The Impact of Shale Exploration on Housing Values in Pennsylvania[1]

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Abstract

Horizontal drilling and hydraulic fracturing processes to extract shale gas have raised concerns among local residents over the safety of these new drilling techniques. To assess whether potential negative externalities associated with shale gas exploration are capitalized into surrounding homeowners property values, we estimate a hedonic model combining data on 3,464 housing sales occurring between 2008 and 2010 in a suburban/rural county south of Pittsburgh, PA which experienced large numbers of new horizontal Marcellus wells beginning in late 2008. Using hedonic methods, we find a negative and significant impact to households in close promixity both spatially and temporally to this activity. Further we find that this negative impact disproportionately accrus to homeowners near additional agricultural areas and on well water. In all cases, the negative impact appears relatively short-lived.

Keywords: Shale gas; Housing values; Risk perceptions; Hedonic

JEL Codes: Q51; Q52; R21

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1. Introduction

Large reservoirs of previously inaccessible, domestic sources of energy offered by natural gas have the potential to fundamentally change the energy makeup and outlook for the United States and global economy. Unlike traditional sources of shale exploration that date back to the 1800s, the recent enthusiasm surrounding shale gas exploration is largely a result of technological advancements which have enabled previously inaccessible shale resources to be profitably extracted. Beginning in 2005 with exploration of the Barnett Shale in Texas, innovations in the use of horizontal drilling and hydrofracturing techniques have ushered in a rapid expansion of shale gas exploration across the United States. In the Northeast United States, initial exploration of the Marcellus Shale underlying much of Pennsylvania, New York, and West Virginia began in 2005 with substantial exploration activity since early 2007.

The U.S Geological Survey estimates that the Marcellus shale alone contains over 84 trillion cubic feet of undiscovered gas deposits. Exploration and development of the natural gas reserves contained in the Marcellus and Utica Shale deposits in Ohio, Pennsylvania, West Virginia and New York is progressing rapidly and providing substantial private benefits to landowners, with leases upwards of $5,000 per acre and royalty payments approaching 20%. While the private benefits to landowners, and the potential for enhancing state revenues arising from these has resulted in much enthusiasm, much less is known about the private and public costs associated with shale exploitation, particularly the environmental impacts stemming from new drilling techniques required to access this resource.

In the Marcellus Shale region of Pennsylvania, the viable deposits of shale gas often occur at depths of one mile or deeper. To access these deposits, innovations in hydraulic

fracturing and the use of horizontal drilling have enabled profitable exploration of this resource, although their use has created considerable controversy stemming from perceived environmental and health risks. A central component of hydraulic fracturing (the process which fractures the shale allowing gas to escape) is the use of large volumes of water, often between 2 million and 8 million gallons per well, mixed with additional chemicals which are forced under pressure into a well to form fissures allowing natural gas to flow out of the dense shale (Abdalla et al., 2012). A byproduct of the hydraulic fracturing process is the flowback (or return to surface) of between 10 and 40 percent of the total water volume used over a period of approximately 30 days (PA DEP). This water is often laden with heavy metals, salts, hydrofracturing chemicals and, potentially, low-levels of radioactivity posing a serious environmental and health risk if not contained and disposed of properly. Furthermore, concerns over methane leaching into surrounding water supplies have been raised in both the popular press ("Gasland") as well as in academic research (Osborn *et al.*, 2011). The potential for environmental and health impacts has led many nearby residents to voice concerns over potential water quality issues.

The perception of environmental and water quality risks associated with shale gas exploration are likely to vary spatially and temporally. It is highly likely that perceptions of water quality risks depend on the proximity of households to gas drilling activity. In addition to proximity, other spatial factors likely contribute to these perceptions including the source of drinking water (well water or municipal water), the intensity of new drilling activity, as well as households' expectations surrounding future oil and gas exploration activity near their homes. One potential window into the likely future expansion of oil and gas activity in an area is the amount of undeveloped land, typically agricultural, with which oil and gas companies can lease,

set up well drilling operations, and access with the machinery and equipment required for exploration.

In this paper, we present one of the first empirical studies to measure the impact of early shale exploration as capitalized into property values using a hedonic pricing framework for the real estate market of single-family residential homes in Washington County, Pennsylvania. This county typifies the public debate over shale exploration and perceived environmental and health risks as many areas of the county have large populations living in close proximity to recent Marcellus Shale exploration activity, making it an ideal location to study the impacts of shale exploration on surrounding property values. We focus on an early phase of the activity to ensure that we capture the impact of shale activity before housing values are potentially confounded with inflationary trends due to expectations of future royalty payments and any other positive externalities that accompany the expansion of the activity.

Previewing our results, we find evidence that households are negatively impacted by shale gas exploration activity, but that this impact largely depends on the location of the household and diminish over time as risk perceptions adjust following the cessation of exploration activity. In particular, we find that households relying on well-water who are within 1 mile of recent and ongoing exploration activity see housing values decline by approximately 3.8 percent. This effect becomes insignificant if the shale gas activity began more than 1 year prior, suggesting that the effect is temporary and largely associated with risk perceptions from ongoing activity. In contrast, we find a large and more persistent negative effect associated with homes surrounded by large amounts of agricultural areas, likely reflecting expectations about the potential for continued shale exploration in these areas over longer time frames. As shale gas activity moves forward, both in the region and nationally, understanding the potential for and

impacts on surrounding populations is a key component of effective policy. The remainder of the paper is structured as follows. The next section briefly describes the hedonic framework we employ in studying the impact of shale exploration on housing nearby housing values. The third section describes the data and Marcellus Shale activity in the county. The fourth section presents results from our econometric analysis and the fifth section concludes.

2. Hedonic valuation of shale gas activity

It is well established that land and housing markets respond to changes in environmental conditions with prices adjusting to reflect differences in environmental quality and amenities across space. Since the introduction of the hedonic pricing method by Rosen (1974), hedonic models have become one of the most common tools used by economists to estimate the value (cost) of environmental (dis) amenities that are capitalized in property values. The hedonic price function decomposes the value of a residential property, itself a bundle of many individual attributes, into housing and environmental characteristics, including property characteristics such as lot size, number of bedrooms and bathrooms, the age of the property, and type of construction; neighborhood characteristics such as quality of the school district, crime rate, and proximity to city services; and environmental amenities such as air or water quality (Leggett and Bockstael, 2000), amount and quality of open space nearby (Abbott and Klaiber, 2011), proximity to amenities such as beaches and beach quality (Gopalakrishnan et al., 2011); and disamenities such as proximity to industrial waste disposal (Smith and Desvousges, 1986).

The hedonic framework begins by expressing the individual's utility as a concave function of a bundle of attributes that are capitalized in property values and a composite numeraire commodity.

(1) $U_{ij} = U(C_i, X_i, Z_{ij}, N_j, \alpha_i)$

Households are assumed to have different preferences, α with the utility of an individual

household i in location j dependent on characteristics of the property (X_i), neighborhood or

location specific characteristics (N_j), environmental attributes that can vary by location and by

household (Z_{ij}), and a composite numeraire commodity (C_i). The budget constraint is given by:

(2) $Y_i = C_i + P(X_i, N_j, Z_{ij})$

where $P_i(X_i, N_j, Z_{ij})$ is the hedonic price function of the property. Maximizing utility subject to

the budget constraint, the individual's marginal willingness to pay for a specific environmental

attribute is given by:

(3) $\dfrac{\partial U_i}{\partial z_{ij}} \Big/ \dfrac{\partial U_i}{\partial C_i} = \dfrac{\partial P_i}{\partial z_{ij}}$

The implicit value of a particular attribute is the partial derivative of the implicit price function

with respect to that attribute.

　　　In this paper, we combine real estate data with data on Marcellus shale activity in

Pennsylvania to examine the potential impact of early shale activity on nearby housing prices.

Our focus on the early period of shale exploration is an attempt to limit the potential of

widespread revenue from royalty payments and land leases to nearby residents, improved public

expenditure from rising tax revenue, and other positive externalities associated with shale gas

activity that would be expected to capitalize into housing values to confound our results. To the

extent that some of these positive spillover effects were occurring during our study period, they

would tend to attenuate any potential negative effects from shale gas exploration.

　　　We estimate a semi-log hedonic price function following Cropper et al. (1988) and

include numerous spatial fixed effects to control for potentially unobservable determinants of

housing prices as outlined by Kuminoff et al (2010). The specific functional form for the hedonic we estimate is given by

$$(4) \qquad \ln(P_{ij}) = \alpha_0 + \alpha_1 X_i + \beta_j N_j + \gamma_1 Z_{ij} + \varepsilon_{ij}$$

where X_i includes property characteristics such as number of rooms, number of stories, built-up area (sq ft.), age of the property, presence of a garage, pool, distance to Pittsburg, and distance to the nearest road. To distinguish the impact of shale exploration from other confounding unobserved factors that are specific to the area, we include location-specific fixed effects (N_j) at the level of the school district.[3]

The impact of shale gas activity on surrounding homes is contained in the environmental attribute indexed by (Z_{ij}) with variables that vary by house and location. A primary challenge in this analysis is that shale exploration is relatively recent in this area and started only in early 2008 for our county. In exploring this early effect we are limited by the number of shale gas wells and the small sample of residential properties that are impacted by the activity. A specific site can have 8 or more horizontal wells per site (Abdalla et al., 2012) due to the directional nature of horizontal drilling. To capture both a proximity and intensity effect, we use the number of horizontal shale gas wells within distance bands and specific time windows around each property sale as an explanatory variable. In the hedonic price function, the coefficient γ_1 represents the marginal willingness to pay for (or to avoid) an additional shale well within a given distance buffer and time window.

With recent advances in the literature on hedonic estimation of environmental values, researchers are increasingly concerned with spatial and temporal variation in environmental amenities, and therefore the need to control for the spatial and temporal extent of the housing

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[3] We also explored including municipality fixed effects and found no qualitative differences.

market that capitalizes these values (Kuminoff *et al.*, 2010). Previous studies have separately explored spatial extents of capitalization of environmental and land use characteristics (Geoghegan et al. 1997; Paterson and Boyle, 2002; Anderson and West, 2006), and timing of sales relative to the introduction of a hazardous waste site (Michaels and Smith, 1990). To capture the localized effect of shale exploration, we estimate the marginal impact of shale exploration activity (number of shale wells) within one mile from housing properties and for which a permit had been acquired no more than 6 months prior to the sale of the property. We then vary the spatial and temporal extent to analyze changes in the impact of activity. [4]

The reliance on both spatial and temporal windows is intended to reflect both the ongoing shale drilling activity, which is typically a short-term activity, as well as the expectations and risk perceptions of households. It is likely that households perceive considerable risks that are capitalized while activity is ongoing, but upon completion of nearby activity those risk perceptions are updated with additional information on whether or not significant impacts to those homeowners were realized. If risk perceptions vary over time, as this would suggest, we would expect to see any potential negative impacts transmitted through risk perceptions to attenuate over time. Similarly, as one moves outside the likely range of perceived risks in space, the effects of shale gas activity as capitalized into housing values are also likely to attenuate.

Environmental concerns regarding the impact of shale exploration on ground water quality has garnered much interest in the scientific community and the popular press. There is growing concern over methane leaching into surrounding water supplies (Osborn *et al.*, 2011) and the potential health risks associated with this effect of water quality. To explore the potential risk due to lower water quality, we control for the source of drinking water by including an

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[4] While we would ideally be able to include multiple time/spatial windows in a single hedonic model, the low number of observations available in close proximity to shale gas wells raised problems of colinearity resulting in our decision to use multiple hedonic regressions.

indicator variable for whether the property is provided with municipal water supply or private well water. The impact of shale gas activity on particular subsets of the broader housing market can be captured in a hedonic framework through the inclusion of an interaction between the number of shale wells and the source of water supply to identify the marginal effect of shale activity on a property that uses private well water.

In addition to potentially disproportionate impacts on households reliant on well water, we would also expect that the perception of additional future drilling would reasonably be capitalized into housing values as future drilling would pose additional risks to nearby homeowners. It has been noted in previous research that expectations about future land use patterns can influence the value of open space (Smith et al 2002; Irwin, 2002). We therefore include a variety of land use categories to capture nearby land use patterns, noting that the vast majority of shale exploration activity occurs on agricultural lands. We test this hypothesis by including an interaction between surrounding agricultural lands and shale gas activity. Including these interaction terms, the environmental attributes of interest shown in equation (4) are expanded to include $\left(z_{ij},\left(z_{ij} \times L_i^{AG}\right),\left(z_{ij} \times X_i^{WATER}\right)\right)$.

Incorporating these additional environmental attributes into the hedonic specification results in the following

$$(5) \quad \ln(P_{ij}) = \alpha_0 + \alpha_1 X_i + \beta_j N_j + \gamma_{11} z_{ij} + \gamma_{12}\left(z_{ij} \times L_i^{AG}\right) + \gamma_{13}\left(z_{ij} \times X_i^{WATER}\right) + \varepsilon_{ij}$$

where L_i^{AG} is the portion of agricultural land in the buffer, X_i^{WATER} is an indicator variable for well water, and z_{ij} is the number of shale wells in the buffer. The marginal effect of an additional shale well is decomposed as:

$$(6) \quad \left(\frac{1}{P_i}\right)\left(\frac{\partial P_i}{\partial z_{ij}}\right) = \gamma_{11} + \gamma_{12}\left(L_i^{AG}\right) + \gamma_{13}\left(X_i^{WATER}\right)$$

3. Data

Southwestern Pennsylvania began to experience Marcellus Shale gas exploration activity during 2007 with this activity rapidly expanding over the following months and years. In our study are of Washington County, PA this activity began in 2008. Unlike much of Pennsylvania underlain by shale gas resources, the activity in southwestern PA took place in close proximity to suburban and rural areas containing relatively large numbers of residents. To exploit the unique incidence of large numbers of housing transactions in close proximity to shale gas activity for econometric identification, this paper uses data from Washington County, a county to the south of Pittsburgh, as the basis for our econometric analysis. The location of this county in relation to the larger Pittsburgh metro is shown in figure 1 with the extent of the Pittsburgh metro extending into the northern tier of Washington County. Data on housing transactions, well locations and dates, and surrounding land use was assembled and each is described below.

3.1 Housing transactions

Housing transactions were purchased from Dataquick, a private data vendor, spanning January 2008 through October 2010. This dataset contains a complete set of housing characteristics, sales prices, and sales dates as well as location and address information for each transaction. Structural characteristics included in the data include square footage, lot size, bedrooms, baths, stories, year built, presence of a garage, presence of a fireplace, and presence of a pool. After removing non-arms length transactions and data with missing attributes or extreme outliers for structural characteristics our final estimation sample consists of 3,646 single-family residential transactions occurring in 2008, 2009, and 2010. Summary statistics for these are

shown in table 1 and largely conform to our prior expectations about the rural/suburban nature of this area. In particular, the average home has a sales price slightly under $150,000 with an average square footage of 1,659 and is located on 0.61 acres of land. The relatively large acreage for the average home reflects the rural/suburban character of much of the county.

Using information on house addresses and zip codes each transaction was geocoded to provide a precise latitude and longitude for use in additional data assembly. The resulting geocoded transactions are shown in figure 2 overlaid on school districts. This figure shows that a large number of transactions are located in close proximity to the county seat, Washington, located at the intersection of interstates 79 and 70 as well as further north along Interstate 79 in Canonsburg and along the Allegheny County line in the northeast section of the county. Using the geocoded property locations, we formed several supplemental data elements using ArcGIS including distance to the nearest highway or interstate and distance to downtown Pittsburgh.

Information on the location of water services and school district boundaries was obtained from PASDA, a data clearing house for spatial data maintained by Pennsylvania State University which assembles data from local governments across the state. Information on statewide boundaries for public water service providers is provided by the Pennsylvania Department of Environmental Protection and information on school district boundaries is provided by the Pennsylvania Department of Education. This information was attached to each transaction by overlaying the shapefiles with the geocoded transactions points in ArcGIS. In total, our transactions fall across 14 school districts and approximately 91% of our transactions are in a water provider's coverage area. A map showing the location of transactions with water service providers is shown in figure 3.

3.2 Shale exploration activity

Data on Marcellus shale gas activity was obtained from the Pennsylvania Department of Environmental Protection and includes information on both permitting of wells and the actual drilling of shale gas wells across the state. Historically, many shallow oil and gas wells located in Pennsylvania were of the "vertical" type where a single vertical well shaft is drilled to access oil and gas resources, usually at shallow depths. Exploration of deeper shale resources across the country has seen a transition from vertical wells to horizontal wells that are able to extend horizontally under the ground up to 1 mile from the well pad in a specified direction. This technological innovation has allowed oil and gas companies to profitably access shale gas resources at greater depths and is by far the most common drilling technique in the Marcellus shale of Pennsylvania. In addition, the use of horizontal drilling and high pressure hydraulic fracturing has generated a significant amount of public discourse over perceived safety risks to residents. For these two reasons, we focus our analysis only on the impacts of horizontal Marcellus shale wells to surrounding property values.

Determining the timing of shale gas activity presents additional challenges that arise due to the multiple steps involved in securing permitting, beginning to drill, and ultimately completing drilling activity. Shale exploration activity frequently involves the expansion of gravel roads to access drill sites as well as substantial increases in truck traffic to deliver water, equipment, and hydrofracturing materials and culminates in the construction of the drilling rig as drilling activity begins. Due to the considerable amount of preparations required prior to drilling, much of this activity occurs in the months preceding the actual commencement of drilling activities and could be proxied for by the date at which a permit is issued to allow drilling activities on a particular site. To capture the impact of any disruptive activity associated with the

drilling, we use the permit date for each well drilled as the start time for the activity rather than the date of actual drilling.

Because a large portion of shale gas "visibility" to the public occurs between permitting being approved and the beginning of drilling operations, typically over a period of several months we are interested in identifying the likely time period in which this activity becomes apparent to nearby residents. To fully capture the likely impacts of shale exploration on surrounding housing values, we have obtained both drilling and permitting data from the Pennsylvania Department of Environmental Protection and merged each data source to attach the permit date to each drilled well in our study area. We use this date in our subsequent analysis.[5]

Summary statistics for the numbers of shale gas wells near residential properties for various time and distance thresholds based on permit dates are shown in table 2. Extending the distance buffer to 2 miles and 12 months reveals an average number of shale gas wells of 0.63 across all homes with a maximum of 19 wells located within those cutoffs for at least one home. This large number of nearby wells drops to a maximum of only 7 wells when examining a 0.75-mile and 3-month range. The large numbers of wells are reflective of the horizontal nature of drilling activity with multiple wells often located on a single well pad. While multiple wells can originate from a single location, as the number of wells increase, the size of the drilling operation and amount of associated traffic and "visibility" to homeowners is likely to increase as well. For this reason, we argue that focusing on the total count of wells captures important differences across space that would be overlooked if using a simple indicator variable for nearby activity.[6]

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[5] We also examined using the spud date, or date that the drill bit touches the ground, but found that decision led to a general loss of significance across all models. This loss of significance is likely reflecting that we are failing to capture the full effects of shale gas activity on surrounding homes and led us to instead rely on permit dates.
[6] In preliminary analysis using a single indicator variable, we uniformly found a loss of significance suggesting that intensity is a key determinant in uncovering capitalized impacts from shale gas activity.

3.3 Surrounding land use

The final data component consists of land use data obtained from the 2006 National Land Cover Database (NLCD) obtained from the USGS. Using this data, we calculated percentages of land cover within 1 mile of each house in our transactions data for the categories of agriculture, forest, water, commercial, industrial, residential, and miscellaneous. Summary statistics for surrounding land use percentages are shown in table 1 and reflect the relatively low-density rural nature of much of Washington County with an average of 27.5% of surrounding land from each home classified as agriculture and a further 29.5% of surrounding land classified as forested lands.

Shale gas exploration largely occurs in agricultural areas resulting from the presence of easier access and fewer landowners to negotiate leases. For our econometric analysis, identifying and controlling for these surrounding land use types takes on an important role. In addition to controlling for surrounding land use, the presence of particular land use types may also influence the "visibility" of shale gas activity in this area. In particular, it is likely that high percentages of surrounding agricultural land may make activity more visible and could also influence expectations about the extent and location of future activity.

4. Results

We estimated the hedonic models shown in equations (4) and (5) using a semi-log specification where the dependent variable is the log of sales price and the explanatory variables are in levels. To explore the early impact of shale activity surrounding residential properties, we first consider the number of nearby shale gas wells, within 1 mile of a property, that were permitted no more than six months prior to the property sale (Table 2). Coefficients on the

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property characteristics (e.g. square footage, number of bedrooms, age, fireplace, pool) have the expected sign and are statistically significant at 5%. Being located farther away from the city of Pittsburg decreases housing values by 1%. To control for unobservable factors that influence housing prices, we include sale-year and school-district fixed effects in the model.

To highlight our identification strategy for estimating the impact of shale gas activity on surrounding homes, figure 4 shows the well locations and transactions within 1 mile and 6 months of a well permit date (denoted by triangles). For these thresholds, there were 129 wells located within 1 mile of 89 housing transactions, approximately 2.4% of our total transactions database. This figure also highlights the clustering of wells in a single location, a result of the directional horizontal drilling techniques which enable many wells to emanate from a single location with each drilling in a different direction. Lastly, the presence of school district fixed effects are evident by the lightly colored lines bisecting the study area which are included to capture spatially varying and time-invariant unobservable that if left unaccounted for could bias our results. Identification arises from differences in shale activity for homes near wells within a school district relative to other homes within the school district that are not near wells or near fewer wells either due to spatial or temporal differences in transactions time and well permitting dates.

Our primary findings are shown in table 3 and include the aforementioned housing characteristics as well as additional controls for surrounding land use and whether a house is dependent on well water. The first model of table 3 estimates a standalone parameter which measures the count of horizontal wells near houses but does not include any interaction effects between spatially varying features of the landscape (land use and presence of urban services) and the intensity of shale activity measured using the number of nearby horizontal shale wells.

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Controlling for surrounding land use appears to be important in this rural/suburban area with many of the land use coefficients significant at 90% and above. Relative to residential areas, which are the omitted category, we find that the marginal effect of having additional agricultural, forest or industrial land surrounding the property decreases housing values significantly. The explanatory variable we are most interested in – the number of shale wells drilled in the 1-mile buffer around the property – indicates that having an additional horizontal well close to the property decreases the value of the property by 1.5%. This modest negative effect is statistically significant at 5%.

To further explore the effect of shale activity in agricultural regions and the impact on perceived water risks, we estimate a second model shown in table 3 which includes interaction effects between the number of shale wells near a property and reliance on well water as well as an interaction between the count of wells and the percent of agricultural land surrounding each home, which may indicate expectations about the likelihood of future shale gas activity. When we include interaction terms, the coefficient on number of shale wells becomes insignificant. The effect of an additional shale well on properties that rely on well water is negative (-3.8%) and has a p-value of 0.11. A negative and strongly significant interaction effect is associated with properties surrounded by agricultural land with an additional shale well located near a home surrounded by agricultural lands found to decrease property values by 7.2%. While the average impact of shale activity is modest, the effect on rural homes is significant and large.

For each of these models, we considered a tight space and time window by using the number of shale wells permitted and subsequently drilled within one mile and 6 months prior to the property sale. The large effect on agricultural land could reflect both the disamenity of increased truck traffic and disruption during the exploration process, as well as an expectation of

increased shale activity in the future. As rural areas have fewer roadways, the presence of nearby activity was likely to be more visible which may partially reflect the large interaction terms associated with agriculture in addition to the likely increased expectations for additional shale gas activity occurring in the future on surrounding agricultural lands.

To examine the sensitivity of our results to varying time and distance windows, we estimated a series of models whose results are reported in table 4.[7]   In table 4 we present results for 3 different spatial buffers – 0.75 miles, 1 mile and 2 miles – and three time windows – 3 months, 6 months and 12 months. Turning to the results, note that the coefficients on all non-shale related explanatory variables are virtually identical across all model specifications, which provides a robustness check and makes us confident that the model accurately estimates coefficients on all non-shale attributes, and that differences in coefficients across different specifications reflect the differential impacts of shale activity. We also find that the coefficient on the number of shale wells is not statistically different from zero in any of the models, which suggests that any effects are likely to be heterogeneous and will be picked up through interaction terms in the model specification.

For models that employed a very small spatial buffer of activity within 0.75 miles of the property using only a 3 month window from permit date to sale date, we find a large negative and statistically significant effect (12.2%) on properties that are sourced by well water. This effect on well water persists in the 6-month time frame but becomes insignificant when we consider all sales within a year from the start of the activity, suggesting that home owners are concerned about the ground water risks of shale activity in the short term when the activity occurs very close to their property. When we consider a 1-mile buffer (models (4), (5) and (6))

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[7] While ideally we would be able to include multiple time and distance treatment effects variables in a single model, issues of colinearity and low numbers of observations precluded us from estimating these effects in a one model.

we find a smaller, 3.1%, negative impact with significance only at the shortest time period of 3 months.   When we increase the time frame to include all sales within 6 months of the activity we find that the effect on well water is not significant, but retains a negative 3% effect. This finding could reflect that households' risk perceptions have updated following drilling activity and potentially that some households have had water tested and been found not to have any significant contamination.

Turning to the interactions with agricultural land surrounding properties reveals even stronger, and more persistent impacts from nearby shale gas activity. While this effect does not appear when we consider a very small spatial buffer (0.75 miles), potentially due to few observations, we find a negative and persistent interaction at the 1-mile buffer across 3, 6 and 12 month time intervals. In models (4), (5) and (6) we found a clear trend of the impact of shale activity in areas surrounded by agricultural land. The immediate impact within 3 months of the activity is largest and we find that additional shale activity decreased property values by 8.2%. The magnitude of the effect decreased to 7.2% when we examined sales within 6 months and further decreased to 4.0% when we considered all transactions within a year from the start of the activity.

Finally all models, we found no significant shale impacts when we considered all houses within 2 miles of nearby activity. Given the extent of horizontal drilling is approximately 1 mile, the few observations that would remain "untreated" within a school district for identification, and the loss of visibility as one moves away from shale gas activity this result is not surprising. It also suggests that the potential pool of impacted homeowners is relatively small, and largely dependent on the overall spatial extent and patterns of shale gas activity.

5. **Discussion**

The recent expansion of shale gas activity across large regions of the United States has created a lot of public discourse over perceived safety and environmental risks associated with its use. Despite the voluminous amounts of public discourse, there is surprisingly little applied research which examines direct impacts to surrounding populations. This lack of empirical research is likely due to the relatively recent expansion of this activity as well as the often isolated and sparse populations impacted which makes econometric identification challenging. In this paper, we have assembled a unique dataset, which allows us to examine the early impact of shale gas activity on surrounding homeowners in a relatively populated area of Pennsylvania, Washington County.

Our hedonic estimates reveal that households do appear to be negatively impacted by nearby shale gas activity, but that this effect is often short term and does not extend over large geographic regions. The short term capitalization response is consistent with a story about households updating risk perceptions over time and/or obtaining additional information to verify whether or not adverse impacts have been experienced. The relatively tight spatial extent of impacts is also consistent with the technological limitations of the current shale gas exploration activity, which limits the extent of horizontal fracturing and drilling to approximately 1 mile from the well site.

In addition to finding fairly short term and spatially concentrated impacts, our research also provides insights into the heterogeneous impacts shale gas activity is likely to have across populations. When one considers that much of the recent expansion in shale gas activity is likely to occur in relatively populated areas, particularly in the Northeast and Midwest, understanding the distributional impacts of this activity is central to policymakers. We find that homeowners'

dependent on well water and surrounded by large amounts of agricultural land are disproportionally negatively impacted, and these effects also dissipate relatively quickly over time and space. Given the likely impacts to this group of homeowners, it is not surprising that some oil and gas companies have begun to mandate water testing (e.g. Chesapeake) of surrounding areas which may serve the dual role to protect them from future litigation as well as to provide additional reassurance to the most likely impacted households.

One limitation of our analysis with different space-time buffers is that the extent of substitution between environmental and housing attributes could vary under different specifications. While our analysis found virtually no differences in the estimates for non-shale related coefficients across our hedonic specifications, the lack of available data precludes us from estimating a single hedonic with additional distance/time buffers. Ideally we would want to examine the impacts of different buffers within the same model but sparse data and collinearity issues restrict our ability to consider multiple buffers in a single model.

Moving forward, econometric identification of impacts from shale gas activity will continue to face challenges stemming in large part from the potential for localized housing price inflation due to increased demand for housing from new workers, as well as the influx of additional royalty and lease payments to rural areas. Future work which tries to unbundle these competing effects will likely need to obtain information on land leasing and royalty data, which to date is not easily accessible to researchers. By focusing on the earliest time periods of exploration in this paper, we attempted to avoid much of the difficulties associated with this longer run phenomenon and provide timely and policy relevant information as many local and state governments assess whether to alter regulations, permitting procedures, and potential impact fees on expanded shale gas exploration.

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Table 1. Summary statistics (N=3646)

Variable	Mean	Std. Dev.	Min	Max
Sale price	148,401	117,683	10,150	1,812,812
Square feet (100s)	16.5916	7.1931	4.52	72.09
Lot size	0.6088	1.1013	0.03	28.68
Bedrooms	2.9558	0.8121	1.00	9.00
Bathrooms	1.6829	0.7677	1.00	9.00
Stories	1.8206	0.8797	0.00	5.00
Age	54.3804	33.8200	0.00	239.00
Garage (0/1)	0.7885	0.4084	0.00	1.00
Fireplace (0/1)	0.3486	0.4766	0.00	1.00
Pool (0/1)	0.0176	0.1313	0.00	1.00
Well water (0/1)	0.0883	0.2838	0.00	1.00
Inv. Dist highway (1/feet)	260	6,579	0	361,752
Dist Pittsburgh	19.0010	5.0004	10.58	39.51
Age sq	4,101	4,320	0	57,121
Square feet sq	327.0075	329.8147	20.43	5196.97
Lot size sq	1.5831	14.9085	0.00	822.54
Land use buffers (1 mile)				
% Ag	0.2757	0.2411	0.00	1.00
% Forest	0.2946	0.1476	0.00	0.96
% Residential	0.2907	0.1736	0.00	0.71
% Water	0.0144	0.0326	0.00	0.18
% Commercial	0.0507	0.0569	0.00	0.24
% Industrial	0.0199	0.0352	0.00	0.14
% Miscellaneous	0.0111	0.0267	0.00	0.27
Sales year (counts)				
1998	1324			
1999	1355			
2000	967			

Table 2: Horizontal wells by distance and permit time

Variable	Miles	Months	Mean	Std. Dev.	Min	Max
# Horizontal wells	0.75	3	0.0148	0.2230	0	7.00
Horizontal-x-Well water	0.75	3	0.0019	0.1159	0	7.00
Horizontal -x- % Ag	0.75	3	0.0042	0.0984	0	4.49
# Horizontal wells	0.75	6	0.0283	0.3046	0	7.00
Horizontal-x-Well water	0.75	6	0.0036	0.1293	0	7.00
Horizontal -x- % Ag	0.75	6	0.0077	0.1197	0	4.49
# Horizontal wells	0.75	12	0.0464	0.4552	0	8.00
Horizontal-x-Well water	0.75	12	0.0096	0.2226	0	8.00
Horizontal -x- % Ag	0.75	12	0.0187	0.2600	0	7.18
# Horizontal wells	1	3	0.0436	0.3962	0	7.00
Horizontal-x-Well water	1	3	0.0038	0.1536	0	7.00
Horizontal -x- % Ag	1	3	0.0147	0.2083	0	5.57
# Horizontal wells	1	6	0.0713	0.5263	0	10.00
Horizontal-x-Well water	1	6	0.0107	0.2493	0	10.00
Horizontal -x- % Ag	1	6	0.0251	0.2831	0	7.56
# Horizontal wells	1	12	0.1133	0.7641	0	13.00
Horizontal-x-Well water	1	12	0.0236	0.3777	0	10.00
Horizontal -x- % Ag	1	12	0.0497	0.4658	0	10.72
# Horizontal wells	2	3	0.2479	1.0248	0	11.00
Horizontal-x-Well water	2	3	0.0307	0.4251	0	11.00
Horizontal -x- % Ag	2	3	0.0887	0.5754	0	8.33
# Horizontal wells	2	6	0.3919	1.4261	0	14.00
Horizontal-x-Well water	2	6	0.0570	0.6281	0	11.00
Horizontal -x- % Ag	2	6	0.1434	0.8297	0	11.14
# Horizontal wells	2	12	0.6358	2.1239	0	19.00
Horizontal-x-Well water	2	12	0.1078	1.0374	0	18.00
Horizontal -x- % Ag	2	12	0.2496	1.2722	0	15.51

Table 3: Estimation results (Distance = 1 mile, Time = 6 months)

Variable	(1) No Land use interactions	(2) With Land use interactions	Variable	(1) No Land use interactions	(2) With Land use interactions
Square feet (100s)	0.0393***	0.0392***	Lot_size2	-0.0029***	-0.0029***
	(0.0050)	(0.0050)		(0.0010)	(0.0010)
Lot size (acres)	0.0840***	0.0853***	Number of Horizontal Shale wells within 1 mile	**-0.0145****	**0.0255**
	(0.0120)	(0.0120)		**(0.0060)**	**(0.0160)**
Number of Bedrooms	0.0373**	0.0384**	Count_Horizontal*Well Water		**-0.0381**
	(0.0170)	(0.0170)			**(0.0220)**
Number of Baths	-0.005	-0.0051	Count_Horizontal*AgLand		**-0.0716*****
	(0.0130)	(0.0130)			**(0.0220)**
Stories	-0.0064	-0.0061	Landuse-Agriculture	-0.2290***	-0.2205***
	(0.0110)	(0.0110)		(0.0660)	(0.0640)
Age of Property	-0.0118***	-0.0119***	Landuse-Forest	-0.2333*	-0.2371*
	(0.0020)	(0.0020)		(0.1090)	(0.1100)
Garage	0.2439***	0.2435***	Landuse-Water	-1.9433*	-1.9487*
	(0.0320)	(0.0320)		(1.0570)	(1.0550)
Fireplace	0.1704***	0.1701***	Landuse-Commercial	-0.3017	-0.3445
	(0.0230)	(0.0230)		(0.3610)	(0.3660)
Pool	0.1208**	0.1224**	Landuse-Industrial	-2.5868***	-2.5205**
	(0.0520)	(0.0510)		(0.8520)	(0.8480)
Well Water	-0.0677	-0.0619	Landuse-Other	-0.1458	-0.1298
	(0.0390)	(0.0390)		(0.4850)	(0.4840)
1/Distance to road	0.0000*	0.0000*	Sale Year 2009	0.0228	0.0239
	(0.0000)	(0.0000)		(0.0240)	(0.0240)
Distance to Pittsburg	-0.0101**	-0.0106**	Sale Year 2010	0.1717***	0.1678***
	(0.0040)	(0.0040)		(0.0420)	(0.0420)
Age2	0.0000**	0.0000**	Constant	11.4163***	11.4228***
	(0.0000)	(0.0000)		(0.1620)	(0.1600)
Sqft2	-0.0002*	-0.0002*	School District FE	Included	Included
	(0.0000)	(0.0000)			
Observations	3,646	3,646			
R-squared	0.692	0.691			

Clustered robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 4: Robustness results for spatial and temporal variations

	Model Specification (school district and time fixed effects not shown)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	.75 miles	.75 mile	.75 mile	1 mile	1 mile	1 mile	2 miles	2 miles	2 miles
Variable	3 months	6 months	12 months	3 months	6 months	12 months	3 months	6 months	12 months
Square feet (100s)	0.0393***	0.0394***	0.0394***	0.0394***	0.0392***	0.0393***	0.0393***	0.0392***	0.0393***
	(0.0050)	(0.0050)	(0.0050)	(0.0050)	(0.0050)	(0.0050)	(0.0050)	(0.0050)	(0.0050)
Lot size (acres)	0.0855***	0.0851***	0.0835***	0.0838***	0.0853***	0.0831***	0.0833***	0.0837***	0.0836***
	(0.0120)	(0.0120)	(0.0120)	(0.0120)	(0.0120)	(0.0120)	(0.0120)	(0.0120)	(0.0120)
Number of Bedrooms	0.0380**	0.0381**	0.0376**	0.0379**	0.0384**	0.0379**	0.0377**	0.0376**	0.0377**
	(0.0170)	(0.0170)	(0.0170)	(0.0170)	(0.0170)	(0.0170)	(0.0170)	(0.0170)	(0.0170)
Number of Baths	-0.0045	-0.0044	-0.005	-0.0046	-0.0051	-0.0055	-0.0055	-0.0054	-0.0048
	(0.0130)	(0.0130)	(0.0130)	(0.0130)	(0.0130)	(0.0130)	(0.0130)	(0.0130)	(0.0130)
Stories	-0.0065	-0.0064	-0.0065	-0.0064	-0.0061	-0.0061	-0.0065	-0.0064	-0.0065
	(0.0110)	(0.0110)	(0.0110)	(0.0110)	(0.0110)	(0.0100)	(0.0100)	(0.0100)	(0.0100)
Age of Property	-0.0118***	-0.0118***	-0.0119***	-0.0118***	-0.0119***	-0.0119***	-0.0119***	-0.0119***	-0.0119***
	(0.0020)	(0.0020)	(0.0020)	(0.0020)	(0.0020)	(0.0020)	(0.0020)	(0.0020)	(0.0020)
Garage	0.2437***	0.2450***	0.2442***	0.2438***	0.2435***	0.2440***	0.2435***	0.2438***	0.2439***
	(0.0320)	(0.0320)	(0.0320)	(0.0320)	(0.0320)	(0.0320)	(0.0320)	(0.0320)	(0.0320)
Fireplace	0.1699***	0.1702***	0.1701***	0.1705***	0.1701***	0.1700***	0.1694***	0.1698***	0.1701***
	(0.0230)	(0.0230)	(0.0230)	(0.0230)	(0.0230)	(0.0230)	(0.0230)	(0.0230)	(0.0230)
Pool	0.1339**	0.1371**	0.1200**	0.1235**	0.1224**	0.1169**	0.1184**	0.1190**	0.1185**
	(0.0470)	(0.0470)	(0.0520)	(0.0490)	(0.0510)	(0.0530)	(0.0530)	(0.0520)	(0.0530)
Well Water	-0.066	-0.062	-0.0675*	-0.0661	-0.0619	-0.0681*	-0.0711*	-0.0673	-0.0755*
	(0.0380)	(0.0400)	(0.0370)	(0.0380)	(0.0390)	(0.0380)	(0.0390)	(0.0390)	(0.0400)
1/Distance to road	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Distance to Pittsburg	-0.0103**	-0.0104**	-0.0103**	-0.0105**	-0.0106**	-0.0105**	-0.0100**	-0.0101**	-0.0101**
	(0.0040)	(0.0040)	(0.0040)	(0.0040)	(0.0040)	(0.0040)	(0.0040)	(0.0040)	(0.0040)

Table 4, continued

Variable	(1) .75 miles 3 months	(2) .75 mile 6 months	(3) .75 mile 12 months	(4) 1 mile 3 months	(5) 1 mile 6 months	(6) 1 mile 12 months	(7) 2 miles 3 months	(8) 2 miles 6 months	(9) 2 miles 12 months
Number of Shale wells	0.0023	0.0131	-0.0011	0.0261	0.0255	0.0136	-0.0117	-0.0071	-0.0025
	(0.0410)	(0.0270)	(0.0170)	(0.0210)	(0.0160)	(0.0120)	(0.0160)	(0.0070)	(0.0050)
Count_Horiz*Well Water	-0.1224***	-0.1263*	0.0131	-0.0307***	-0.0381	0.013	0.0113	-0.0002	0.0082
	(0.0280)	(0.0660)	(0.0520)	(0.0100)	(0.0220)	(0.0160)	(0.0120)	(0.0090)	(0.0060)
Count_Horiz*AgLand	-0.0336	-0.0988	-0.0359	-0.0823**	-0.0716***	-0.0395**	0.0134	0.0073	-0.0022
	(0.0570)	(0.0980)	(0.0270)	(0.0280)	(0.0220)	(0.0170)	(0.0250)	(0.0120)	(0.0100)
Landuse-Agriculture	-0.2288***	-0.2251***	-0.2266***	-0.2225***	-0.2205***	-0.2215***	-0.2353***	-0.2341***	-0.2312***
	(0.0660)	(0.0650)	(0.0650)	(0.0640)	(0.0640)	(0.0630)	(0.0620)	(0.0610)	(0.0650)
Landuse-Forest	-0.2307*	-0.2359*	-0.2356**	-0.2334*	-0.2371*	-0.2369**	-0.2366**	-0.2374**	-0.2419**
	(0.1090)	(0.1120)	(0.1090)	(0.1090)	(0.1100)	(0.1080)	(0.1070)	(0.1080)	(0.1080)
Landuse-Water	-1.9470*	-1.9412*	-1.9520*	-1.9567*	-1.9487*	-1.9567*	-1.9628*	-1.9540*	-1.9584*
	(1.0540)	(1.0590)	(1.0560)	(1.0500)	(1.0550)	(1.0530)	(1.0520)	(1.0500)	(1.0460)
Landuse-Commercial	-0.3103	-0.314	-0.3081	-0.336	-0.3445	-0.3249	-0.2985	-0.3048	-0.3204
	(0.3660)	(0.3710)	(0.3610)	(0.3670)	(0.3660)	(0.3630)	(0.3550)	(0.3550)	(0.3500)
Landuse-Industrial	-2.5595***	-2.5543***	-2.5631***	-2.5340**	-2.5205**	-2.5342**	-2.5746***	-2.5742***	-2.5783***
	(0.8400)	(0.8450)	(0.8450)	(0.8440)	(0.8480)	(0.8470)	(0.8290)	(0.8370)	(0.8390)
Landuse-Other	-0.1423	-0.1453	-0.1428	-0.1275	-0.1298	-0.1365	-0.1617	-0.1554	-0.1392
	(0.4820)	(0.4820)	(0.4850)	(0.4850)	(0.4840)	(0.4860)	(0.4890)	(0.4860)	(0.4920)
Constant	11.4102***	11.4269***	11.4220***	11.4144***	11.4228***	11.4247***	11.4163***	11.4177***	11.4190***
	(0.1620)	(0.1610)	(0.1640)	(0.1610)	(0.1600)	(0.1610)	(0.1620)	(0.1630)	(0.1610)
Observations	3,646	3,646	3,646	3,646	3,646	3,646	3,646	3,646	3,646
R-squared	0.692	0.692	0.691	0.692	0.692	0.691	0.691	0.691	0.691

Robust standard errors in parentheses

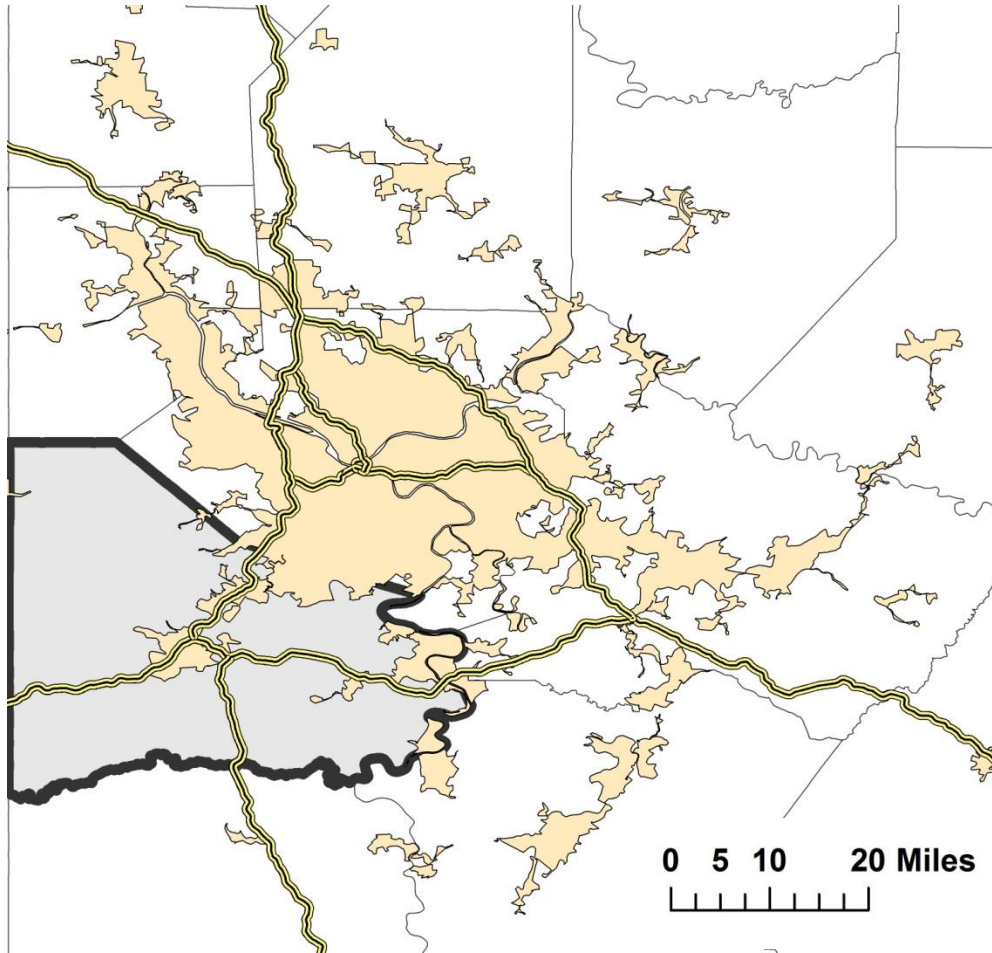*** p<0.01, ** p<0.05, * p<0.1
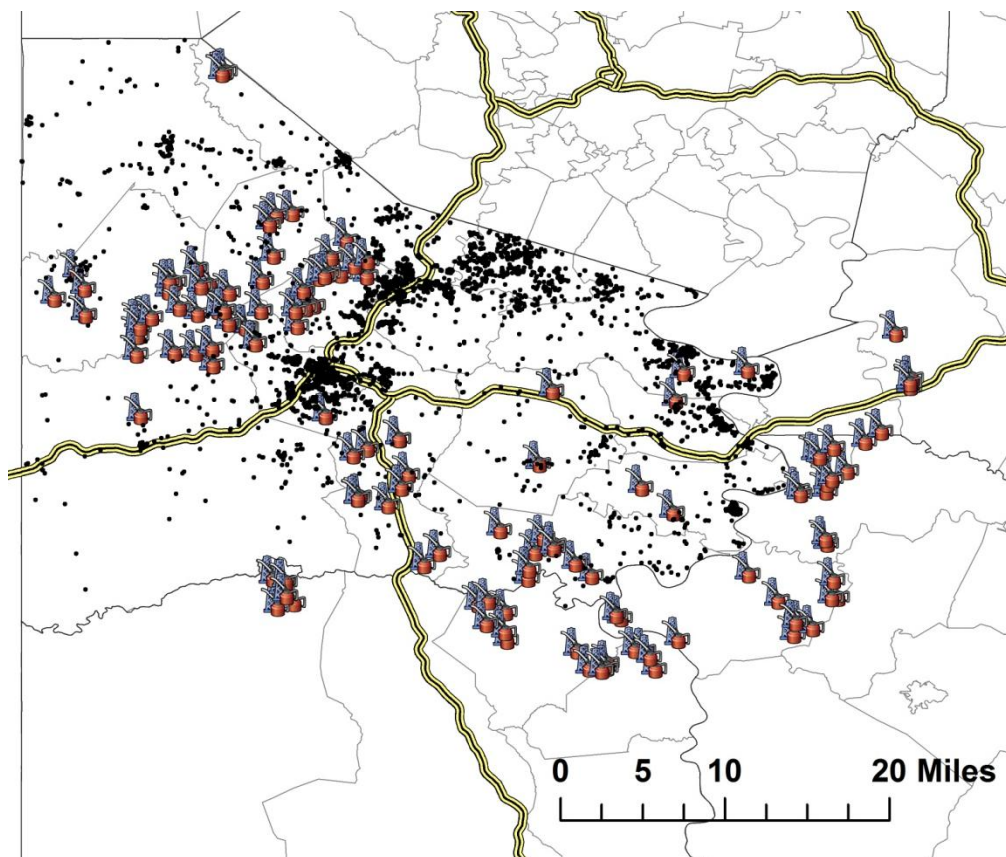
Figure 1: Study area

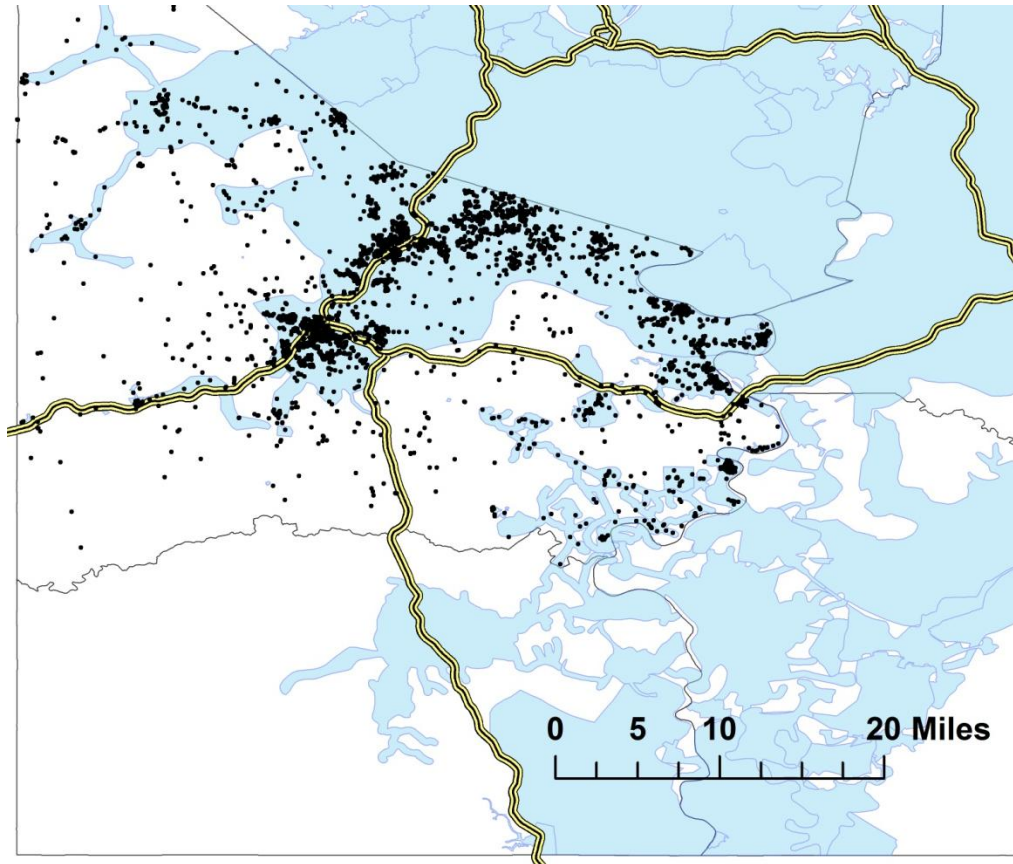**Figure 2: Housing transactions and shale gas wells**
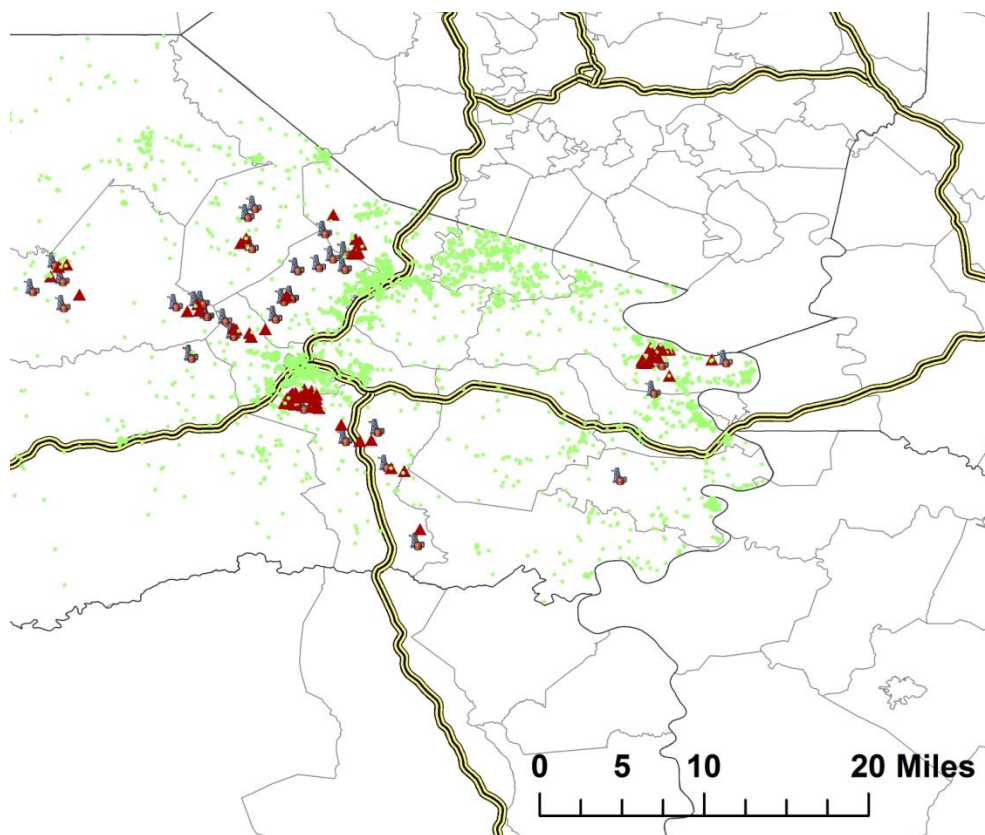
Figure 3: Water provider service areas

Figure 4: Treated and control observations (6 months, 1 mile)