Q. As a result, three sets of difference-in-differences equations will be estimated. The outcome variable of the first one will be quantity of houses sold (when the unit of observation is a house, it is equivalent to probability of sale) and in the second equation the dependent variable will be quantity measure Q. Because of the potential heterogeneity in households, the same equations will be estimated on subsamples of houses with different levels of Q[22]. Finally, the price effect will be estimated.

Equation 2.3 presents the empirical specification on foreclosure and probability of sale for nearby houses. The study area is reduced to all residential properties located within 750 feet of the foreclosed and/or vacant houses. The sample includes all properties located inside the control and treatment areas. The unit of observation is a property. This specification incorporates 3 indicators for the three different stages of foreclosure and interactions of the treatment indicator (within 250 feet of the foreclosure sites) with each of these 3 indicators. The outcome variable is an indicator of sale in quarter t. Thus, the counterfactual change in probability of sale of houses in areas immediately surrounding the foreclosure sites is estimated using probability of sale of houses in areas just slightly farther away in the same periods.

$$Sale_{ijt} = \alpha_{st} + \beta X_i + \omega_0 D_{ij}^{250} + \omega_1 Fore_{jt} + \omega_2 Vac_{jt} + \omega_3 ReOcc_{jt} \\ + \pi_1 \cdot (D_{ij}^{250} * Fore_{jt}) + \pi_2 \cdot (D_{ij}^{250} * Vac_{jt}) + \pi_3 \cdot (D_{ij}^{250} * ReOcc_{jt}) + +\varepsilon_{ijt} \qquad (2.3)$$

$Sale_{ijt}$ equals 1 if house i in the area of foreclosed property j in neighborhood s is sold in quarter[23] t. α_{st} is a neighborhood-quarter fixed effect. In all, there are 89 neighborhoods in the study area. X_i is the observable housing and neighborhood characteristics for house i. $Fore_{jt}$

[22] Type H houses are those with higher Q, while Type L houses are those with lower Q

[23] Here a quarter is the same as a calendar quarter

Table 2.7 - Comparing Magnitudes of Estimates in the Price Regression

Log (Sale Price)	(1)
Treated * Q * Vacancy	-0.0018
	(0.0079)
Foreclosure	0.0024
	(0.0129)
Vacancy	-0.0164
	(0.0134)
Reoccupied	0.00642
	(0.0152)
Treated*foreclosure	-0.0313
	(0.0221)
Treated*reoccupied	-0.0221
	(0.0254)
Observations	195,935

Standard errors clustered at foreclosure ring level are reported in parentheses. All regressions control for housing and neighborhood characteristics X_i and quarter*neighborhood fixed effects α_{st}.

Table 2.8 - OLS Results on Q by Length of Vacancy

$Q = log(\widehat{price}^{2005})$	(1) Vacant for 0-3 months	(2) Vacant for 3-6 months	(3) Vacant for 6-12 months	(4) Vacant for 12-18 months	(5) Vacant for >18 months
Treated * foreclosure	-0.0182	-0.0191	-0.0114	-0.0262	-0.0228
	(0.0249)	(0.0158)	(0.0121)	(0.0261)	(0.0249)
Treated * vacant first 3 months	-0.0134	-0.0124	-0.0140	-0.0125	-0.0182*
	(0.0165)	(0.0083)	(0.0108)	(0.0146)	(0.0109)
Treated * vacant for 3-6 months		-0.0291*	-0.0163	-0.0178	-0.0254
		(0.0169)	(0.0119)	(0.0175)	(0.0163)
Treated * vacant for 6-12 months			-0.0326*	-0.0258	-0.0332*
			(0.0187)	(0.0197)	(0.0188)
Treated * vacant for12-18 months				-0.0373*	-0.0395**
				(0.0203)	(0.0175)
Treated * vacant > 18 months					-0.0447**
					(0.0214)
Observations	16,213	18,803	21,751	13,518	15,923
#Foreclosed homes	278	310	364	209	242

Standard errors clustered by foreclosure property rings are reported in parentheses. Housing controls and year*neighborhood interactions are included.

Table 2.8 presents the estimation results of Equation 2.4 on subsamples of house sales taken place near foreclosed homes experiencing different lengths of vacancy. While almost all coefficients on vacancy are positive, most of them lose significance, possibly due to reduction in sample sizes. For areas surrounding houses vacant for more than 18 months, the coefficients on having been vacant for longer terms are larger in magnitude and statistically significant, which is consistent with results in Table 2.5. Moreover, foreclosure alone seems to have a negative impact, though none of the coefficients are statistically significant, possibly due to loss of sample size. Given the results on housing compositions, it is unlikely that the estimates on probability of sale and the price effect presented in Table 2.4 and 2.6 are the result of heterogeneity in treatment. Overall, these results are consistent with estimates in Table 2.5 and confirm the absence of compositional effect in the setting of this paper.

2.7 DISCUSSION

The estimation results show reduced sales volume at the upper end of housing market due to foreclosure, which is consistent with the observation of positively linked housing price and sales volume by researchers and housing specialists. While it is important to document such effects, the mechanisms behind the results are worth exploring. The quantity changes indicate that the second-hand housing supply may have shifted or is not perfectly inelastic in the short run.

As mentioned in previous sections, homeowners may be more eager to leave the neighborhood because of foreclosures. In this case, they will lower the reservation prices and supply will shift to the right. But my results show the opposite: some people tend to stay their houses when their neighbor's house is foreclosed. Therefore, it may be the case that the second-hand housing supply curve is upward-sloping: a decreased demand for houses near foreclosure will lead to less frequent transactions.

Researchers have conjured several hypotheses to explain the positive relationship between housing price and sales. Genesove and Mayer (2001) attribute this phenomenon to seller's loss aversion. Using property listing information for Boston condominiums, they show that owners subject to nominal losses set higher asking prices and their properties stay much longer on the market. They argue that according to prospect theory (Tversky and Kahneman, 1991), sellers are averse to realizing losses in that they set up a reference point equal to the last sale price. Any offer lower than that point is considered a loss and the sellers are unwilling to accept such an offer.

Though I do not observe listing price and time on the market, my results exhibit similar pattern: transactions for higher-end houses are much less frequent when a foreclosure is present in the neighborhood, and the effect disappears when the foreclosure is cured. It may be the case that owners of those houses set higher asking prices and had to wait for longer time for a suitable buyer, if their reference points are higher than the selling prices with foreclosures present. It is also possible that those owners set up a reference point that is different from the last sale price, because in Pittsburgh it takes 16.7 years on average for a homeowner to move to another house. Most likely the nominal sale price is much higher than the buying price. As a result, it is possible that a homeowner's reference point is the fair market value of her house not long before the foreclosure in the neighborhood.

Another explanation is that sellers cannot significantly lower the reservation price because minimum down payment is required for the purchase of a new home (Stein, 1995, Genesove and Mayer, 1997). However, this theory may not be true for Pittsburgh housing market, given that the median time between two sales for a house is 16.7 years. People who stayed in the house for more than 10 years are likely to have paid enough mortgages to gain the amount of cash needed for a new home's down payment after selling their houses. In addition, many of the homeowners are elderly who look for downsizing and will buy smaller houses with less required down payments.

The third theory on housing price and sale volume is that sellers are slow to adjust their expectations. This hypothesis is empirically equivalent to loss aversion story, in that sellers do not change their reference points quickly.

On a separate note, because foreclosure is only temporary, home sellers have more incentive to wait for the foreclosure to disappear before selling their houses.

However, if many foreclosures can be resolved within a couple years, and the neighborhood condition will improve then, why is there price reduction at the first place? Because the long-term attractiveness of the neighborhood is generally not affected by one or two foreclosures, a rational buyer may be willing to purchase a nearby house at pre-foreclosure price. Possible explanations include the uncertainty about the length of vacancy and that some buyers may choose to move again in a few years. Those buyers will place a lower reservation price for a house near foreclosure, thus reducing the average prices of non-foreclosed properties in the neighborhood.

2.8 CONCLUSION

This paper has shown that foreclosures affect quantities and prices of houses that are sold in the neighboring areas, especially for higher-end houses. Data from Pittsburgh during the years of large scale foreclosure crisis show that: 1. both foreclosure and vacancy reduce the neighboring houses' probabilities of sale, and the effect is as much as 23% for vacancy and 13% for foreclosure; 2. there is little impact on houses with lower quantity measure; 3. the impact of vacancy is more significant; 4. the effects disappear when foreclosed house is reoccupied. 5. consistent with literature, foreclosure depresses sale prices of the neighboring houses. These impacts are most likely caused by homeowners' loss aversion. At the same time, I conjecture that owners of Type H houses are less liquidity and credit constrained and are therefore can afford to delay the sale, while owners of Type L houses are forced to sell.

The paper's results have broad implications for the understanding of second-hand housing market and spatial externality. First, the second-hand housing supply may be more elastic than previously assumed. Second, hedonic analysis on housing market should be more cautious when using home sale prices to estimate the impact of local (dis)amenities, as the quantity of sale may be affected too.

Lastly, the conclusions of this paper indicate that the previous literature may have underestimated the external costs of foreclosure by focusing only on the price effect. As shown in this study, home sellers living close to foreclosures will suffer the losses from sale price reductions and any additional costs associated with delaying of the sales. Those who did not end up selling their houses may face the same extra costs of sale delays, because they may have wanted to sell but failed. Such costs include real estate taxes, utility bills, maintenance expenses, and all possible indirect costs (such as loss of investment opportunities). Although estimating the exact costs associated with sale delays are beyond the scope of this paper, such losses can be substantial. Another issue overlooked by the literature is that the effect of foreclosure can be different across various types of housing, as demonstrated in this study. Again, the reason the literature underestimated the true costs of foreclosure is that hedonic analysis may yield biased results because the supply curves have shifted too.

3.0 SHALE GAS DRILLING AND THE RURAL HOUSING MARKETS

3.1 INTRODUCTION

The recent Marcellus Shale drilling boom has brought heated debates over future regulations in several northeastern states. With the introduction of new drilling techniques, drilling and production of shale gas have had unimaginable economic impacts to the Marcellus region. At the same time, the rapid development of shale gas has created concerns on potential health and environmental risks. Despite the numerous media stories, there are very few studies on the impact of shale gas drilling. This paper intends to provide the first piece of evidence on the perceived environmental and health risks of shale gas drilling by estimating its impact on nearby property values.

At the core of shale gas development are two key technologies: horizontal drilling and hydraulic fracturing. Techniques used to hydraulically fracture horizontal wells often involve injecting large volumes of chemically charged water into wells. Such practice has attracted critical interest regarding risks posed to groundwater and surface water. Other potential risks and disamienties include air pollution, gas explosion, road damage and noise. As a result, the values of properties located close to gas wells are expected to drop because of decreases in the perceived neighborhood amenity levels.

Although the area has a tradition of natural gas drilling activities, the Marcellus Shale formation was not considered to be an important gas resource until a 2008 report[24] showed that it contains the most natural gas in all the shale formations in the US. From the econometric standpoint, the sudden discovery of Marcellus Shale's natural gas potential may serve as a great natural experiment for hedonic analysis, because the geological factors determining well locations are mostly independent of pre-existing residential settlement patterns.

The only study to date focusing on the issue of shale gas drilling is Osborn et al. (2011). They find methane contamination of drinking water associated with shale gas extraction. The methods employed in these studies, however, have not been the typical techniques employed by economists.

Though there has been no literature on the external effect of shale gas drilling, many studies have examined the effect of local disamenities on nearby property values. Among them, some have looked at the external impact of oil and gas facilities. A few studies on the impact of sour gas facilities found no impact on prices (Lore and Associates Ltd., 1988; Serecon, 1997). These studies grouped relatively small samples of properties according to their proximity to infrastructure and compared prices across these groupings, or used price regression that included few property variables. One study on the same topic documented significant negative impact on rural property values (Boxall et al., 2005). Other studies focusing on similar local disamenities sometimes find reasonably large effects on land prices. Examples include refineries (Flower and Ragas, 1994), changes in water quality (Leggett and Bockstael, 2000), and electricity transmission lines (Hamilton and Schwann, 1995).

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[24] Terry Englander and Gary Lash estimated that the Marcellus might contain more than 500 trillion cubic feet of natural gas.

This paper reports efforts to determine the impact of proximity to natural gas drilling sites on rural residential property values using data from three counties with most shale gas drilling activities in Pennsylvania. In theory, the impact comes from the environmental and health disamenities associated with hydraulic fracturing and horizontal drilling. The estimation results show that at this moment, shale gas drilling has no measurable impact on nearby property sales. Such lack of evidence may reflect two data limitations of this study.

The first issue is sample size. Because Marcellus gas drilling is a new phenomenon and sales are infrequent in the study area, the number of post-drilling transactions of properties located close to gas wells is rather limited, even though the study area includes more than half of the shale gas wells in Pennsylvania. The second issue is that property sales may involve mineral right transfers, which cannot be observed separately from surface right transfers. This leads to a downward bias in estimating the negative impact. A detailed discussion of those two issues can be found in data and empirical strategy sections.

I proceed as follows; Section 3.2 of the paper presents background information on the Marcellus gas boom. In Section 3.3, I describe the data used in this study. In Section 3.4, I describe the empirical methodology and present the estimation equations. Results are presented in Section 3.5. Discussions on estimation results are provided in Section 3.6. I conclude in Section 3.7.

3.2 BACKGROUND

3.2.1 Overview on Marcellus Shale Gas Drilling

Experts have known for years that natural gas deposits existed in deep shale formations, but until recently the vast quantities of natural gas in these formations were not thought to be recoverable. During the past decade, through the use of hydraulic fracturing technologies, combined with sophisticated horizontal drilling, shale gas has become an increasingly important source of natural gas in the United States.

In these shale formations, the challenge is recovering the gas from very tiny pore spaces in a low permeability rock unit. To stimulate the productivity of wells in organic-rich formations, companies drill horizontally through the rock unit and then use hydraulic fracturing to produce artificial permeability. Done together, horizontal drilling and hydraulic fracturing can make a productive well where a vertical well would have produced only a small amount of gas.

The Marcellus formation is a Devonian black shale lying about one mile beneath much of Ohio, West Virginia, Pennsylvania and New York. Because of the proximity to densely populated areas in the northeastern and the central part of the country, gas recovered from the Marcellus Shale has a distinctive transportation advantage. And the presence of an enormous volume of natural gas has a great economic significance. In additional to the positive impact on the stability of natural gas supply of the surrounding region, drilling activities have brought thousands of jobs, significant incomes for residents who lease their land to the drillers and revenues for the state and local governments.

However, there are considerable environmental safety and health concerns surrounding the current implementation of hydraulic fracturing practice. As mentioned in Section 3.1, hydraulic fracturing practice may be associated with contamination of groundwater and surface water, air pollution, gas explosion, road damage and noise.

Hydraulic fracturing involves injecting hundreds of millions of gallons of chemically charged water (frac fluid) at high pressure underground to fracture a formation and release trapped gas. Anywhere from 10 percent to 40 percent of the water sent down the well during the process returns to the surface, carrying drilling chemicals, very high levels of salts and, at times, naturally occurring radioactive material. The wastewater is usually stored at the drilling site before sending to the treatment plants. At this stage, leaking can be a serious issue. In fact, in the past three years, at least 16 wells in Pennsylvania reported spills, leaks or failures of pits where wastewater is stored, according to Pennsylvania Department of Environmental Protection records. Most of the wastewater is eventually discharged into the waterways because it is difficult to treat, and many treatment plants are not equipped to process such huge volume of wastewater. The gas industry estimates the amount of wastewater needing disposal in Pennsylvania will increase from 9 million gallons per day in 2009 to 20 million gallons per day by 2011. The wastewater contains many unknown toxics and possible radioactive materials that may pose serious threats to clean drinking water for Pennsylvania and other states over the Marcellus Shale formation.

In addition to water contamination, there is evidence that natural gas drilling causes air pollution. Toxic gases are released into the atmosphere by the process of drilling and hydraulic fracturing. In many cases, these are leading to increases in health-related problems for people living and working nearby[25]. Furthermore, occasional explosions at drilling sites have caused

[25] Though no empirical study has confirmed the health impact of drilling, there have been many media reports on increased cases of asthma and other breathing disorders from toxic fumes released in the drilling process.

injuries and death and the destruction of homes[26]. Hydraulic fracturing noise, drilling noise and road damages caused by heavy trucks carrying frac fluid all bring extra disamenities to the adjacent areas.

Finally, a majority of wells have at least one violation that directly endanger the environment and/or the safety of communities: the Pennsylvania Land Trust Association recently compiled data on citations given to Marcellus well drillers and found that the most-cited companies had an average of 0.76 violations per well. Because of all the potential environmental and health risks discussed above, New York State had a moratorium on hydraulic fracturing for one year[27].

3.2.2 Marcellus Gas Drilling in Pennsylvania

In Pennsylvania, the Marcellus Shale rests beneath the entire western half of the state and the northeastern corner. The Pennsylvania Department of Environmental Protection reports that the number of drilled wells in the Marcellus Shale has been increasing rapidly. In 2007 only 27 Marcellus Shale wells were drilled in the state, however, in 2010 the number of wells drilled had risen to 1386. Currently, natural gas companies have leased about 7 million acres of public and private property — about one-quarter of the state's entire land mass.

Figure 3.1 presents the distribution of Marcellus wells in Pennsylvania. It shows that counties with most number of wells are Bradford County, Tioga County and Washington County, the three counties included in this study. The map also shows that areas with most frequent Marcellus activities are located in northeastern Pennsylvania.

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[26] For example, two Eastern Pennsylvania gas explosions in early 2011 resulted in a total of six deaths and several injuries

[27] The moratorium is lifted on July 1, 2011.

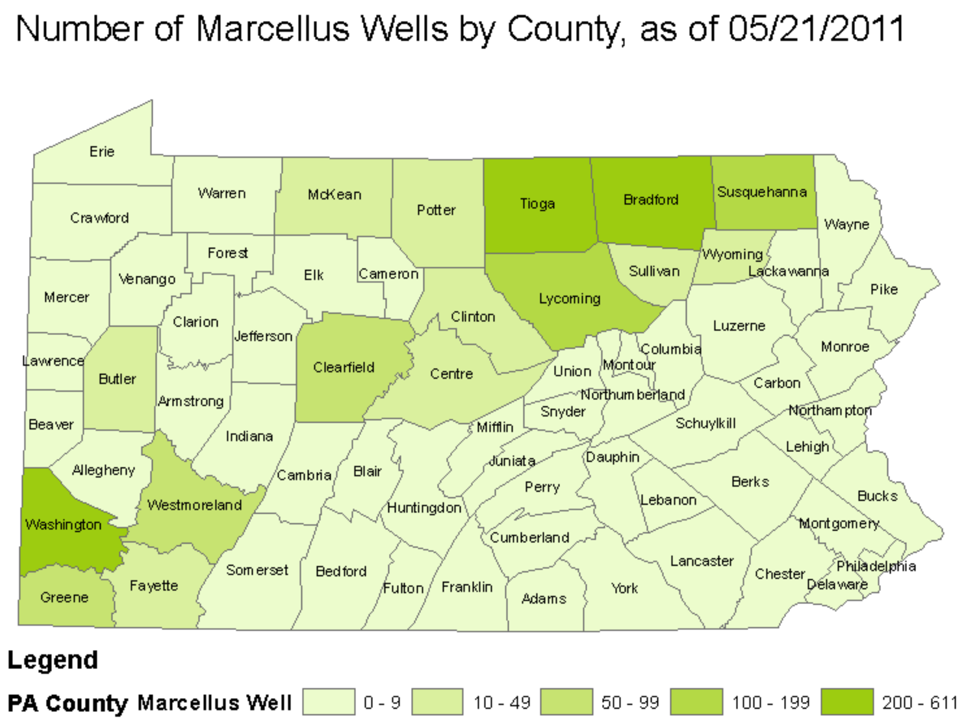

Figure 3.1 - Marcellus Shale Gas Wells in Pennsylvania, by County

3.2.3 Locations of Gas Wells and Leasing from Private Land Owners

Although gas is ubiquitous in the Marcellus region, the highest production potential is where the net thickness of shale is the greatest and where the shale can be drilled at minimum depths. These two factors explain why the northeastern Pennsylvania has seen most activities in gas drilling.

Each Marcellus Shale drill site consists of a 2 to 10 acre drilling pad that typically has 1 to 6 gas wells on it, drilled vertically and then turned horizontally. A single drill site can recover shale gas from underneath an area of 640 acres.

Because mineral rights can be privately owned and separated from surface rights in the United States, many landowners who own the mineral rights to their properties are being approached with offers to lease their rights. The gas companies will need to sign oil and gas leases with every mineral right owner to form the 640-acre drilling unit. The owners are typically compensated with a signing bonus priced by acreage and a minimum 12.5% royalty for all the gas drilled from their lands. However, if the landowners only own the surface rights, they receive no benefit from drilling and they have little control over where and when the gas companies choose to drill[28]. After successfully collecting enough gas leases to drill a unit, the gas companies apply for a drill permit and start building the drilling pad once the permit is granted. It may take several months to complete drilling the wells and have the frac fluid ready to perform hydraulic fracturing. The gas companies are also building thousands of miles of natural gas gathering systems to transport natural gas to major markets, because the total natural gas pipeline capacity currently available is a small fraction of what will be needed.

3.3 DATA

3.3.1 Data Description and Summary Statistics

The data set stems from two sources. Marcellus Shale drilling permit data are obtained from Pennsylvania's Department of Environmental Protection. Combining various data sets available on their website, I construct a file with information on every Marcellus Shale permit in the state.

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[28] The surface owners will be notified when the gas company obtains a permit and plans to start drilling. They can negotiate compensations for damages occurred to their properties.

These records include the approval date and geo-coded location of those permits, the operator name, and an indicator for horizontal drilling technique. The data set also links each permit to the well drilled subsequently (if any), with information on the start date of drilling, natural gas production in 2009 and 2010, type and amount of waste water produced, and date and description of safety violations for each well. Since horizontal drilling technique has greater environmental and health impacts and is widely adopted by the industry, I remove all non-horizontal permits from the sample. I also exclude a small number of permits approved prior to 2007. In addition, I assign a uniform pair of latitude and longitude to all wells located on the same pad. Between 2007 and May 2011, there were 5,392 unique drilling permits in Pennsylvania, while more than 50% of those (2,758) were located in Bradford County, Tioga County or Washington County.

Second, I also obtain the exact locations (in shapefile format) of all properties from the three counties, with building characteristics attached. The data also includes the most recent transaction date and its sale price for each property. All nonresidential properties are removed from the sample. Also, all transactions between family members are excluded. The property records are merged with drilling permit data by geographic locations using ArcMap. Because all of the data are geo-coded, I am able to cross-check the two datasets and remove any property with Marcellus Shale gas leases. In this sense, the study aims to measure only the external effects associated with shale gas drilling.

Descriptive statistics of the gas permits and wells are reported in Table 3.1. Average characteristics for all counties are reported in column 1 while statistics for each county are reported separately. The first row shows that the average depth of wells drilled is 6,842 feet, which is more than 1 mile deep. For the two counties (Bradford and Tioga) in northeastern part of the state, the wells are noticeably shallower than those in Washington County, which is located in southwestern Pennsylvania. As mentioned in Section 3.2, this geological condition leads to more permits in Bradford County and Tioga County reported in the third row. In addition, Table 3.1 shows that the shallower wells in the two counties have higher production than the deeper wells in Washington. As for violation record, on average, 82.57% of all wells have violated health and safety regulations. Finally, gas drilling in the Marcellus region is still at its early stage, as the median days elapsed since the approval of a gas permit is about one year, and it takes on average 72 days to start the drilling process. Overall, Table 3.1 shows county variations in many key features of gas drilling. However, most of such differences are caused by factors unrelated to the local housing markets.

Table 3.2 provides summary statistics of parcels in the three counties. Overall, Washington County is less rural than the other two counties, with smaller average lot size (3.471 acres) and more frequent housing transactions (thus higher last sale prices). Other housing characteristics are more similar. In general, houses are old and the time between two transactions for a house is quite long. The average building age is 64.28 years and days since last sale is 4,280, which is about 12 years. The fact that housing transactions are rather infrequent (and also that gas drilling started in the recent 4, 5 years) reduces the concern of missing sale information, as only the most recent sale record is included in the data[29].

[29] I randomly selected 20 properties in Tioga County and checked their sales records online from the county assessment database, which contains the 3 most recent sale records, and found no missing sale after 2007.

Table 3.1 - Characteristics of Marcellus Shale Gas Permit and Well by County

	All counties	Bradford	Tioga	Washington
Marcellus Shale permit				
Well depth (feet)	6,842	6,566	6,577	8,047
	(1,708)	(1,553)	(1,613)	(1,757)
Median days since approval	362	357	340	417
Sample size	2,758	1,452	746	560
Marcellus Shale gas well				
Median days between permit approval and start of drilling	72	70	66	85
% producing as of Dec 2010	13.34	10.60	15.42	17.68
	(34.01)	(30.80)	(36.13)	(38.18)
Gas quantity Jul-Dec 2010 (mcf*)	350,276	401,338	346,887	274,783
	(406,471)	(300,601)	(621,078)	(138,092)
Waste water Jul-Dec10 (mcf)	3,695	2,926	5,232	3,864
	(4,308)	(3,430)	(4,783)	(4,992)
#Health & safety violations per well (All producing wells)	0.8257	1.096	0.6769	0.5632
	(1.385)	(1.484)	(1.065)	(1.545)
Sample size	1,266	605	321	340

Standard errors are reported in parentheses. *mcf = 1000 cubic feet

Table 3.2 - Characteristics of Properties by County

Housing Characteristics	All counties	Bradford	Tioga	Washington
Lot area (in acres)	8.004	17.07	16.97	3.471
	(28.70)	(41.73)	(44.35)	(15.83)
Building age	64.28	65.82	62.10	64.34
	(64.79)	(47.91)	(41.80)	(72.63)
Bedroom	2.966	3.138	2.818	2.951
	(0.958)	(1.080)	(1.024)	(0.898)
Bathroom	1.326	1.394	1.231	1.328
	(0.603)	(0.623)	(0.621)	(0.591)
Average story height	1.482	1.483	1.283	1.526
	(0.437)	(0.458)	(0.249)	(0.451)
Square footage	1,671	1,699	NA	1,663
	(744.3)	(703.5)		(755.1)
Assessed land value	13,822	NA	23,933	11,558
	(23,891)		(23,860)	(23,305)
Assessed building value	53,414	NA	62,014	51,489
	(49,843)		(43,991)	(50,862)
Last sales price (valid sale)	102,780	72,476	71,135	118,674
	(136,287)	(97,138)	(96,864)	(150,153)
Days since last sale	4,280	5,554	4,365	3,829
(valid sale)	(3,637)	(5,054)	(3,404)	(2,954)
Sample size	110,144	20,427	16,411	73,306

Standard errors are reported in parentheses

3.3.2 Gas Drilling and Mineral Right Transfer

As mentioned in Section 3.1, it is very difficult to obtain information on mineral right ownership. In fact, even the owners themselves have to resort to title companies sometimes to determine the ownership of mineral rights. As a result, when a sale is observed, it is unclear whether it is only a surface right transfer or a transfer including mineral rights too. Even so, with information on well location and owner name, we are able to identify mineral right ownership in two cases and exclude such properties from the sample.

First, properties with gas permits are excluded. The mineral rights of those properties are leased by the gas drillers. The second column in Table 3.3 presents housing characteristics of residential properties where gas permits are located. In all there are 363 such properties. It is quite obvious that those properties are much different from their neighbors. They are on average 18 times the size of a property without gas permits. The properties with gas permits are in general older and have more rooms and living area. As a result, the assessed land values are much higher. Finally, transactions of the gas permit properties are even more infrequent.

Second, since the transaction records include names of current owners, I am able to identify all sales with buyers from the gas drilling industry. I exclude such sales from the sample because those transactions often involve mineral right transfers that may obscure the effect of gas drilling on surface land values. Housing characteristics of such properties are reported in the last column of Table 3.3. It is evident that those properties are sold recently at much higher prices than their assessed value: the average sale price is almost 1.6 million dollars, and most of them are sold in 2010 or 2011. Other characteristics indicate that they are more similar to properties with existing gas permits than to those without.

Table 3.3 - Characteristics of Properties Associated with Gas Drilling

Housing Characteristics	All Data	With Gas Permits	Sold to Gas Drillers
Lot area (in acres)	8.004	144.21	95.67
	(28.70)	(101.58)	(93.69)
Building age	64.28	107.46	65.00
	(64.79)	(199.74)	(46.10)
Bedroom	2.966	3.592	3.010
	(0.958)	(1.613)	(0.707)
Bathroom	1.326	1.449	1.264
	(0.603)	(0.765)	(0.447)
Average story height	1.482	2.343	1.642
	(0.437)	(0.853)	(0.894)
Square footage	1,671	2,229	1,305
	(744.3)	(1,054)	(565.5)
Assessed land value	13,822	89,849	73,387
	(23,891)	(59,281)	(64,450)
Assessed building value	53,414	66,292	84,620
	(49,843)	(47,485)	(99,685)
Last sales price (valid sale)	102,780	59,326	1,599,750
	(136,287)	(126,588)	(1,825,948)
Days since last sale	4,280	6,408	248
(valid sale)	(3,637)	(6,246)	(141.71)
Sample size	110,144	363	15

Standard errors are reported in parentheses

From Table 3.3, it is obvious that including the properties sold to gas drillers will significantly bias the estimation results upward, because most of such sales take place after drillers obtain the permits. A likely scenario is that drillers buy those lands with mineral rights to reserve for future drilling.

In addition, as discussed in Section 3.2, one drilling unit can cover about 640 acres (1,609 by 1,609 feet), which means that the minimum distance between two drill pads is roughly 3,218 feet (as a result there should be no clustering in treatment areas as long as they are within 1500 feet from the pad). It also implies that any post-drilling property sale taken place within the boundary of a unit has to be a surface-right-only transfer (if they are not sold to gas drillers, as discussed above), because all the mineral rights have to be leased before drilling starts.

3.4 EMPIRICAL STRATEGY AND ESTIMATION FRAMEWORK

As discussed in previous sections, Marcellus gas drilling carries environmental and health risks and will in theory lower the demand for nearby lands. Because of the mechanisms, hedonic analysis can be used to examine the negative effect of drilling on the valuation of nearby properties through reduced sale prices. The following paragraphs provide discussions on how the analysis will be shaped by the specific setting of the problem and the availability of data.

From many perspectives, the locations of gas wells are independent of the choice of housing. First of all, gas companies choose to lease the lands where they can achieve the highest production potentials, and this is mainly determined by the thickness of the Marcellus formation and how deep they are underneath. These geological conditions are most likely unrelated to where people choose to live. Also, for most households, Marcellus gas drilling took place after they settled in the area. In fact, the gas companies showed little interest in drilling until researchers published their new estimates on Marcellus gas potentials in 2008. It was a surprise for both landowners and gas companies. In addition, surface owners and neighbors of landowners who signed the oil and gas leases have no power over where the wells are drilled, though it is true that gas companies will drill their first wells in places where they could gather enough leases to form a unit, and the mineral right owners who signed the leases quickly may be a selected group. Therefore, Marcellus gas drilling serves as a good natural experiment.

On the other hand, it is obvious that gas companies will choose to drill first in areas close to existing pipelines and major roads to reduce transportation costs. Also, Table 3.3 indicates that wells tend to locate in the more rural areas, maybe because more acreage means gas companies could negotiate with fewer people to acquire enough land[30]. But selection on those factors may diminish as more wells are drilled – the gas companies have started building new pipelines and are gradually moving to more urbanized areas as most rural lands are leased.

For all the reasons stated above, Marcellus gas drilling is largely exogenous to housing choices. However, selection on observables such as lot size does exist. As a result, this study will apply both cross-sectional and difference-in-differences design to analyze the effect on property values.

There are two issues related to sale records used in this study. First, because only the most recent sale information is available, it is impossible to adopt repeated sales approach, which is an attractive design as it can control for all the property-specific time-invariant unobserved factors. Second, as discussed in Section 3.1, there are sample size issues in this study. Because

[30] There are also anecdotes that gas companies target at out-of-state mineral right owners because they do not live the area and are possibly not familiar with the bargaining process when leasing.

transactions are infrequent and Marcellus drilling is still a relatively new phenomenon, the number of post-drilling sales is limited, especially in the rural areas adjacent to gas wells.

Table 3.4 - Characteristics of Properties around Gas Permit Locations

	500 feet	1000 feet	1500 feet	2000 feet	2500 feet	3000 feet	6000 feet
Housing Characteristics							
Lot area (in acres)	53.294	41.302	34.557	30.316	27.040	25.637	15.420
	(71.758)	(64.272)	(59.826)	(55.835)	(52.347)	(50.836)	(39.166)
Building age	66.506	66.075	64.612	62.960	61.529	60.981	61.465
	(74.538)	(80.981)	(79.478)	(73.552)	(72.419)	(69.878)	(66.938)
Bedroom	3.238	3.156	3.112	3.070	3.059	3.052	3.002
	(1.236)	(1.160)	(1.119)	(1.080)	(1.074)	(1.064)	(1.012)
Bathroom	1.383	1.356	1.349	1.341	1.349	1.349	1.336
	(0.6942)	(0.6544)	(0.633)	(0.6186)	(0.6252)	(0.6248)	(0.6101)
Average story	1.446	1.421	1.406	1.399	1.397	1.397	1.434
height	(0.4125)	(0.4117)	(0.4108)	(0.4179)	(0.4151)	(0.4150)	(0.4285)
Last sales price	112,636	101,818	92,632	90,618	91,388	92,475	95,681
(valid sale)	(218,919)	(172,734)	(139,358)	(125,803)	(126,155)	(123,178)	(128,113)
Days since last sale	5,197	5,024	4,986	4,966	4,913	4,849	4,638
	(3,932)	(3,706)	(3,704)	(3,667)	(3,652)	(3,625)	(3,595)
Sample size	1,247	2,778	4,779	7,182	9,913	11,095	33,683

Standard errors are reported in parentheses.

Table 3.4 compare housing characteristics of properties within various distances from the gas permit locations (latitude and longitude). There are three noticeable features. First, properties closer to gas permits has more acreage, reflecting the tendency that gas companies choose to lease in the more rural areas to reduce bargaining costs. Second, because properties closer to gas locations have more lands, they generally sell for higher prices and transactions are less frequent. Third, even though those properties have bigger lots, the buildings on these lands are not much different from buildings on smaller lots in terms of several key housing characteristics, such as number of bedroom and number of bathroom. Overall, though selection on lot size is obvious, other measures relating to housing conditions are more homogenous among properties in various distances from gas permit locations. Due to the possible non-linear effect of lot size on property values in this setting, I include a polynomial[31] of lot size as a set of controls in the estimation equations.

Since there is no consensus on how far the effect of hydraulic fracturing would reach, I experiment with various sizes of impacted areas shown in Table 3.4. Also, because Marcellus gas drilling boom started around 2007, the samples are restricted to arm's length sales[32] in and after 2007. I further define the treatment as the drilling of a well, instead of the permit granting. The argument is that the activity of drilling is visible to nearby residents but the permit approval is not necessarily so[33]. For the same reason, I define the start of treatment period as the date on which the first well on a given pad is drilled.

The cross-sectional specification takes the following form:

$$\log(P_{ijt}) = \alpha + \pi_1 Post\_Drill_i + \beta_0 X_i + \beta_1 \cdot (Mun_j * Q_t) + \varepsilon_{ijt} \quad (3.1)$$

The sample includes every arm's length transaction in and after 2007 of residential property located within certain distance from the drill pad. $\log(P_{ijt})$ is the logarithm of sale price of house i in neighborhood j in quarter t. $Post\_Drill_i$ equals 1 if house i is sold after the date on which drilling of the first well on a given pad starts. X_i is the observable housing characteristics for house i. Mun_j is a municipality fixed effect and Q_t is the year-quarter fixed effect. The parameter of interest is π_1.

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[31] A square term and a cubic term of lot size are included in some of the specifications

[32] Defined as transactions with sale price greater than $5,000

[33] As discussed in Section 3.2, when a permit is approved, the drillers only need to notify surface owners whose lands will be drilled underneath.

Equation 3.2 presents the difference-in-differences equation with control areas located outside the treatment areas:

$$\text{Log}(P_{ijt}) = \alpha + \pi_1 Treated_i + \pi_2 Post\_Drill_{it} + \pi_3 \cdot (Treated_i * Post\_Drill_{it})$$
$$+\beta_0 X_i + \beta_1 \cdot (Mun_j * Q_t) + \varepsilon_{it} \quad (3.2)$$

The sample includes every arm's length transaction in and after 2007 of residential property located in the treatment or control areas. $\log(P_{ijt})$ is the logarithm of sale price of house i in neighborhood j in quarter t. $Treated_i$ equals 1 if house i is located inside the treatment ring. Similar to Equation 3.1, $Post\_Drill_i$ equals 1 if house i is sold after the date on which drilling of the first well on a given pad starts. X_i is the observable housing characteristics for house i. Mun_j is a municipality fixed effect and Q_t is the year-quarter fixed effect. The parameter of interest is π_3, which measures the impact of gas drilling on sale price of houses in the treatment areas sold after the start of drilling.

In addition to the price effect, gas drilling may impact probability of sale. Because transaction is rather infrequent, the average probability of sale in a given quarter is close to 0. Therefore, a probit model with difference-in-differences indicators similar to Equation 3.2 is also estimated:

$$\text{Prob}(Sale_{ijt} = 1 \mid \boldsymbol{x}) = \emptyset(\alpha + \pi_1 Treated_i + \pi_2 Post\_Drill_{it}$$
$$+\pi_3 \cdot (Treated_i * Post\_Drill_{it}) + \beta_0 X_i + \beta_1 \cdot (Mun_j * Q_t)) \quad (3.3)$$

Note that the sample in Equation 3.3 includes all properties located in the treatment or control areas. $Sale_{ijt}$ equals 1 if there is an arm's length transaction in or after 2007 on property i in municipality j in quarter t.

3.5 RESULTS

Table 3.5 presents the coefficients from the estimation for Equation 3.1. Parameter of interest is reported in the first row, while coefficients on selected housing characteristics are also presented. Each column reports the results of cross-sectional regression on a different sample. For example, in column (1), the sample includes all arms' length sales within 1000 feet of a drill pad since 2007.

The results in the first row of Table 3.5 indicate that drilling does have a negative impact on sale prices of nearby properties, and the effect is gradually decreasing as distance from the drill pad increases. At its peak, drilling depresses sale prices of properties within 1000 feet of a drill pad by 7.8%. At 2500 feet, the impact reduces to 0.48%. However, none of the coefficients are statistically significant, possibly due to rather small sample sizes. Even so, the coefficient at 1500 feet in column (2) has a p-value of 0.163, which is close to being 10% significant. At such distance, the presence of gas wells reduce nearby property sale prices by about 5%.

Table 3.6 presents the difference-in-differences results on sale price. Results on different treatment and control combinations are reported in the 3 columns. For example, the treatment area in column (1) is within 1000 feet of the drill pad while the control area is between 1000 and 3000 feet away; in column (3), the treatment is within 1 mile of the pad and the control is between 1 and 3 miles away.

Across all samples, the indicator of being treated is insignificant, which means the treatment and control areas are relatively homogenous. Similar to the cross-sectional results, the coefficients on difference-in-difference estimators reported in the third row are negative across all treatment and control combinations, though none of them is statistically significant. Note that the magnitudes of the estimator of interest are comparable with the cross-sectional results, which is at least some evidence on the negative impact of gas drilling.

Table 3.7 presents the marginal effects in the probit model (Equation 3.3) on probability of sale, while including the nonlinear terms of lot size. Almost all the marginal effects are close to 0. In other words, gas drilling has little effect on the sale probability of nearby properties.

Taken together, results from Table 3.5, Table 3.6 and Table 3.7 do suggest there might be negative impact of gas drilling on surrounding properties, though none of the results is statistically significant.

Table 3.5 - Cross-Sectional Regression Results on Log Sale Price

Log(Sale Price)	(1) 1000 feet	(2) 1500 feet	(3) 2000 feet	(4) 2500 feet
Post drilling	-0.0708	-0.0481	-0.0251	-0.00484
	(0.0744)	(0.0341)	(0.0319)	(0.0234)
Lot area (in acres)	0.0356**	0.0291***	0.0306***	0.0281***
	(0.0156)	(0.00595)	(0.00470)	(0.00375)
Lot area^2	-0.000303	-0.000205***	-0.000209***	-0.000192***
	(0.000230)	(6.92e-05)	(5.50e-05)	(4.34e-05)
Lot area^3	7.04e-07	3.84e-07***	3.79e-07***	3.65e-07***
	(7.49e-07)	(1.70e-07)	(1.31e-07)	(1.01e-07)
Building age	-0.00149	-0.000564*	-0.000336	-0.000185
	(0.00337)	(0.000311)	(0.000306)	(0.000283)
Bedroom	-0.148	-0.111	-0.0885	-0.0524
	(0.126)	(0.0751)	(0.0536)	(0.0494)
Bathroom	0.557**	0.211*	0.241*	0.231***
	(0.224)	(0.125)	(0.103)	(0.0725)
#Post drilling sales	8	15	23	34
Observations	165	328	530	803
Sales included	>=2007	>=2007	>=2007	>=2007

Standard errors clustered at municipality level are reported in parentheses.

Table 3.6 - Difference-in-Differences Results on Log Sale Price

Log(Sale Price)	(1) 1000 vs. 3000 feet	(2) 2000 vs. 6000 feet	(3) 1 vs. 3 miles
Treated	-0.0558	-0.0501	0.0106
	(0.118)	(0.0475)	(0.0168)
Post drilling	-0.0301	-0.121**	-0.0224
	(0.104)	(0.0507)	(0.0260)
Treated*post drilling	-0.0415	-0.0181	-0.0209
	(0.253)	(0.143)	(0.0556)
Lot Area	0.0259***	0.0314***	0.0292***
	(0.00336)	(0.00276)	(0.00200)
Lot area^2	-0.000150***	-0.000224***	-0.000206***
	(3.57e-05)	(3.19e-05)	(2.24e-05)
Lot area^3	2.39e-07**	4.13e-07***	3.76e-07***
	(9.42e-08)	(7.36e-08)	(4.58e-08)
Building age	-0.000377	-2.06e-05	0.000979*
	(0.000338)	(0.000258)	(0.000499)
Bedroom	-0.0425	-0.00493	0.00243
	(0.0515)	(0.0389)	(0.0227)
Bathroom	0.200***	0.221***	0.219***
	(0.0698)	(0.0352)	(0.0302)
Observations	1,064	4,830	40,744
Sales included	>=2007	>=2007	>=2007

Standard errors clustered at municipality level are reported in parentheses.

Table 3.7 - Probit Regression Results on Probability of Sale

Marginal Effect on Probability of Sale	(1) 1000 vs. 3000 feet	(2) 2000 vs. 6000 feet	(3) 1 vs. 3 miles
Treated	-0.00061	-0.00015	-0.00012
	(0.00316)	(0.0002)	(0.00015)
Post Drilling	-0.00185	-0.00069	-0.00084
	(0.00174)	(0.0004)	(0.00076)
Treated*Post Drilling	-0.00458	0.00078	-0.00243
	(0.00405)	(0.0029)	(0.00184)
Observations	18,862	56,545	186,847

Standard errors are reported in parentheses.

3.6 DISCUSSION

Although the negative relationship between gas drilling and property values seems clear in theory, the estimation results show only weak evidence. There are many possible reasons.

First, because Marcellus gas drilling has only been active on a large scale for about one or two years, there may not be enough observations on either gas well or property transaction, as illustrated in this study. The fact that most wells are in rural areas adds to the issue of limited sample size, since the number of rural properties sold in recent years are much lower than the number of urban housing transactions. For example, there are only 34 post-drilling sales within 2500 feet of a drill pad, out of 803 total sales in the same area since 2007, as shown in Table 3.4. In addition, even if the sample sizes are large enough, it may be too soon to have any significant impact on the housing markets. Because there is no literature on shale gas drilling and housing market, there is no benchmark as of how long it takes to have an impact. In the ideal case, we may be able to see some effect in near future, say five years.

Second, as discussed in Section 3.3, some of the sales may include mineral right transfers, and it will obscure the true effect on surface land values. One possible solution is to obtain the deed records from those counties, which include all gas leases signed by mineral right owners. In that case, we can at least exclude all property sales with those people as sellers, because they are likely selling mineral rights too. At the same time, if the same properties are sold by people with other names, we can be sure that those transactions are surface right only transfers, because we have identified separate mineral right owners.

Table 3.8 - Results Including Sales to Drillers and Those with Gas Wells

Log(Sale Price)	A. Cross-Sectional Results			
	(1) 1000 feet	(2) 1500 feet	(3) 2000 feet	(4) 2500 feet
Post Drilling	0.0108	-0.00998	-9.04e-05	0.0120
	(0.0511)	(0.0260)	(0.0277)	(0.0234)
Observations	168	339	539	815
Sales included	>=2007	>=2007	>=2007	>=2007

	B. Difference-in-Differences Results		
	(1) 1000 vs. 3000 feet	(2) 2000 vs. 6000 feet	(3) 1 vs. 3 miles
Treated	-0.0599	-0.0472	0.0118
	(0.118)	(0.0467)	(0.0169)
Post Drilling	-0.0474	-0.123*	-0.0229
	(0.102)	(0.0501)	(0.0259)
Treated*Post Drilling	0.226	0.0451	-0.0120
	(0.188)	(0.145)	(0.0552)
Observations	1,076	4,844	40,788
Sales included	>=2007	>=2007	>=2007

Standard errors clustered at municipality level are reported in parentheses.

In Section 3.3, two possible scenarios are discussed where the mineral rights are identifiable. To see how including mineral right transfers bias the results downward, I estimate Equation 3.1 and 3.2 with the original samples plus sales to drillers and those with gas wells. Coefficients of interest are reported in row (1) in Panel A and row (3) in Panel B. It is evident that including the possible mineral right sales will reduce the negative impact on property sales. In some settings, the impact turns from negative to positive. Those results indicate that the estimates in this study are lower bound of the actual effect, and if all mineral right transfers can be removed from the sample, the negative effect may be larger and statistically significant.

Lastly, it will be helpful to obtain more sale records on one property. At least it makes a repeat-sale approach possible.

3.7 CONCLUSION

The results of this analysis suggest that the presence of horizontal drilling and hydraulic fracturing have little measurable impacts on the values of neighboring rural residential properties. Given that Marcellus gas drilling is still a new phenomenon, we have confidence that in the longer-term there will be more evidence on such effects.

To our knowledge, this is the first academic study of the implication of the new gas drilling technologies upon property values. And naturally the results should be considered with some caution (and awaits further evidence). Still, the study may be of interest to residents, gas companies and regulators.

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