What Can We Learn about Shale Gas Development from Land Values? Opportunities, Challenges, and Evidence from Texas and Pennsylvania

Jeremy G. Weber and Claudia Hitaj

We study farm real estate values in the Barnett shale (Texas) and the northeastern part of the Marcellus shale (Pennsylvania and New York). We find that shale gas development caused appreciation in real estate values in both areas but the effect was much larger for the Marcellus, suggesting broader ownership of oil and gas rights by surface owners. In both regions, the greatest appreciation occurred when land was leased for drilling, not when drilling and production boomed. We find evidence that effects vary by farm type, which may reflect correlation between farm type and ownership of oil and gas rights.

***Key Words*: land values, oil and gas rights, shale**

Success in extracting oil and natural gas from shale formations through horizontal drilling and hydraulic fracturing has led to a wave of drilling in shale-rich states such as Texas and Pennsylvania. The consequences of drilling in shale formations are diverse, affecting jobs, property values, and health (Weber 2012, 2014, Hill 2013, Olmstead et al. 2013, Brown 2014, Gopalakrishnan and Klaiber 2014).

Several recent studies looked at the effect of shale gas development on residential housing values to estimate the cost of real and perceived environmental and human health risks (Muehlenbachs, Spiller, and Timmins 2013, Gopalakrishnan and Klaiber 2014). For residential properties, the real estate value primarily reflects the value of buildings but for farm properties, it mostly reflects the value of undeveloped land. The link between shale development (or the potential for it) and land values generally has not been explored. Just two studies have addressed it and then only tangentially. Weber, Brown, and Pender (2013) found a positive correlation between farm real estate values and lease and royalty payments from oil, gas, and wind activities

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while Borchers, Ifft, and Kuethe (2014) found a weak negative correlation between county-level oil production and farm-level pasture values.

We use self-reported values from five U.S. Department of Agriculture (USDA) Census of Agriculture (1992, 1997, 2002, 2007, and 2012) to estimate how natural gas development affected farm real estate values for two regions that had extensive shale gas development as of 2012: the Barnett shale in Texas and the northeastern part of the Marcellus shale in Pennsylvania.

We first use the estimates as an indication of the ubiquity of "split estates"—properties for which the oil and gas rights have been severed and are not owned by the land owner. Split estates matter because the person bearing the disamenities from drilling is not the one who negotiates the terms of the drilling lease. As extracting natural gas from shale formations becomes increasingly profitable, oil and gas rights will increase in value and we thus expect that property values will appreciate more in areas in which there are relatively few split estates. And when split estates are common, local residents capture little of the royalties generated by extraction of the minerals.

We then use our long panel data to see how farm real estate values changed during leasing and development periods. As natural gas is withdrawn, subsurface rights grant access to a continually shrinking resource, causing properties with subsurface rights to also decline in value. A decline to less than the pre-development level would indicate a long-term cost of wells and related infrastructure built on or near the property if farmers do not invest their royalty incomes in improving their land. We estimate a medium- to long-term net effect on property values. Our data set does not permit us to separate competing positive and negative effects of drilling, and the farms are observed at five-year intervals so our estimates primarily reflect effects that persisted for several years. Consequently, the estimates are not comparable to those of studies that estimate short-term changes in real estate values (from shortly before to shortly after drilling of a well).

Lastly, we leverage the data to see how drilling affects the suitability of land for various uses. Residential values, which were considered in earlier research (e.g., Gopalakrishnan and Klaiber 2014, Muehlenbachs, Spiller, and Timmins 2013), reveal how drilling affects a property's attractiveness for use as a home. Larger parcels reveal how drilling affects suitability for the nonresidential purposes that give them value. An example is a 100-acre property that includes a house and a barn and is used both as a residence and for crops, livestock, and recreation. Because of its potential impact on local water quality, drilling may reduce the value of land dedicated to livestock but not the value of land planted to crops. Similarly, land used primarily for recreation may be relatively sensitive to the environmental, health, and visual consequences of drilling.

Limitations of the data preclude us from drawing concrete conclusions but we can glean significant insights regarding the effect of gas extraction on farm property values and can fuel further research in this area.

We find that shale gas development has a small positive effect on property values in both formations and that the effect is much larger in the Marcellus formation, which suggests that split estates are far less common there. This conclusion is consistent with Fitzgerald (2014), which found that local ownership of mineral rights was more than two times greater in Pennsylvania than in Texas.

For both regions, the difference in appreciation between shale and nonshale areas was greatest when land was leased for drilling, and shale properties appreciated faster. These higher values persisted throughout the drilling period, indicating that extraction had a net positive effect through 2012, the last year of our analysis. This suggests that any long-term disamenities associated with drilling were not yet large enough to outweigh the positive effects of gas development.

Regarding the effects of drilling on properties used for different purposes, we find evidence that shale development in both regions increased real estate values more for residence farms—farms with limited agricultural sales owned by someone whose primary occupation is not farming (not to be confused with "small farms")—than for nonresidence farms. Weaker evidence suggests that the value of livestock farms appreciated less and in some cases declined in value. Both findings potentially reflect correlation between farm type and ownership of oil and gas rights, underscoring the value of information on who owns the oil and gas rights in studies of the effect of shale energy development on property values.

Shale Gas Development and Land Values: Perils Facing the Researcher

Limited Data

Data on property sales that include detailed information on the properties' characteristics, including whether subsurface rights were conveyed in the sales, would provide a firm foundation on which to quantify how shale gas development affects the value of oil and gas rights and surface rights. Standard sales data, however, typically do not include such information and cover only properties that have been sold. Thus, a researcher who wants to control for time-invariant unobservable characteristics must further limit the study to properties sold twice during the study period. This is less of a challenge when considering residential properties since the lots usually are small and sales are numerous. The same cannot be said of properties that consist primarily of land, which are fewer in number and are sold infrequently. Many are sold only once in a lifetime. This problem can be exacerbated if oil and gas development slows sales of such properties.

A researcher using data from a survey asking property owners for market values may avoid the pitfalls of small samples but stumble into other problems. Surveys such as the USDA Census of Agriculture used in this study provide panel data on a large number of proprieties in a given area. However, unless a survey is constructed with subsurface issues in mind (the Census of Agriculture was not), it will not collect information on ownership of oil and gas rights. Furthermore, even when survey respondents own those rights, they may not think to report them in the market value of their land unless explicitly asked to do so.

Heterogeneous Effects

Other characteristics of properties may interact with shale development in determining property values, thus requiring researchers to obtain data that will allow them to segregate the effects. Pope and Goodwin (1984) argued that rural land has value not only because of its agricultural productivity but also because it can be enjoyed for its own sake—what the authors labeled as a consumptive component of value. One might expect the value of land for which demand comes primarily from people who want to escape city life and enjoy the outdoors to be more sensitive to the disamenities of drilling than other types of rural property. If, instead, the land is used for growing crops, drilling should matter less as long as it does not affect crop yields. One might also expect heterogeneous effects for different types of agricultural land. Beef cattle and dairy cows require a high-quality source of drinking water. If drilling through an aquifer muddies a spring used to water cows, it will likely reduce the value of the property for use as a livestock farm. For crop farms, muddy spring water may not affect productivity, especially if irrigation is not used.

A Moving Target

The effect of gas extraction on a property's value may change over time, making interpretation of the estimates difficult. Suppose that land directly over a formation appreciates more than land just outside the formation during the initial leasing period and that the price differential declines as the gas development process matures. The natural resource economist might say that the change in value reflects the decline in the resource stock while the environmental economist might point to it as evidence of environmental disamenities. Both could be true.

We expect differences in land value between shale and nonshale areas to vary over time for at least three reasons. First, to the extent that subsurface rights are incorporated into land values, changes in the quantity of the oil or gas in the ground and/or in its price will affect land values. Second, and perhaps most important in the short term, drilling reveals information about the energy richness of an area. Wells drilled in some parts of every major U.S. shale formation have yielded disappointing results. That was the case for BP America, which acquired 84,000 acres in the Utica shale in 2012. After test wells failed to produce, the company chose to abandon development and sell the acres in 2014 (Seeley 2014). Thus, as wells generate knowledge about the resource, investment (and therefore production, royalties, and the value of subsurface rights) dries up in some areas and flows to other areas. Third, disamenities generated by extraction activities change over time. Initially wells are drilled, creating noise and truck traffic, both of which subside as drilling slows. In time, however, other disamenities can emerge—well cement can crack, for example, allowing gas or other liquids to migrate within the ground, potentially contaminating soil and water supplies. Since we can track land values only at five-year intervals, our estimates of the net effect of shale development on land values reflect primarily longer-term disamenities.

What We Hope to Learn from Self-reported Market Values

Despite the perils presented, self-reported data on land values can be creatively leveraged. We address four primary questions.

Do self-reported land values incorporate subsurface rights at all? For an answer, we look at two regions, Pennsylvania and Texas, to see if shale development's effect on land values is larger in the region that has fewer split estates (Pennsylvania). Fitzgerald (2014) found that 66 percent of mineral leases in Pennsylvania were executed by a resident of the county in which the leased land was located. In Texas, on the other hand, only 28 percent of the leases were made by local residents. While nonlocal ownership is not equivalent to split estates, the two should be strongly correlated since split estates occur when someone who owns and potentially lives on a parcel sells the oil and gas rights to someone who does not live there. Splits also can occur when a property owner sells the property but retains the oil and gas rights. Oil and gas rights in shale areas have acquired substantial value since it became clear that shale gas could be profitably extracted. Thus, if increases in value reported for land in Pennsylvania are not greater than increases reported for land in Texas, survey respondents likely are not including the value of their oil and gas rights.

How does the net effect of development change during leasing and drilling periods? For both regions, our data set covers the years in which most of the leasing occurred and drilling boomed. For Texas, the data set also includes a later period when drilling declined. As long as the number of split estates does not change substantially during those years, changes in land values will reflect the net effect of drilling over time.

How common are split estates? Quantile regressions permit us to estimate the effects of shale development based on whether a property appreciated more or less than what we would predict given its observed characteristics. Because we do not control for ownership of oil and gas rights, properties that retain those rights should have larger residuals because they should have appreciated more than properties that have similar observed characteristics but no mineral rights. In areas where most estates are split, we expect appreciation to be confined to the upper quartiles. Note, however, that only observing appreciation in the upper quartiles could reflect unobserved differences in resource richness within shale areas. Some properties within a shale area will not be profitable to drill and thus will not appreciate much even if the surface owner has the oil and gas rights.

How has shale development affected the value of rural residence and livestock properties relative to other properties? Land derives value from what it produces, and land that is more productive is more valuable. Shale gas development may thus affect the value of land by affecting its productivity. Suppose that technology f is applied to land to produce y. If land is paid a rent (π) that equals its marginal value product, the difference in rental rate for land in a shale area versus land in a nonshale area is given by

$$(1) \qquad \pi^{shale=1} - \pi^{shale=0} = p_y[f'(l \mid shale = 1) - f'(l \mid shale = 0)].$$

If the price of land is the discounted value (at rate r) of an infinite stream of rent payments, the equation can be written as

$$(2) \qquad p_l^{shale=1} - p_l^{shale=0} = (p_{crop} / r)[f'(l \mid shale = 1) - f'(l \mid shale = 0)].$$

Equation 2 shows how the effect of shale gas development on the price of land reflects changes in land productivity: $f'(l \mid shale = 1) - f'(l \mid shale = 0)$.

Different types of land presumably have been put to their most productive uses in growing crops, pasturing livestock, or providing recreation. Therefore, the output used to measure productivity may be a consumptive good, such as a place to enjoy the outdoors, or a traditional output such as corn. Many people buy a country property to enjoy fresh air and a bucolic landscape. We hypothesize that, relative to agriculturally intensive farms, farms used mainly as residences will appreciate less in response to shale development because the value of those farms depends largely on producing environmental or aesthetic goods, which drilling could degrade. Under this hypothesis, the productivity of land associated with a residence farm (subscript *res*) will decrease more than the productivity of land devoted to commercial agriculture (subscript *ag*):

$$(3)\quad f'(l_{res} \mid shale=1) - f'(l_{res} \mid shale=0) < f'(l_{ag} \mid shale=1) - f'(l_{ag} \mid shale=0).$$

Similarly, we expect that farmers who primarily raise livestock will value clean water more than farmers who concentrate on other production activities given the risk of water contamination posed by drilling. Bamberger and Oswald (2012), for example, documented cases in which waste water that leaked from wells and drilling-related factors affected the health of livestock in drilling areas. If the frequency of split estates is not correlated with agricultural decisions, estimating separate effects for these types of properties should provide credible information about the heterogeneous effects of shale development on the productivity of land in different uses.

Study Regions, Periods, and Data

We assess the effects of shale gas development on farm real estate values in the Barnett shale in Texas and the northeastern part of the Marcellus shale in Pennsylvania, which are shown in Figure 1. The Barnett shale is where horizontal drilling and high-volume hydraulic fracturing were first applied on a large scale. We exploit the sharp edge of the Barnett shale and compare farms in four counties that are wholly within the boundaries of the shale to farms in four counties that are just outside of its boundaries. For the Marcellus shale, we compare farms in the northeastern Pennsylvania counties of Tioga, Bradford, and Susquehanna with farms in the four adjacent New York counties.

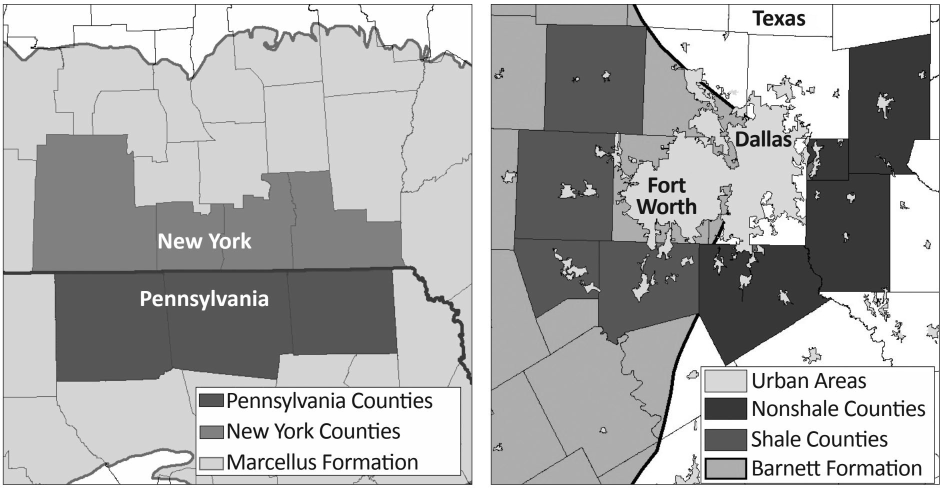

Figure 1. Study Regions and Counties

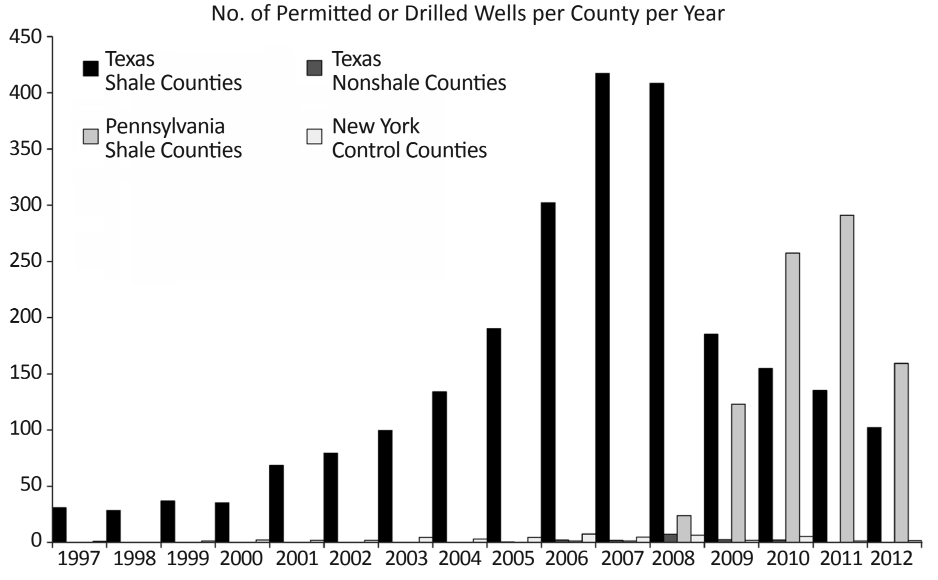

Figure 2. Shale Gas Development, 1997–2012

Source: Pennsylvania Department of Environmental Protection; New York Department of Environmental Conservation; Railroad Commission of Texas.
Note: Only unconventional wells are considered, which are wells drilled in unconventional formations (the Barnett shale in Texas and the (mostly) Marcellus shale in Pennsylvania). For Pennsylvania and New York, the year corresponds to the year in which the well was drilled. For Texas, the year corresponds to when the well permit was approved, excluding permits that were never drilled. The Texas shale and nonshale counties and the Pennsylvania shale and New York control counties correspond to the counties in the map in Figure 1.

Figure 2 shows the number of permitted or drilled wells in each region between 1997 and 2012. Development of the Barnett shale in Texas began in the early 2000s. Leasing, which precedes permitting, began in the late 1990s. The number of well permits issued for the shale peaked in 2007 and 2008 when more than 400 permits were approved (and subsequently drilled) per county per year. In contrast, the nonshale counties (see Figure 1), which are almost entirely outside of the shale and are included for comparison, had an average of seven permits approved per county in 2008.

Development of the Marcellus shale in northeastern Pennsylvania occurred later. Most of the leases were established between 2005 and 2008. Drilling then expanded rapidly beginning in 2008; the average number of shale wells drilled per county per year rose from 24 in 2008 to 291 in 2011. In adjacent counties in New York, fewer than 50 wells were drilled over the entire period.

The lack of drilling in New York reflects political and environmental considerations that led to regulatory restrictions on hydraulic fracturing in the state. Part of the watershed that supplies New York City with drinking water sits atop the Marcellus shale. The New York City Department of Environmental Protection (NYCDEP) is opposed to hydraulic fracturing, arguing that it poses unacceptable risks, particularly related to drinking water (NYCDEP 2009). Ongoing delays in revising the state's environmental standards imposed a de facto moratorium on hydraulic fracturing beginning in 2008, and the formal ban occurred in 2014.

Though no wells were drilled in New York, there is value in comparing the northeastern Pennsylvania shale counties to the New York border counties. Southwestern New York is within the boundaries of the Marcellus shale and drilling may occur there in the future. Thus, land owners in New York might incorporate an expectation of future shale development in their reports of land values, and by ignoring the New York counties, we would underestimate the impact of shale development on land values. We interpret our estimates as lower bounds on the impact of potential shale development.

Since our variables of interest are land values and property tax payments, we are not particularly concerned about spillover effects, which would be more of an issue in an analysis of the impacts of shale development on labor markets or residential housing markets. Demand for temporary housing from shale workers could boost rental prices for apartments and sales prices for single-family homes outside the Barnett shale area and on the New York side of the border but should have little effect on the demand for farms with dozens or hundreds of acres.

Our data set consists of farm-level observations from the USDA Census of Agriculture conducted in 1992, 1997, 2002, 2007, and 2012. In the census, the National Agricultural Statistics Service attempts to collect basic information for every farm in the United States. And because of USDA's broad definition of a farm (a property that has or had the potential to have $1,000 in agricultural sales in a year), many of the enumerated farms show little or no agricultural production and most are best described as rural residences. Consequently, properties covered by the census account for a surprisingly large share of the land area of the United States. The 2007 census denoted 55 percent of the nonurban land of the lower 48 states as owned or operated by farmers (Economic Research Service (ERS) 2013).

The primary variable of interest is farmers' self-reported assessments of the market value of the land and buildings they own, which we divide by total acres owned to determine a per-acre value. Other variables include each farm's sales by commodity type and whether the farm operator lived on the farm. Because of undercoverage and nonresponses in the census, all of the farm observations are assigned a statistical weight indicating how many U.S. farms each represents in the population. We use those weights in our empirical analysis.

Table 1 shows descriptive statistics for the sample of farms that were observed in at least two censuses between 1992 and 2012 and received a version of the survey that asked for self-reported farm real estate values. The number of such farms is much greater in 2007 and 2012 than in prior years because those surveys collected farm values from all respondents. Since we estimate the effects of shale development for residence farms and livestock farms separately, we also report the number of observations for those groups and the percent of the total sample represented.

Empirical Approach

Using data from the 1992, 1997, 2002, 2007, and 2012 censuses, we estimate how the average logarithm of per-acre farm real estate values changed over time in areas with and without extensive shale gas development. Letting *Shale* be a dummy variable indicating the area that had extensive development by 2012 and Y_t be a dummy variable indicating a specific year, we estimate

$$(4) \qquad \ln(value\ per\ acre)_t = \sum_{t=1997}^{t=2012} \delta_t Y_t + \sum_{t=1997}^{t=2012} \beta_t(Shale_i \times Y_t) + \varphi_i + \varepsilon_{it}.$$

In this specification, the β_t terms show how farm real estate values change over time based on whether the properties are in shale or nonshale areas, conditional on year (Y_t) and farm (φ_i) fixed effects. For year fixed effects, the excluded year is 1992. Farm fixed effects imply that only farms observed in at

Table 1. Summary Statistics

	Texas Barnett				Pennsylvania / New York Marcellus			
	Shale		Nonshale		Pennsylvania		New York	
	Dollars per Acre	N	Dollars per Acre	N	Dollars per Acre	N	Dollars per Acre	N
Farm Real Estate Value								
1992	4,295	1,210	3,487	951	2,273	1,176	5,118	426
1997	5,504	1,566	5,895	1,375	3,331	886	2,953	439
2002	6,020	1,234	5,658	987	3,572	631	3,378	291
2007	9,851	10,308	7,334	8,074	4,893	3,353	3,654	1,472
2012	8,505	6,642	5,879	5,203	4,548	2,571	3,167	1,033
Property Taxes Paid								
1992	36	1,186	35	941	29	1,173	97	425
1997	40	1,549	57	1,352	37	885	65	437
2002	52	1,215	53	959	36	625	67	291
2007	92	10,055	74	7,876	44	3,253	81	1,435
2012	69	6,631	52	5,181	46	2,570	54	1,028
	Percent	**N**	**Percent**	**N**	**Percent**	**N**	**Percent**	**N**
Residence Farms								
1992	0.323	1,210	0.323	951	0.139	1,176	0.232	426
1997	0.356	1,566	0.337	1,375	0.269	886	0.296	439
2002	0.432	1,234	0.411	987	0.333	631	0.289	291
2007	0.403	10,308	0.371	8,074	0.304	3,353	0.364	1,472
2012	0.383	6,642	0.375	5,203	0.290	2,571	0.315	1,033
Livestock Farms								
1992	0.265	1,210	0.166	951	0.700	1,176	0.493	426
1997	0.160	1,566	0.119	1,375	0.430	886	0.278	439
2002	0.126	1,234	0.094	987	0.325	631	0.237	291
2007	0.061	10,308	0.060	8,074	0.184	3,353	0.136	1,472
2012	0.082	6,642	0.078	5,203	0.075	2,571	0.033	1,033

Notes: Only farms that were observed in at least two censuses between 1992 and 2012 and received the census questionnaire asking for real estate values are included. The real estate values and property taxes are per acre of land owned by the farmer. Residence farms are defined as any farm with less than $250,000 in agricultural sales for which the principal operator did not identify farming as the primary occupation and lived on the farm at least once in the census year. Livestock farms are defined as farms reporting more than 75 percent of sales from livestock with a minimum of $10,000 in livestock sales. Increases in the number of farms in 2007 and 2012 reflect a change in administration of the Census of Agriculture to collect farm real estate values on all versions of the census questionnaire. The high farm real estate value in New York in 1992 reflects five high-value outliers; the influence of those outliers is mitigated by using a log specification in our empirical model.

least two censuses contribute to identification of parameters other than the farm fixed effect.

Our identification strategy follows those in other studies involving extractive booms. This approach exploits changing macro conditions such as prices or technologies that have regional effects using a fixed characteristic such as the region's initial share of earnings from mining (e.g., Black, McKinnish, and Sanders 2005, Marchand 2012). In the case of the Barnett shale, geology delineates shale and nonshale farms; for the Marcellus shale, it is the Pennsylvania / New York border, which corresponds to different policy regimes. Identification of the effect of shale development rests on the assumption that time trends that affect the value of farm real estate do not affect areas that eventually had shale development ($Shale = 1$) differently than areas that did not ($Shale = 0$).

The assumption of similar time trends is not unassailable. The housing boom of the mid-2000s, for example, may have affected farm real estate values for the New York and Pennsylvania sides differently. But given how similar the proximity to urban areas is for shale and nonshale counties in both regions, we believe that is unlikely. Moreover, the empirical results show that the farms in the shale development regions shared a common trend in appreciation prior to shale development, leading us to expect similar trends in the absence of development.

Results

Do Self-reported Land Values Incorporate Subsurface Rights at All?

We find that, to some extent, farmers include their oil and gas rights in self-reported valuations of their farm real estate (see Table 2). For farms in the Barnett shale where split estates are relatively common, natural gas development had a small positive effect on farm real estate values over time as shown by the coefficients on the $Shale_i \times Y_t$ interaction terms. For farms in the Marcellus shale where split estates are less common, we find much greater appreciation in value in the Pennsylvania counties, which experienced intense gas leasing and drilling, than in the adjacent New York counties. At similar stages of development (2012 in Pennsylvania and 2007 in Texas), the estimated shale effects are a 48 percent increase (0.39 log points) in value for farms in the Marcellus and a 9 percent increase in value for farms in the Barnett.

Our results are consistent with the local ownership numbers reported in Fitzgerald (2014) as we find that split estates are common in the Barnett shale, where, for tax purposes, oil and gas rights are treated as a distinct type of real property or improvement similar to land and houses. Once an oil or gas well begins to produce, the rights associated with it are assessed a value annually, and the owner must pay local property taxes.[1] Weber, Burnett, and Xiarchos (2014) showed that the oil and gas property tax base increased by more than $80,000 per student in school districts in the Barnett region relative to districts just outside the region. The Census of Agriculture collects information on all property taxes paid by farmers so we should see an increase in property taxes paid per acre owned in shale areas if the land owners there commonly own the

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1 Additional information on tax assessments for oil and gas property in Texas is available from Tarrant Appraisal District (*www.tad.org/ftp_data/DataFiles/MineralInterestTermsDefinitions.pdf*).

oil and gas rights. While it is possible that school districts and local governments in the shale area reduced property tax rates as the tax base expanded (causing total taxes collected to return to pre-drilling levels), it is unlikely to have occurred before the initial tax revenue windfall, which we should observe in the data as greater tax payments at some point.

From the fixed effects model with the log of property taxes paid per acre owned as the dependent variable, we find little evidence that farmers in the Barnett shale area began paying more taxes than those outside the shale area as development proceeded (Table 2). If land owners commonly retained the oil and gas rights, their tax assessments should have increased precipitously during peak drilling years, but the coefficient on the $Shale \times Y_t$ interaction actually decreased from 2002 to 2007, a time when drilling and production increased substantially.

Table 2. Shale Gas Development and Farm Real Estate Appreciation, 1992–2012

	Texas Barnett		Pennsylvania / New York Marcellus	
Dependent Variable	**Log(Value/Acre)**	**Log(Property Tax Payment/Acre)**	**Log(Value/Acre)**	**Log(Property Tax Payment/Acre)**
Year = 1997	0.199***	0.128	−0.003	0.115
	(0.076)	(0.109)	(0.063)	(0.078)
Year = 2002	0.195**	−0.003	0.132*	0.177**
	(0.083)	(0.127)	(0.077)	(0.088)
Year = 2007	0.376***	0.027	0.180***	0.167**
	(0.069)	(0.103)	(0.065)	(0.075)
Year = 2012	0.376***	−0.068	0.291***	0.210***
	(0.070)	(0.105)	(0.067)	(0.078)
Shale × Year = 1997	−0.022	−0.299**	0.078	−0.096
	(0.099)	(0.148)	(0.075)	(0.092)
Shale × Year = 2002	0.090	0.115	0.064	−0.083
	(0.109)	(0.170)	(0.096)	(0.108)
Shale × Year = 2007	0.066	0.097	0.397***	0.039
	(0.091)	(0.136)	(0.075)	(0.085)
Shale × Year = 2012	0.155*	0.105	0.366***	−0.023
	(0.092)	(0.138)	(0.077)	(0.089)
Constant	7.891***	2.690***	7.256***	2.851***
	(0.041)	(0.061)	(0.025)	(0.028)
Model	Fixed Effects	Fixed Effects	Fixed Effects	Fixed Effects
No. of observations	25,529	24,719	8,904	8,700
No. of farms	16,151	15,786	5,015	4,935
Adjusted R-squared	0.016	0.003	0.087	0.009

Note: *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. Robust standard errors clustered by farm are shown within the parentheses. The excluded year is 1992. In the Pennsylvania Marcellus analysis, the variable *Shale* equals zero for farms in the New York border counties; although they are in the Marcellus shale, state policy has precluded shale development.

A similar analysis for the Marcellus shale cannot identify whether split estates are common because Pennsylvania does not tax oil and gas rights.[2] Pennsylvania and New York farmers experienced similar trends in property tax payments over the study period. This also gives us confidence that the difference in appreciation in land values in Pennsylvania and New York did not stem from systematic changes in property tax rates or assessments.

How Does the Net Effect of Development Change during Leasing and Drilling Periods?

In both shales, the largest increases in appreciation of farms occurred when leases were being completed. Little if any additional appreciation occurred when wells were drilled and production began. In the Barnett region, the evolution of farm real estate values from 1992 to 1997 was similar in shale and nonshale areas. In subsequent years, real estate values in the shale areas increased more than values in the nonshale areas. The largest period-to-period appreciation occurred from 1997 to 2002 when the coefficient on the *Shale* × Y_t interaction went from –0.022 to 0.090, an increase of 0.112 log points. Neither coefficient, however, is statistically distinguishable from zero. The only estimate that is statistically significant is the *Shale* × 2012 interaction, and it is significant only at the 10 percent level.

The greater appreciation of land values in the Barnett shale region from 1997 to 2002 corresponds to years when leasing intensified. The weakness of this evidence may reflect land owners' investments of oil and gas wealth in land and buildings. Weber, Burnett, and Xiarchos (2014) found that increases in the value of oil and gas rights in Texas caused an increase in the property tax base in shale areas and contributed to increases in residential property values in shale areas relative to nonshale areas in the Dallas / Fort Worth region. Such increases in local property tax revenue also may have contributed to greater appreciation of farm real estate values either through greater demand for residential development or through lower property tax rates.

Farm real estate values in the Marcellus shale evolved similarly through 2002. In 2007, when most of the oil and gas leases were in place, farm real estate appreciated nearly 50 percent more (0.39 log points) in shale areas than in nonshale areas. The greater property values for farms on the Pennsylvania side of the shale persisted through 2012.

These results suggest that having a lease offer in hand matters for a land owner when reporting the value of the farm and any attached mineral rights. In 2007 and 2008, there was no clear moratorium on fracturing in New York. The difference between Pennsylvania and New York at that time was that the rush to lease oil and gas rights had started in Pennsylvania and had only begun to spill into New York at the end of 2007 (Wilber 2012). The percentage of property owners who retained oil and gas rights in the three New York counties included in our model was likely similar to the percentage on the Pennsylvania side. With few executed leases, most New York owners thus likely placed, and thus reported, little value on their oil and gas rights at the time.

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[2] A 2002 decision by the Pennsylvania supreme court interpreted the state's assessment laws as excluding oil and gas rights (Pepe 2009).

How Common Are Split Estates?

Using quantile regressions, we further analyze the relative prevalence of split estates for the two shales. Equation 4 does not control for whether a property retains the oil and gas rights. Initially, those rights would have been almost worthless but then would have gained tremendous value as evolving technologies and rising prices made drilling in shale profitable. The changing value of these rights is embedded in the residual because the value varies from property to property. In addition, the variable that identifies a property as shale or nonshale does not control for oil and gas rights since many land owners in the shale group do not own the mineral rights. Quantile regressions permit us to estimate effects based on a farm's residual. However, such regressions on panel data are difficult to interpret since an observation can change quantiles over time based on its residual. We therefore convert our panel data into a cross-sectional model:

$$(5) \qquad \Delta\ln(\textit{value per acre})_t = \lambda_1 + \lambda_2 \textit{Shale}_i + \boldsymbol{\lambda_3 X_{t-1}} + v_{it}$$

where

$$\Delta\ln(\textit{value per acre})_t = \ln(\textit{value per acre})_t - \ln(\textit{value per acre})_{t-1}.$$

The vector $\mathbf{X}_{t-1}$ incorporates several property characteristics that are potentially correlated with appreciation of land values: the logarithm of property tax paid per acre owned, the log of total acres owned, an indicator variable for whether the farm operator lived on the property, an indicator variable for whether the farm had livestock sales, and, as a measure of land quality, the log value of crop production per acre for the farm.

Our earlier results suggest that shale areas appreciate most during the leasing period of development. For the Barnett sample, we therefore specify $t-1$ as 1997, which is prior to increasing interest in the shale, and t as 2002, the period when leasing was occurring. The Marcellus shale leases occurred later so we specify $t-1$ as 2002 and t as 2007. All of the control variables correspond to values in the initial year, $t-1$.

Using the specification in equation 5, we estimate the difference in appreciation in shale and nonshale areas at the 25th quantile (λ_2^{25}) by finding parameters λ_1^{25}, λ_2^{25}, and λ_3^{25} that minimize the sum of the absolute differences between the actual and predicted values. Observations with positive residuals are weighted by 0.25 and those with negative residuals are weighted by 0.75 (see equation 7.1 in Cameron and Trivedi (2009)). We estimate coefficients at the 25th, 50th (median), and 75th quantiles and, for comparison, at the mean and report the results in Table 3.

The point estimates on the shale variable in the quantile regressions for the Barnett properties show that appreciation for the farms at the 75th quantile is greater than at the mean (median). But even at the 75th quantile, the estimate has a wide confidence interval and is not statistically distinguishable from zero. This result provides further evidence of the prevalence of split estates in the Barnett region. Note, also, that the estimated shale effect at the 25th quantile is larger than at the mean, which does not match our prediction that properties with greater appreciation from unobservable characteristics (presumably the oil and gas rights) should appreciate more than other properties. Nonetheless,

Table 3. Shale Gas Development and Appreciation at the Mean and by Quantile

Dependent Variable: D.Log(Value of Land and Buildings)	Texas Barnett (t = 2002, t – 1 = 1997) Mean	25th Quantile	50th Quantile	75th Quantile	P/NY Marcellus (t = 2007, t – 1 = 2002) Mean	25th Quantile	50th Quantile	75th Quantile
Shale (0/1)	0.126	0.290	0.063	0.173	0.182*	0.125	0.162**	0.304***
	(0.137)	(0.182)	(0.138)	(0.138)	(0.097)	(0.125)	(0.077)	(0.104)
L.Log(property tax payment/acre)	–0.048	–0.009	–0.035	–0.038	–0.268***	–0.207**	–0.147***	–0.165**
	(0.051)	(0.077)	(0.053)	(0.058)	(0.088)	(0.105)	(0.055)	(0.083)
L.Log(acres owned)	0.068	0.073	–0.025	–0.011	0.025	0.005	0.029	0.103
	(0.046)	(0.051)	(0.060)	(0.057)	(0.068)	(0.073)	(0.054)	(0.065)
L.Live on property (1/0)	–0.551***	–0.319	–0.581**	–0.895***	–0.152	–0.270*	–0.144	–0.016
	(0.183)	(0.249)	(0.236)	(0.260)	(0.157)	(0.142)	(0.147)	(0.211)
L.Livestock sales (1/0)	–0.485**	–0.326	–0.132	–0.154	–0.283***	–0.092	–0.066	–0.417***
	(0.205)	(0.252)	(0.185)	(0.244)	(0.105)	(0.129)	(0.091)	(0.135)
L.Value of crop production/acre	–2.342**	–0.959	–1.541	–1.766	–0.286	–0.053	0.065	–0.485
	(1.043)	(1.394)	(1.149)	(1.142)	(0.466)	(0.843)	(0.621)	(0.846)
Intercept	0.646**	–0.444	0.868*	1.483***	1.521***	0.059	1.234**	0.270
	(0.314)	(0.410)	(0.474)	(0.412)	(0.547)	(0.535)	(0.565)	(0.530)
Number of observations	229	229	229	229	390	309	390	309
Adjusted R-squared		0.076				0.104		

Note: *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. Standard errors for the mean regressions (shown in parentheses) are heteroskedastic robust errors; for the quantile regressions, they are bootstrapped using 500 replications. This is a cross-sectional analysis. "L." designates a five-year lag; "D." designates the five-year difference with different five-year periods chosen for the Barnett and Marcellus depending on the start of the leasing periods. In the Pennsylvania Marcellus analysis, the variable *Shale* equals zero for farms in the New York border counties; although they are in the Marcellus shale, state policy has precluded shale development.

all of the point estimates on the shale variable have wide confidence intervals and are statistically indistinguishable from zero.

The results for the Marcellus shale better match our predictions. The effect of being in the shale area (Pennsylvania side) is largest for farms in the 75th quantile, followed by the 50th quantile and then the 25th quantile. We observe a statistically significant effect of shale leasing at the 75th and 50th quantiles and at the mean but not at the 25th quantile based on unobserved characteristics. This may mean that the majority of farmers in the Marcellus study area own the oil and gas rights. It also suggests that resource richness—and, therefore, interest in leasing—is spread fairly uniformly across Tioga, Bradford, and Susquehanna counties. This is consistent with Energy Information Administration maps,[3] which show that drilling in those counties in the Marcellus shale occurred as a broad, relatively uniformly dense swath while drilling in the Barnett shale was less uniform and somewhat concentrated on the Fort Worth side of the counties.

How Has Shale Development Affected Rural Residence and Livestock Properties Relative to Other Properties?

As previously mentioned, the value of livestock and residence farms may be more sensitive to disamenities associated with shale development. In the analysis, we define a livestock farm as one that had a minimum of $10,000 in livestock sales per year and that derived more than 75 percent of its sales from livestock. USDA has traditionally used a farm typology that groups farms into residence, intermediate, and commercial farms. Following this typology, we define a residence farm as one (i) that had less than $250,000 in agricultural sales in a year and (ii) for which the principal operator lived on the farm at least once in the census year and did not identify farming as the primary occupation.[4] The classification of a residence farm does not depend on acreage so it should not be confused with small farms. Large farms with little agricultural production can be termed residence farms while productive small farms cannot.

We estimate a modified version of equation 5 that is augmented with a dummy variable indicating that the property is a livestock or residence farm and interact that variable with the shale dummy variable:

$$(6.1) \quad \Delta\ln(\mathit{value\ per\ acre})_{it} = \pi_1 + \pi_2 \mathit{Shale}_i + \pi_2 \mathit{Livestock}_i + \pi_3(\mathit{Shale}_i \times \mathit{Livestock}_i) + \boldsymbol{\pi_4 X_{t-1}} + v_{it}.$$

$$(6.2) \quad \Delta\ln(\mathit{value\ per\ acre})_{it} = \theta_1 + \theta_2 \mathit{Shale}_i + \theta_2 \mathit{Residence}_i + \theta_3(\mathit{Shale}_i \times \mathit{Residence}_i) + \boldsymbol{\theta_4 X_{t-1}} + \eta_{it}.$$

As in equation 5, this is a cross-sectional analysis focused on the difference in the log value per acre before and after the leasing period. For the Barnett region, t equals 2002 and $t-1$ equals 1997; for the Marcellus region, t equals 2007 and $t-1$ equals 2002. We estimate equations 6.1 and 6.2 separately rather than as a single equation that includes (i) indicator variables for shale, livestock, and residence and (ii) interaction terms since the sample is limited to farms that

[3] Pennsylvania: *www.eia.gov/todayinenergy/detail.cfm?id=6390*. Texas: *www.eia.gov/todayinenergy/detail.cfm?id=2170*.

[4] The results are robust to using $100,000 and $50,000 in agricultural sales as alternative cut-offs.

were recorded in both of the censuses considered for each shale region. If we had included all of the interactions at once, the samples would consist of only a few farms.

We report the results of this analysis in Table 4. For both the Barnett and the Marcellus samples, the point estimates of the effect of being in the shale were smallest for livestock farms. In the Barnett, the shale effect was negative, and in the Marcellus, it was positive but smaller for livestock farms than for nonlivestock farms. In both cases, however, the point estimates are statistically insignificant. Less appreciation (and even depreciation) during the leasing period for properties used to raise livestock may indicate that livestock farmers are less likely to own oil and gas rights. Alternatively, farmers may view drilling as posing a risk to the water supply for livestock, thus reducing the land's value for that purpose.

Table 4. Shale Gas Development and Appreciation by Property Type

Dependent Variable: D.Log (Value of Land and Buildings)	Texas Barnett $t = 2002, t - 1 = 1997$		Pennsylvania Marcellus $t = 2007, t - 1 = 2002$	
Shale	0.005	0.248	0.052	0.247**
	(0.189)	(0.174)	(0.111)	(0.122)
L.Log(property tax payment/acre)	–0.054	–0.057	–0.304***	–0.291***
	(0.056)	(0.057)	(0.087)	(0.091)
L.Log(acres owned)	0.066	0.053	–0.011	0.018
	(0.054)	(0.056)	(0.069)	(0.075)
L.Live on property (1/0)	–0.385*	–0.433**	–0.099	–0.183
	(0.217)	(0.204)	(0.161)	(0.153)
L.Livestock sales (1/0)	–0.496**	–0.494**	–0.341***	–0.190
	(0.233)	(0.240)	(0.105)	(0.116)
L.Value of crop production/acre	–2.334*	–2.064*	–0.314	–0.410
	(1.197)	(1.238)	(0.489)	(0.578)
L.Residence farm	–0.270	—	–0.467***	—
	(0.246)	—	(0.160)	—
L.Shale × Residence farm	0.430	—	0.450**	—
	(0.280)	—	(0.200)	—
L.Livestock farm	—	0.367	—	–0.057
	—	(0.290)	—	(0.190)
L.Shale × Livestock farm	—	–0.499	—	–0.177
	—	(0.318)	—	(0.195)
Constant	0.620	0.576	1.521***	1.234**
	(0.405)	(0.403)	(0.547)	(0.565)
Number of observations	229	229	390	390
Adjusted R-squared	0.053	0.054	0.132	0.120

Note: *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. Robust standard errors are shown within parentheses. This is a cross-sectional analysis. "L." designates a five-year lag and "D." designates the five-year first-difference with different five-year periods chosen for the Barnett and Marcellus depending on the start of the leasing periods. In the Pennsylvania Marcellus analysis, the variable *Shale* equals zero for the farms in New York border counties; although they are in the Marcellus shale, state policy has precluded shale development.

The effect of being in the shale was largest for residence farms in both the Marcellus and the Barnett. The point estimates of the coefficients on the *Shale* × *Residence* interaction are similar, 0.43 and 0.45, though the estimate for the Barnett sample is less precise (standard error of 0.28 compared to 0.20). This result is the opposite of our prediction that the value of residence farms would be relatively more sensitive to the disamenities associated with drilling (or expected drilling). Like nonlivestock farmers, owners of residence farms may more often retain the oil and gas rights. Perhaps prior interest in oil and gas development (and therefore splitting of estates) was concentrated on larger, more accessible tracts of land and thus on larger farms. Alternatively, farmers may be less able than residence land owners to move away in the event of land or water contamination, which could make farmers less willing to sign leases.

How Has Shale Development Affected Land Values in Southwestern Pennsylvania Where Split Estates Are Said to be Common?

Southwestern Pennsylvania experienced a wave of drilling that began around 2005, slightly earlier than drilling in northeastern Pennsylvania. Southwestern Pennsylvania has a history of energy development that, like the Texas Barnett shale, is associated with a large number of split estates. We perform a brief analysis of two shale counties in that region, Washington and Greene, which are southwest of Pittsburgh. We use Beaver and Lawrence counties, just northwest of Pittsburgh, as comparison counties; both are within the Marcellus shale region but only partly occupy the high-formation-pressure area that delivers greater production rates. Thus, far fewer wells are drilled there. Between 2002 and 2012, 87 wells were drilled in Beaver County and 55 in Lawrence County while 2,207 were drilled in Greene County and 2,826 were drilled in Washington County (Pennsylvania Department of Environmental Protection 2014).

Based on the results of our fixed effect regression, shale development had no significant effect on property values during the study period and only a significant negative effect from 1997 to 2002 (results not shown). The lack of statistically significant effect is consistent with the weak effect of shale development on properties in the Barnett shale, where split estates are common. We can find no plausible explanation for the relative depreciation of property values in shale counties or for appreciation in nonshale counties from 1997 to 2002. The results of the quantile regression for southwestern Pennsylvania are more in line with those of northeastern Pennsylvania, where split estates are uncommon. Combined, these results best fit a general assessment that split estates are most common in Texas, least common in northeastern Pennsylvania, and somewhat common in southwestern Pennsylvania and gives some credence to our method of assessing the prevalence of split estates through a combination of panel fixed effects and quantile regression.

Conclusions

We find that shale gas development affects self-reported farm real estate values and that, to some extent, farmers include their oil and gas rights when reporting the market value of their farms. Researchers using land values self-reported after 1999 should keep in mind that ownership of oil and gas rights and development of those resources may cause large changes in property values in some areas and may be correlated with variables of interest. Moreover, if a study conceptualizes land values as excluding subsurface rights, owners who include the value of such rights will overestimate the land value. And to the extent that the frequency of retained oil and gas rights varies by region—our findings suggest that it does—differences in land values across space may also be biased.

Most of the appreciation occurs during the leasing period rather than during the drilling period. The lack of appreciation in the drilling period may reflect competing forces. On one hand, investment of royalty income in improvements to the land and/or buildings, greater local public revenue, and overall greater demand for land should cause appreciation during the peak drilling phase. On the other hand, some factors should cause depreciation: productivity can decline exponentially shortly after a well is drilled and drilling can produce environmental and visual disamenities and can affect a property's suitability for the uses that give it value.

The nature of the data used in this study limits our estimates to long-term net effects of shale development on land values. We do not know if specific channels are at work and, if so, how much those channels contribute to appreciation or depreciation. Isolating the importance of various channels would provide a richer description of the effects of shale development. It will be interesting to track land values in these regions in the future as they will reveal how the collective effect of the causal channels evolves as shale development matures. The Barnett shale was near the peak of its production in 2012, the final year of this analysis, while production at the Marcellus shale continued to expand after 2012.

Shale development's effect on property values appears to vary by how the property is used, though our samples are too small to provide rigorous, fine-grained breakouts. For both the Barnett and the Marcellus, we find that residence farms appreciated more than other types of farms during leasing. In contrast, livestock farms appreciated less than other types of farms, though the differences were not statistically significant in either region. This is a fertile area for research and one in which regional differences will matter. Water scarcity in the West may reduce the value of farms that depend on ground or surface water for producing crops and livestock. In the East, water quality may matter more and mostly for livestock farms since most crops are rain-fed.

An ongoing empirical challenge is lack of data on ownership of oil and gas rights. It remains a glaring omission in studies of property values and oil and gas development both for self-reported data and for sales data. With self-reported data, one must know if oil and gas rights are attached to the land ownership and whether rights that are attached are included in the reported land values. With sales data, it is important to know if the mineral rights were initially attached to the land and, if so, whether they were conveyed to the buyer with the land. Our empirical approach provides indirect evidence that split estates are much more common in the Barnett shale than in the northeastern part of the Marcellus shale. Ownership of oil and gas rights may also be correlated with characteristics of the property that independently increase or decrease its value, such as its accessibility and distance from urban centers. Data on ownership of the mineral rights would therefore allow segregation of environmental disamenities associated with drilling from changes in oil and gas right ownership or valuation.

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