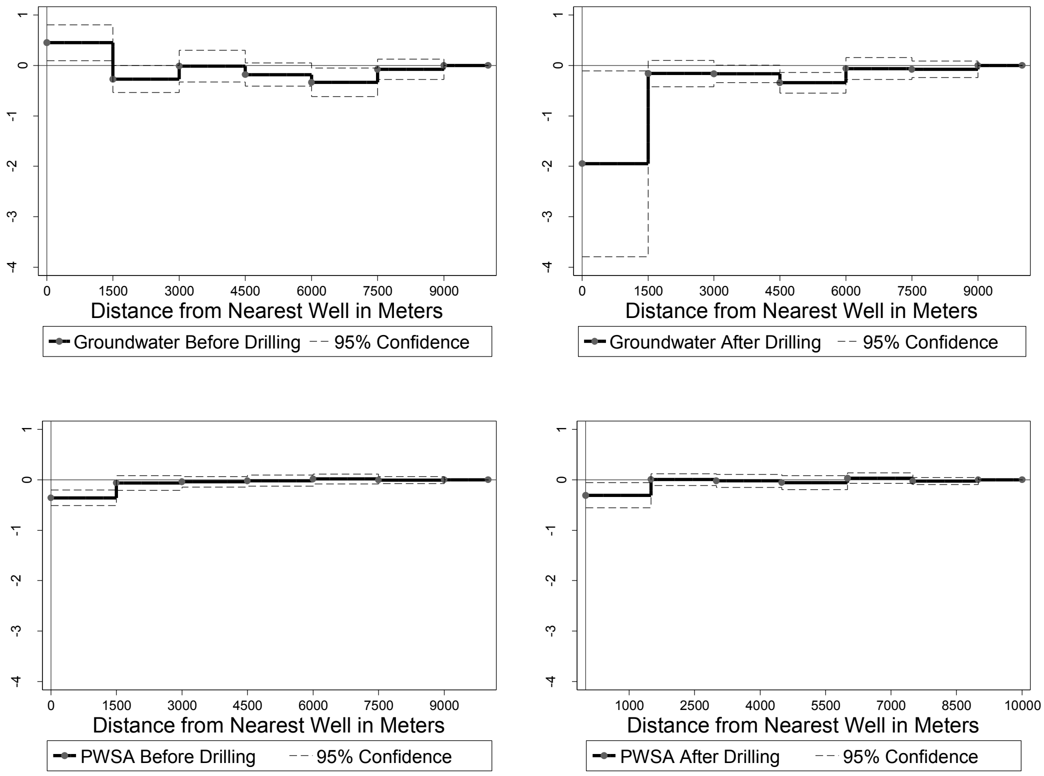

Figure 6: Coefficients from Equation (1) by Drinking Water Source and Timing of Drilling

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 provide 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.[9] 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.[10] 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. 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.

[9]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.

[10]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 sub-section A.2.

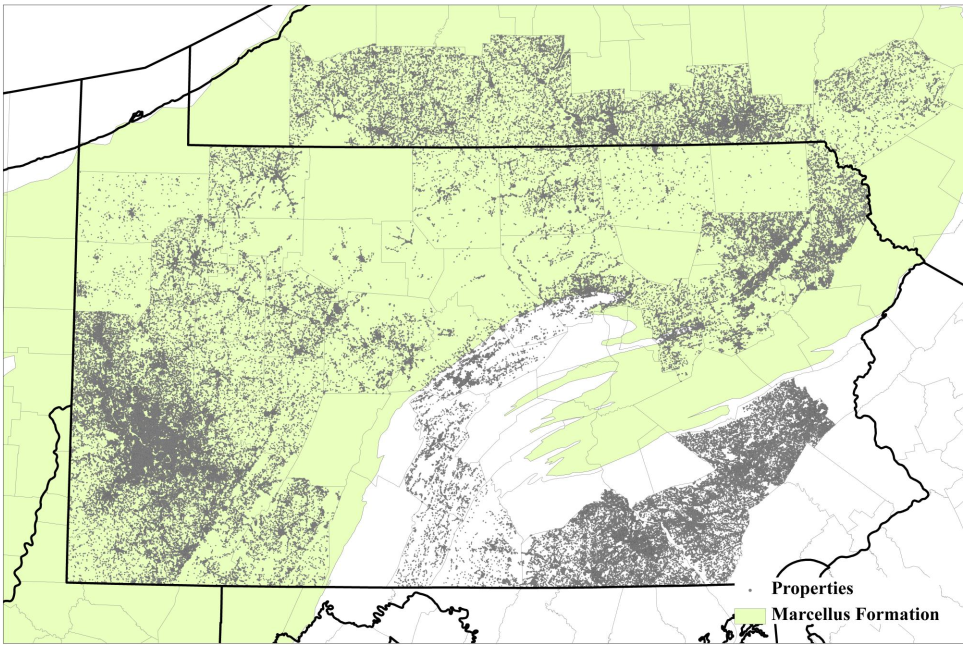

Figure 7: The Marcellus Shale Formation and Property Sales in Pennsylvania and New York

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 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 distributers, 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.[11] For each wellbore we obtained the volume of natural gas produced for each wellbore from the PADEP's Oil & Gas Reporting Website.[12]

Because operators are able to drill horizontally underground, they can

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

[12] The data are reported as annual quantities (and biannual from 2010).

locate the top 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 wellbores close together (within a 63-meter, or 1 acre, distance) are located on the same well pad.[13] 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.

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 Pennsylvania Department of Environmental Protection (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).[14] In the case of Pennsylvania, any property that was outside the PWSA was assumed to be groundwater dependent.[15]

[13]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).

[14] 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 250 meter 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.

[15]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 a personal communication with the development manager at the Washington County Planning Commission, April 24, 2012.

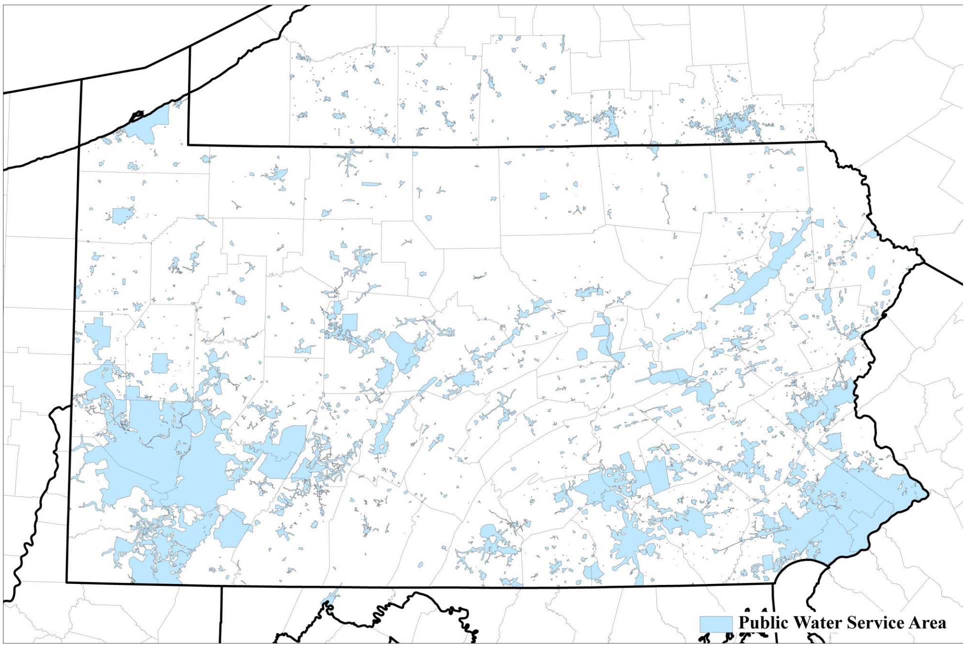

Figure 8: Public Water Service Areas in Pennsylvania and Bordering Counties in New York

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 source 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 5.2.1 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 importance of estimating the impacts of shale development on groundwater homes. Figure 9 demonstrates the GW boundary sample for an example county, Armstrong County, Pennsylvania.

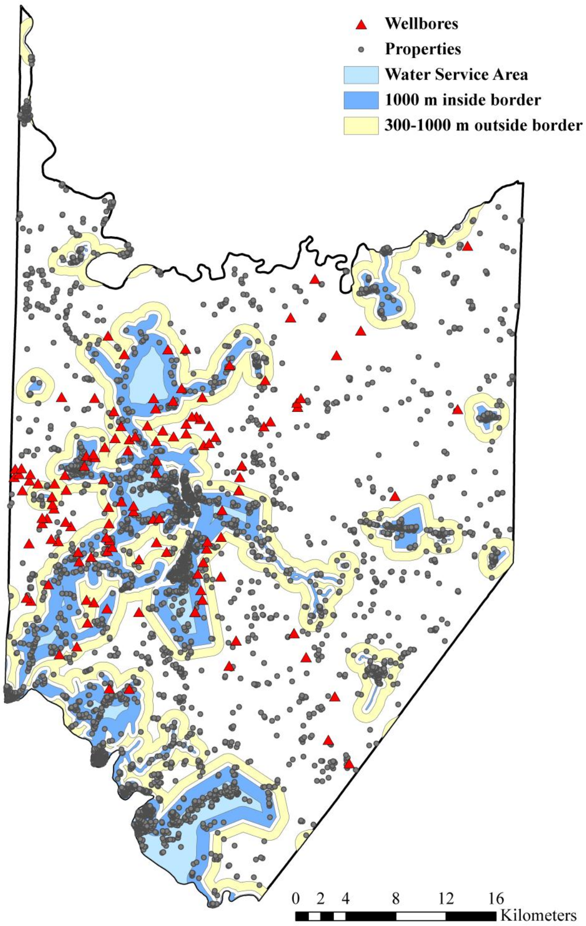

Figure 9: Example indicating the 1000 meter boundary inside and 300-1000 meter boundary outside of public water service areas in Armstrong County, Pennsylvania.

Figure 10 plots mean log prices over time for three different samples: properties in Pennsylvania located on the Marcellus Shale, properties in Pennsylvania located off the shale, and properties in New York. This graph demonstrates that during the recession (December 2007 to October 2009) prices of Pennsylvania properties located off the shale appear to fall more than properties on the shale, providing some evidence that shale gas drilling may have curbed the negative impacts of the recession. Of course, the data also suggest that prices rose less quickly during the preceding housing bubble for houses located on the shale, although this was largely prior to

Table 1: Summary Statistics by Sample

	Ground Means(SD)	**Piped** Means(SD)	**PA/On** Means(SD)	**PA/Off** Means(SD)	**NY** Means(SD)
Transaction Price (k 2012 Dollars)	173.399	147.245	126.776	165.244	100.357
	(105.822)	(95.740)	(98.460)	(96.053)	(77.919)
Groundwater	1.000	.000	.120	.217	.381
	(.000)	(.000)	(.325)	(.412)	(.486)
Age	41.521	53.083	57.911	50.600	63.037
	(38.709)	(33.703)	(31.951)	(39.304)	(37.018)
Total Living Area (1000 sqft)	1.767	1.659	1.598	1.699	1.649
	(.739)	(.660)	(.823)	(.660)	(.654)
No. Bathrooms	1.918	1.872	1.778	1.882	1.737
	(.850)	(.857)	(.877)	(.848)	(.750)
No. Bedrooms	3.093	3.106	3.001	3.201	3.143
	(.816)	(.825)	(.932)	(.866)	(.969)
Lot Size (acres)	3.475	.637	.895	1.812	4.111
	(11.467)	(126.656)	(5.981)	(250.044)	(16.778)
Distance to nearest MSA (km)	22.300	18.135	22.916	15.429	19.817
	(11.070)	(10.540)	(12.739)	(7.830)	(13.550)
% Age 25 w/High School	42.311	36.286	37.899	39.416	35.167
	(7.925)	(10.368)	(11.233)	(8.428)	(8.665)
% Black	1.158	5.821	6.501	5.099	2.128
	(1.935)	(10.789)	(13.568)	(7.098)	(2.201)
% Hispanic	.457	1.507	.576	3.137	.695
	(.698)	(3.812)	(2.019)	(5.742)	(1.151)
% Unemployed	3.690	4.286	4.127	4.763	4.485
	(1.345)	(2.378)	(2.070)	(3.009)	(2.102)
Mean Income (k Dollars)	68.662	66.041	64.109	63.810	59.448
	(15.739)	(25.942)	(27.260)	(19.263)	(14.920)
Distance to Closest Well Pad (km)	10.319	12.238	11.148	16.059	15.243
	(5.635)	(5.132)	(5.413)	(2.487)	(3.012)
Pads within 1km	.002	.001	.004	.000	.000
	(.062)	(.037)	(.095)	(.000)	(.000)
Pads within 1.5km	.006	.002	.011	.000	.000
	(.123)	(.075)	(.195)	(.000)	(.000)
Pads within 2km	.011	.005	.023	.000	.000
	(.200)	(.129)	(.335)	(.000)	(.007)
Bores in 20 km, <1 yr. before	1.307	1.630	3.223	.017	.717
	(10.946)	(8.869)	(13.583)	(.559)	(4.620)
Bores in 20 km, ≥1 yr. before	1.203	2.130	4.136	.015	.478
	(11.756)	(14.198)	(21.120)	(.442)	(3.896)
Marcellus Indicator	.465	.630	1.000	.000	1.000
	(.499)	(.483)	(.000)	(.000)	(.000)
Observations	120644	632643	555785	386135	92723

Notes: Ground refers to properties without access to piped water. Piped refers to properties with access to piped water. PA/On refers to properties off 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).

the onset of drilling in much of the state.

To obtain information on neighborhood attributes, we merge in census tract data compiled by SimplyMap, a national data mapping software tool.[16] 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.

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

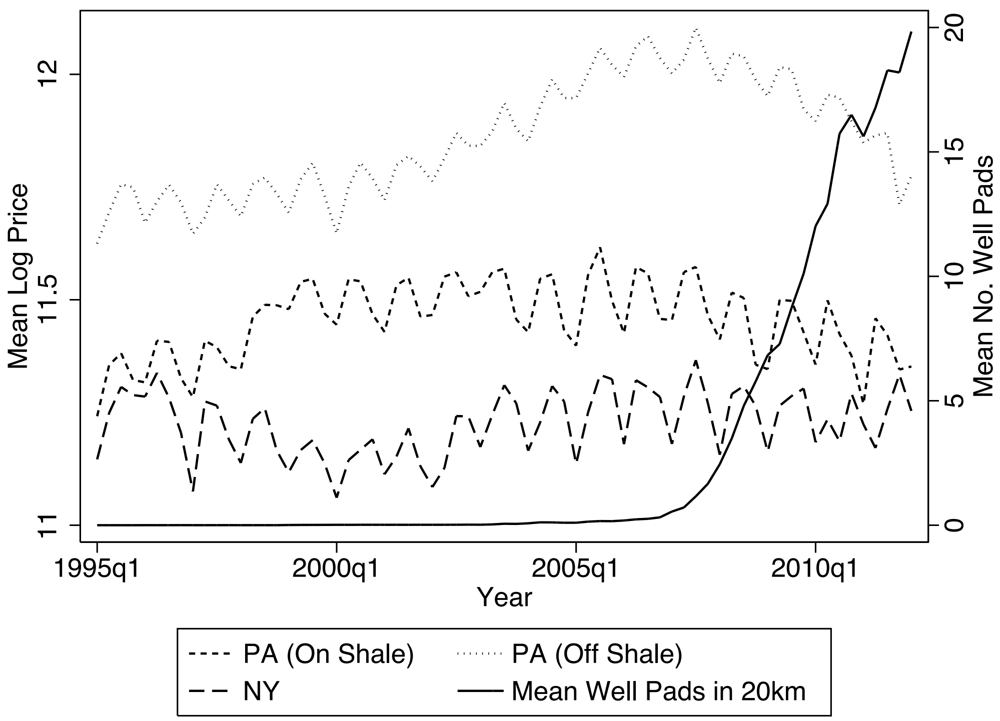

Figure 10: Average Transaction Prices

5 Empirical Strategy and Results

5.1 Vicinity

The first effect of shale gas development on housing prices in the broader geographical area that we estimate 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.

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.[17] We do this by regressing the natural logarithm of the transaction price for house i in year t in 2012 dollars ($\ln P_{it}$) 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, $bores20_{it}$.

$$\ln P_{it} = \zeta_j bores20_{it} + \nu_{it} + \mu_i + \epsilon_{it} \tag{2}$$

We use a vector of county × year fixed effects, ν_{it}, to control for macro effects, and property fixed effects, μ_i, to control for unobservable time invariant property characteristics. Further regressions explore the impact of undrilled permits, production data, and the timing of the drilling on property values.

Results are reported in Table 2. This table includes four different samples. The first sample only includes properties that at some point during the sample period are within 20km of a shale gas well. This initial specification implies that identification is based on the timing of when drilling occurred. The second sample adds to the control group homes in PA that are on the shale but are not, at any time in our sample period, in the vicin-

[17]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.

Table 2: Vicinity Effects

	Using ≤20km	Using PA/On or ≤20km	Using PA/Off or ≤20km	Using NY or ≤20km
	(1)	(2)	(3)	(4)
	ln(price)	ln(price)	ln(price)	ln(price)
A. Log Sale Price on Cumulative Well Bores				
Bores in 20km	-4.4e-05	-6.3e-05	-4.6e-05	-6.6e-05
	(1.4e-04)	(1.5e-04)	(1.4e-04)	(1.4e-04)
B. Log Sale Price on Well Bores and Permits				
Bores in 20km	1.8e-04	1.4e-04	1.8e-04	1.7e-04
	(1.6e-04)	(1.6e-04)	(1.5e-04)	(1.5e-04)
Undrilled Permits in 20km	-8.3e-04**	-7.2e-04**	-8.1e-04**	-8.6e-04***
	(3.3e-04)	(3.5e-04)	(3.3e-04)	(3.3e-04)
C. Log Sale Price on Production				
Annual Production in 20km (MMcf)	4.0e-07	3.9e-07	4.0e-07	3.9e-07
	(4.1e-07)	(4.1e-07)	(4.1e-07)	(4.1e-07)
D. Log Sale Price on Timing of Well Bores				
New Bores (drilled ≤ 365 days)	.0013***	9.4e-04**	.0013***	.0012***
	(3.9e-04)	(3.8e-04)	(3.9e-04)	(3.9e-04)
Old Bores (drilled > 365 days)	3.9e-05	6.2e-05	3.7e-05	5.8e-05
	(2.6e-04)	(2.5e-04)	(2.6e-04)	(2.6e-04)
New Undrilled Permits	-2.6e-04	-2.5e-04	-2.3e-04	-3.3e-04
	(3.8e-04)	(3.9e-04)	(3.8e-04)	(3.7e-04)
Old Undrilled Permits	-.0023***	-.0019***	-.0023***	-.0022***
	(6.3e-04)	(6.1e-04)	(6.3e-04)	(6.3e-04)
Property Effects	Yes	Yes	Yes	Yes
County-Year Effects	Yes	Yes	Yes	Yes
n	207,252	583,826	594,037	286,216

Notes: Dependent variable is log sale price in 2012 dollars. Each column represents a different sample. All columns include properties that are at some point in time closer than 20 km of a wellbore but exclude those that at some point in time are within 2 km of a wellbore. Column (2) also includes properties farther than 20 km as long as they are on the Marcellus shale and in PA. Column (3) includes all properties in Column (1) as well as properties farther than 20 km as long as they are off the Marcellus shale in PA. Column (4) includes properties in Column (1) and properties farther than 20 km as long as they are in NY. *** Statistically significant at the 1% level; ** 5% level; * 10% level.

ity of shale gas wells. The third sample instead adds to the control group homes in PA that are off the shale, and the fourth sample instead adds to the control group homes in the border counties of New York. Each of these four samples excludes homes within 2km of a shale gas well, in order to avoid confounding the vicinity and adjacency impacts.

Examining the specification in Panel A, regardless of the sample used, we find insignificant negative effects of increased exposure to wellbores within 20km. 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. The result now shows that undrilled permits have a negative impact on property values. This is likely due to the fact that undrilled permits refer to locations where the area has 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.

We next test whether having productive wells in the vicinity affects property values. Our regressor "Annual Production" is the total amount of natural gas produced by the wellbores within 20km of a property at the time of sale. We find that annual production positively impacts property values, although the coefficient is not significant.

We next divide the wellbores based on the timing of the drilling. Panel D demonstrates that new bores (i.e., those that were drilled within 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 ago no longer have any economic impacts. Indeed, permits that have been issued over a year ago, and are still undrilled have a negative economic impact and thus, may be associated with the bust portion of the boom-bust cycle of development. To provide some context for these results (using the results from Panel D), drilling 10 wellbores within a year before the property sale and within 20km would increase its value by 1.3%, however, 10 old, undrilled permitted wells would decrease its value by 2.3%.

These results suggest that the main broader economic impacts are felt when new well bores are being drilled in the vicinity- drilling requires an influx of workers, which can boost the local economy. Production per se may not lead to extra economic activity, but leaving an area cleared without actually drilling on it can produce a disamenity that is felt in the broader region. Thus, benefits from shale gas development may come quickly with the influx of drilling activity, and then fade once the drilling is done, providing some evidence of a boom-bust cycle.

5.2 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 due to lease payments made from the gas company to a property owner, or negative, given perceived impacts of groundwater contamination or localized noise pollution from drilling. As the location of shale gas wells can be very strategic on the part of gas companies, it is important to account for a wide range of unobservable attributes correlated with location to both the property and the shale well. Thus, we employ a difference-in-difference technique and a triple difference technique that makes use of a PWSA boundary sample (described in more detail below) in order to eliminate unobservables and thus more accurately capture the impact of adjacency.

5.2.1 Role of the PWSA Boundary

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 × 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—1000 meters on either side, ignoring houses on the GW side within 300 meters (to avoid potential mis-codes of PWSA houses as GW houses).[18] GW and

[18] Our final results are robust to removing 300 meters on the PWSA side as well; doing

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 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.[19]

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:

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

lnP_{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 11 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

so, we find an even larger decrease in values of GW dependent homes and a statistically significant increase in PWSA homes.

[19]In our matching technique described in Section 5.2.2 the definition of our control group and requirement of exact matching on year and census tract do this job.

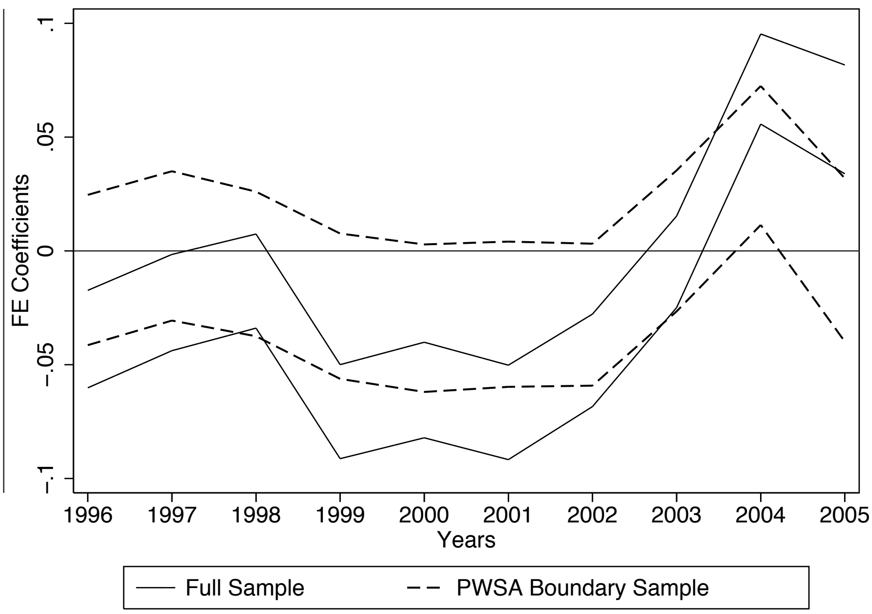

Figure 11: 95% Confidence Bands on Groundwater × Year Fixed Effect Interaction - Full Sample v. PWSA Boundary Band

the PWSA band eliminates (most) time varying unobservables that may confound our estimates of shale gas impacts on property values.

5.2.2 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 (in the following sections, we describe how we measure impacts on adjacent PWSA houses, and how we recover vicinity effects, which occur at a broader geographic scale). 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] However, even if correlated unobservables are not a problem, the imputation will be biased if (1) the assumed functional form is incorrect or (2) there is a lack of common support in the distributions of the regressors across the treatment and control groups. In addition, the typical hedonic regression specification generally assumes an additively separable treatment effect. This requires that the virtual price of the (dis)amenity does not depend in any way upon the values of other observable attributes (or depends upon these characteristics in an extremely regimented way in the case of a log-linear specification).

Matching estimators address both of these concerns by imputing counterfactual observations by pairing treated houses with similar houses from a control group (Abadie et al., 2004).[21] The effect of treatment is then found by averaging across the price differences for matched pairs. More detail on the techniques 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 geographical 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

[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 matching, see Cochran and Rubin (1973), Rubin (1974), Rosenbaum and Rubin (1983), Rubin and Thomas (1992), and Heckman et al. (1998).

the treatment buffer to be either 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 found in similar neighborhoods. 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 of 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. Considering 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 3. 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.

Table 3: 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 is comprised of 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 (lotsize, square footage, number of bedrooms, number of bathrooms, and year built). Treatment buffer size varies between 1 - 2km. Bias adjustment equation contains all matching variables and census tract fixed effects. 90% confidence intervals reported in parentheses.

In all cases, the difference-in-difference 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 (2012), as discussed in Section 2, are therefore not relevant.

5.2.3 Triple Difference Estimator

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 (GW) properties adjacent to shale gas development to the change in prices of PWSA (GW) 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 now look at well pads rather than wellbores for adjacency effects. We choose to look at pads in order to identify GWCR because we are in essence 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 vary $pads_{it}$ for different counts of well pads within 1, 1.5, or 2km of property i at time t of sale. Our first regression specification takes the following form:

$$\ln P_{it} = \theta pads_{it} + \lambda(GW \times pads)_{it} + \nu_{it} + \mu_i + \epsilon_{it} \quad (3)$$

Importantly, we use only houses that are ever inside the treatment buffer. This causes the impact of proximity to be identified only off of the change over time (i.e., we compare homes before the drilling to homes after the drilling). We include controls for county × year, ν_{it}, and property, μ_i, fixed effects. To measure the GWCR, we include an interaction between the count of well pads and an indicator for groundwater, $(GW \times pads)_{it}$.

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

Table 4: Adjacency and GWCR

	Using $K\leq$1km		Using $K\leq$1.5km		Using $K\leq$2km	
	Full	Boundary	Full	Boundary	Full	Boundary
	(1)	(2)	(3)	(4)	(5)	(6)
	ln(price)	ln(price)	ln(price)	ln(price)	ln(price)	ln(price)
B. Log Sale Price on Well Pads						
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)
B. Log Sale Price on Productivity of Pads in K km						
Producing Pads	.067*	.076**	.052***	.066**	.017*	.030***
	(.036)	(.032)	(.020)	(.029)	(.009)	(.010)
Non-Producing Pads	-.057	-.033	-.020	.022	-.061	.006
	(.085)	(.149)	(.049)	(.083)	(.039)	(.050)
Producing Pads*GW	-.020	-.258***	-.032	-.108**	.007	.040
	(.058)	(.042)	(.026)	(.051)	(.018)	(.075)
Non-Producing Pads *GW	-.023	.240	.183**	-.027	.120***	-.028
	(.130)	(.324)	(.084)	(.183)	(.044)	(.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 wellpads drilled within Kkm before the sale date. Robust standard errors are clustered by censust tract. *** Statistically significant at the 1% level; ** 5% level; * 10% level.

θ measures ΔP_C and $\lambda{+}\theta$ measures ΔP_A; therefore, $\Delta P_A - \Delta P_C$ is 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. Restricting attention to the band surrounding the PWSA boundary, that effect is negative, large, and statistically significant. 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]

One thing to note is that the overall *impact* of adding an extra well within 1km is not just the GWCR, but must also take into account the pos-

[23]We re-estimate our vicinity regressions, 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 wellbore 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 source.

itive (although sometimes statistically insignificant) adjacency effect. The results from Panel A, Column 4 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. 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 tamper the positive impacts of lease payments. Moving farther from the shale gas 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 intuitively provides some evidence that there are reduced perceptions of groundwater contamination risk at farther distances from the well. For PWSA homes, on the other hand, the positive benefits decrease at 2km relative to 1.5km; this is likely the result of fewer homes at this distance receiving lease payments (the horizontal portion of the well is generally less than about 1.6km).

We next explore how adjacent production affects GWCR and adjacency impacts in Panel B. Specifically, we divide the pads into producing and non-producing, and interact these with the GW indicator. Column 4 results in similar impacts as in Panel A, although now it is clear that the positive impact on property values comes only from producing pads, thereby justifying the idea that production royalties are being capitalized into the home value. Furthermore, the GWCR is only identified off of the producing pads, as non-producing pads would not be likely to contaminate groundwater.

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 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 may be large, causing important, negative impacts on groundwater-dependent properties near wells.

While it is clear that groundwater contamination risk 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 from productive wells, a year after they were first drilled. 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 well gets closer to the house. These 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 PWSA homes are better off being slightly farther from a well, and are able to capitalize on lease payments to increase the value of the property.

Similarly, for GW homes, the negative impacts of adjacency are very 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%), suggesting that there could be large gains from minimizing this risk, particularly in the housing market. These losses may also be quite important in terms of property tax revenues for local governments, which could potentially justify costly regulation to diminish groundwater contamination risk.

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 that are located in close proximity to one another helps to reduce the potential for these unobserved neighborhood differences to bias our results while still permitting comparison based on water source.

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 only within the year that they are drilled; wells that were drilled more than a year ago do not have an effect on property values, while old, undrilled permitted wells negatively affect homes in the vicinity. 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 and these wells are no longer being actively worked on, wellbores can have detrimental impacts on property values as the negative externalities associated with wells (e.g., pollution and aesthetic costs) come to dominate. These results hold regardless of the control sample we use.

7 Effects on Sociodemographics

Finally, 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 if that function moves over time. Kuminoff and Pope (2012) discuss a number of conditions that must hold in order for this to not 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 5 describes the results of this analysis. In particular, we regress the change in each of 32 tract-level attributes, X, over the period 2000 to 2012 on the change in the number of cumulative wellbores within 20km of that tract by 2012.[24]

$$(X_{i,2012} - X_{i,2000}) = \gamma pads20_{i,2012} + \epsilon_i$$

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, 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 32 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, the average increase in wellbores over the period 2000 to 2012 yields no change 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.

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

Table 5: Change in Sociodemographic Characteristics, 2000-2012

Variable	Mean in 2012	Coefficient on Wellbores	% Δ from Wells
Household Income per Capita	30080.30	-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	3964.24	-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 Highschool	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

Notes: % Δ from Wells is calculated as the average across Census tracts of (Δ Well Bores*Coefficient on Well Bores)/(Mean in 2012)*100.

8 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 the 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 can bring positive impacts to small towns, such as 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 vicinity surrounding a well. Netting out these different impacts, we find statistically significant evidence of boom-town positive impacts associated with shale gas development, as evidenced by property value increases from wells drilled within 1 year of sale. However, the long-term negative impacts of inactive wells (either non-producing or never drilled) are cause for concern, as the boom is short-lived.

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.[25]

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 large amount of attention being placed in the media 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 the 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

[25] For example, "How the fracking boom could lead to a housing bust," *The Atlantic: Cities*, 19 August 2013.

economically significant manner with the introduction of shale gas.

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 high gas production, while areas with lower gas production 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. 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.

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A Appendix

A.1 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 number of transactions, 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 cumulative wellbores in the previous years, wellbores in the current year, wellbores in the subsequent year, and the quadratic of these terms is small and statistically insignificant for the number of properties sold (Table 6). We therefore do not worry about sample selection in our housing transactions data induced by the well exposure treatment.

Given the concern that mortgages might have become more difficult to obtain after 2010, in columns (2) and (3) of Table 6 the sample is divided into properties sold before an d after 2010 respectively. Dividing the sample as such does not impact our results.

Table 6: Log Number of Sales on Drilling Activity

	Using Full Sample	Using < 2010	Using ≥ 2010
	(1)	(2)	(3)
	ln(# Sales)	ln(# Sales)	ln(# Sales)
Cumulative Well Pads	4.10e-04	2.59e-04	5.50e-04
	(3.28e-04)	(4.83e-04)	(1.48e-03)
County-Year Effects	Yes	Yes	Yes
Census Tract Effects	Yes	Yes	Yes
n	28,569	23,458	5,111

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 well pads within 20km of the centroid of the census tract in the year of observation. *** Statistically significant at the 1% level; ** 5% level.

A.2 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 positive vicinity effect accompanied by a strong increase in new housing supply may result in a failure to find any increase in prices. 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.[26] 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 7—we find that cumulative wellbores are weakly negatively correlated with the likelihood of a transaction being a new construction.

Table 7: 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 Well Pads	-3.67e-04*	-1.93e-03
	(2.13e-04)	(2.56e-03)
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 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.

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