What can we learn about shale gas development from land values? Opportunities, challenges, and evidence from Texas and Pennsylvania

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Abstract: We study farm real estate values in the Barnett Shale (Texas) and the northeastern part of the Marcellus Shale (Pennsylvania and New York). Shale gas development caused appreciation in both areas but the effect was much larger in the Marcellus, suggesting broader ownership of oil and gas rights by surface owners. In both regions, most 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 a correlation between farm type and the presence of oil and gas rights.

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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 like Texas and Pennsylvania. Drilling in shale formations has varied consequences, creating jobs while also affecting residential property values and human health (Weber 2012; Hill 2013; Olmstead et al. 2013; Weber 2013; Brown 2014; Gopalakrishnan and Klaiber 2014).

Several recent studies look at the effect of shale gas development on residential housing values to estimate the cost of environmental and human health risks, real or perceived (Muehlenbachs et al. 2013; Gopalakrishnan and Klaiber 2014). The value of residential properties primarily reflects the value of buildings. The value of properties like farms, in contrast, mostly reflects the value of undeveloped land. The link between shale development (or the potential for it) and land values remains unexplored aside from two studies that address it tangentially. Weber, Brown, and Pender (2013) found a positive correlation between farm real estate values and lease and royalty payments from oil, gas, or wind activities, while Borchers, Ifft, and Keuthe (2014) found a weak negative correlation between county-level oil production and farm-level pasture values.

We use self-reported farm real estate values from five Censuses of Agriculture (1992, 1997, 2002, 2007, 2012) to estimate how natural gas development affected farm real estate values, which primarily consist of the value of undeveloped land. We focus on two regions that have had extensive shale development as of 2012: the Barnett Shale in Texas and the northeastern part of the Marcellus Shale in Pennsylvania. We use these data to inform several questions related to shale gas development.

First, we use estimates of the effect of development on farm real estate values as an indication of the ubiquity of split estates – properties where the rights to oil and gas are owned by someone other than the land owner. As extracting natural gas from shale formations becomes profitable, the oil and gas rights appreciate. We expect shale development to cause greater land appreciation in areas with few split estates than in areas with many split estates. Split estates matter because they imply that the person bearing most of the disamenities from drilling – the person living on the surface near the well – is different than the person negotiating the leasing terms for drilling. It is also likely that the greater the frequency of split estates, the less royalty income captured by local residents.

Second, with our long panel data we can see how farm real estate values changed during the leasing and development periods. We expect farm real estate values to change over time. As natural gas is withdrawn, the subsurface rights grant access to fewer and fewer resources, causing properties with subsurface rights to gradually decline in value. A decline in value to below pre-development levels would indicate a long-term cost of having wells and related infrastructure on or near a property, assuming that farmers did not invest royalty income in land improvements. We note here that the effect of shale development on farm real estate values that we estimate is a medium to long-term net effect. Our data do not permit separating competing positive and negative effects of drilling, and with farms observed at five-year intervals, our estimates primarily reflect effects that persist for several years. As such the estimates are not comparable to studies that estimate the change in real estate values from shortly before to shortly after the drilling of a well.

Lastly, we leverage the data to see how drilling affects the suitability of land for a variety of uses. Residential values, which prior research has considered (e.g. Gopalakrishnan and Klaiber 2014; Muehlenbachs et al. 2013), reveal how drilling affects a property's attractiveness for use as a residence. Properties with more land reveal how drilling affects their suitability for the nonresidential purposes that give it value. Properties with a house and barn and 100 acres, for example, are used as a residence but also for growing crops, raising livestock, and recreation. Because of potential effects on local water quality, drilling may lower the value of land dedicated to livestock but not the value of cropland. Similarly, land used primarily for recreation may be more sensitive to the environmental, health, and landscape consequences of drilling.

Data limitations prevent us from clean and concrete conclusions. Our findings, nonetheless, provide greater understanding of all three topics and should help further research in this area. First, we find a small positive effect of shale development in both the Barnett (Texas) and the Marcellus (Pennsylvania) but the effect is much larger in the Marcellus, suggesting that split estates are far less common there. This conclusion is consistent with Fitzgerald (2014) who finds that local ownership of mineral rights is more than two times higher in Pennsylvania than in Texas.

For both regions, most appreciation occurred when land was leased for drilling. Higher values then persisted through the drilling period, indicating a net positive effect of drilling through the last year of our analysis, 2012. This indicates that long-term disamenities that affect farm real estate values have not yet been large enough to outweigh the effects of development that are positively related to farm values.

Regarding different effects for different properties, we find evidence that shale development caused real estate in residence farms – those with limited agricultural sales and whose owners have a primary occupation other than farming (not to be confused with “small” farms) – to appreciate more than real estate in nonresidence farms. This finding holds for both regions. Weaker evidence suggests that livestock farm real estate appreciated less or even lost value. Both findings potentially reflect a correlation between farm type and the presence of oil and gas rights – a possibility that underscores the value of information on oil and gas right ownership when studying the effect of shale energy development on property values.

Shale Gas Development and Land Values: The Perils Facing the Researcher

Limited Data

Property sales data with detailed land characteristics, including whether the subsurface rights were conveyed in the sale, would provide a firm foundation to quantify how shale gas development affects the value of oil and gas rights and surface rights. Standard sales data, however, typically lacks information about the conveyance of oil and gas rights. They also only include properties sold, and if the researcher wants to control for time-invariant unobservable characteristics, she must further limit her study to properties sold twice during the study period. This is less of a challenge when considering residential properties with little land because they are so numerous. The same is not true of properties consisting primarily of land, which are fewer and only a small fraction of them are sold in a given year. Many are only sold once in a lifetime, let alone twice in a researcher's study period. The problem may be exacerbated by oil and gas development if development slows land market turnover.

A researcher using survey data asking property owners for market values may avoid the small sample pitfall of sales data but may stumble into others. Surveys – such as the Census of Agriculture, which we use – may provide panel data on more proprieties in a given area. However, unless the data was collected with subsurface issues in mind, the questionnaire probably did not ask landowners if they own the oil and gas rights to their land, and the Census of Agriculture is no exception. Even if landowners own the rights, they may not report them in the market value of their land if the questionnaire lacks explicit instructions.

Heterogeneous Effects

Oil and gas rights aside, shale development may have different effects on different types of land. This increases the researcher's data needs to include the characteristics associated with the distinct effects. Pope and Goodwin (1984) argued that rural land has value because of its agricultural productivity but also because it can be enjoyed for its own sake – what the authors label as a consumptive component of value. We might expect the value of land whose demand comes primarily from people who want to escape city life and enjoy the outdoors to be more sensitive to the disamenities of drilling. If instead the land is used for growing crops, drilling should matter less as long as it does not affect yields. We may also expect heterogeneous effects for different types of agricultural land. Beef cattle and dairy cows require quality water. If drilling through the water table muddies a spring used to water cows, it may 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 a property being located over a shale formation will change with time, making it hard to interpret estimates. Suppose that during the initial leasing period the land inside of a formation appreciates more than land just outside the formation, but the price differential declines as development matures. The natural resource economist might say the finding reflects the decline in the resource stock; the environmental economist points to it as evidence of environmental disamenities. Both could be true.

We expect the difference in land values across shale and nonshale areas to vary over time for at least three reasons. First, to the extent that subsurface rights are incorporated in land values, changes in the quantity or price of the oil or gas in the ground will cause changes in 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 all the major U.S. shale formations have yielded disappointing results. After acquiring 84,000 acres in the Utica Shale in 2012, BP America saw disappointing results from test wells and decided to abandon development and sell the acreage in 2014 (Seeley 2014). As wells generate knowledge, investment (and therefore production, royalties, and the value of subsurface rights) dries up in one area and flows to another. Third, disamenities change over time. Initially wells are drilled, creating noise and truck traffic, both of which subside as drilling slows. In time, however, other disamenities may emerge as the well cement cracks and allows gas or liquids to migrate underground. Since we are able to track land values only at 5-year intervals over time, our estimates of the net effect of shale development on land values will reflect primarily longer-term disamenities, as we are unable to capture any short-term disamenities.

What We Hope to Learn from Self-Reported Market Values

Despite the perils presented, self-reported land value data can be creatively leveraged to inform four questions.

Do self-reported land values incorporate subsurface rights at all?

For an answer, we look at two regions and see if shale development's effect on land values is larger in the one with fewer split estates (Pennsylvania) than the one with more split estates (Texas). Fitzgerald (2014) shows a local mineral ownership rate of 66 percent for Pennsylvania, which he measured by the percent of leases where the mineral lessor was a resident of the county of the lease. In Texas, on the other hand, only 28 percent of minerals were locally owned. While nonlocal ownership is not equivalent to split estates, the two should be highly correlated, since split estates occur when someone who owns and potentially lives on a parcel sells oil and gas rights to someone who does not live there. Alternatively, a split can happen when a property owner moves and sells a property but retains the oil and gas rights.

Oil and gas rights in shale areas acquired substantial value as it became clear that shale gas could be profitably extracted. If the increase in the value of rights does not cause greater land appreciation in Pennsylvania than in Texas, then it suggests that land owners typically do not include the value of their oil and gas rights in their self-reported land values.

How does the net effect of development change during the leasing and drilling periods?

For both regions, our data covers the period when most leasing occurred and the period when drilling boomed. In Texas the data also include the period of declining drilling. As long as the number of split estates did not change substantially, changes in land values will reflect the net effect of drilling over time.

How common are split estates?

Quantile regressions permit estimating different 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 oil and gas right ownership, properties with the rights should have larger residuals because they should have appreciated more than other properties with similar observed characteristics but without the rights. In areas where most estates are split, we expect appreciation to be confined to the upper quartiles. We also note, however, that only observing appreciation in the upper quartiles could reflect unobserved differences in resource richness within shale areas. Not all properties within a shale area will be profitable to drill. Such properties will not appreciate much, even if the surface owner has the oil and gas rights.

How has shale gas development affected the value of rural residence and livestock properties relative to other properties?

Land derives value from what it produces, with more productive land being more valuable. Shale gas development may affect land values by affecting land productivity. Suppose that the technology *f* is applied to land to produce *y*. If land is paid a rent π that equals its marginal value product, then the difference in rental rates for land in shale and nonshale areas will be given by

$$(1)\quad \pi^{shale=1} - \pi^{shale=0} = p_y[f'(l|shale = 1) - f'(l|shale = 0)]$$

If the price of land is the discounted value (at rate *r*) of an infinite stream of rent payments, then (1) can be written as

$$(2)\quad p_l^{shale=1} - p_l^{shale=0} = \frac{p_{crop}}{r}[f'(l|shale = 1) - f'(l|shale = 0)].$$

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

Different types of land presumably have been put to their most productive uses – to grow crops, pasture livestock, or provide recreation. The output used to measure productivity may therefore be a consumptive good such as a place to enjoy the outdoors or a traditional output such as corn. We hypothesize that compared to agriculturally-intensive farms, farms used mainly as a residence property will appreciate less from development because their value depends more on producing environmental or aesthetic goods, which drilling potentially degrades. After all, many people buy a country property to enjoy fresh air and a bucolic landscape. Under this hypothesis, the productivity of land in a residence farms (subscript *res*) decreases more than that of land in production agriculture (subscript *ag*):

$$(3)\quad f'(l_{res}|shale=1)-f'(l_{res}|shale=0)<f'\left(l_{ag}\middle|shale=1\right)-f'\left(l_{ag}\middle|shale=0\right)$$

Similarly, we expect farms engaged primarily in raising livestock to value clean water more than other farms because they would suffer greater losses if drilling contaminated the farm's water source. Bamberger and Oswald (2012), for example, document cases where waste water leakage from drilling and other drilling-related factors affected livestock health in drilling areas. If the frequency of split estates is not correlated with agricultural decisions, estimating separate effects for different 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. 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, comparing farms in four counties wholly inside the Shale to farms in four counties just outside of it. For the Pennsylvania analysis, we compare farms on either side of the northeastern Pennsylvania-New York border, focusing on the three most gas abundant Pennsylvania counties and the four adjacent counties inside New York (Figure 1).

Development of the Barnett Shale began in the early 2000s, with leasing, which preceded permitting, occurring in the late 1990s and early 2000s (Figure 2). The number of well permits peaked in 2007 and 2008 when more than 400 permits were approved (and subsequently drilled) each year in each shale county. In contrast, the nonshale comparison counties in Figure 1, which were almost entirely outside of the shale, had an average of 7 permits approved per county in 2008.

Development of the Marcellus Shale in northeastern Pennsylvania counties of Tioga, Bradford, and Susquehanna occurred later, with much leasing occurring during the 2005-2008 period. Drilling then grew rapidly from 2008 to 2011, with the average number of unconventional wells drilled per county per year increasing from 24 to 291. In adjacent counties in New York, there was very modest drilling over the entire period.

The lack of drilling in New York reflects various political and environmental considerations leading to regulatory roadblocks to hydraulic fracturing in the state. Part of the watershed supplying New York City with drinking water sits atop the Marcellus Shale. The New York City Department of Environmental Protection is opposed to hydraulic fracturing, arguing that it “poses an unacceptable threat to the unfiltered water supply of 9 million New Yorkers” (NYC DEP 2009). Continual delays in revising environmental standards have imposed a de facto moratorium on hydraulic fracturing since 2008. By the fall of 2008, the NY Department of Environmental Conservation had received less than a dozen permit applications for high volume fracking of horizontal wells and had approved none of them (NY DEC 2008). Afterwards the Department of Environmental Conservation continued to postpone issuing regulations suitable for high volume hydraulic fracturing and horizontal drilling, precluding the use of the technology through the end of our latest study year, 2012.

While no wells were drilled in NY, the comparison of northeastern PA to the NY border counties is of a different nature than inside and outside the Barnett shale in TX, since southwestern NY is still within the Marcellus shale and drilling may occur in the future. To the extent that landowners in NY have incorporated an expectation of future shale development into their self-assessed land values, we would be underestimating the impact of shale development on land values. We can interpret our estimates as serving a lower bound of the potential shale development impact.

Since our variables of interest are land value and property tax payments, we are not particularly concerned about spillover effects, which would be more of an issue in an analysis of shale development impacts on the labor market or residential housing market. Demand for temporary housing from shale workers would boost the sale or rental price of apartments and single family homes outside the Barnett shale area or on the NY side of the border, but this should have little effect on the demand for multiple-acre farms.

Data

We use farm-level data from the Censuses of Agriculture conducted in 1992, 1997, 2002, 2007, and 2012. In the Census the National Agricultural Statistics Service attempts to collect basic information on all farms in the U.S. Because of the broad USDA definition of a farm – a place that has sold or has the potential to have $1,000 in agricultural sales in a year – many places enumerated as a farm have little or no agricultural production and in most cases are best described as rural residence properties. Consequently, the properties covered in the Census of

Agriculture account for a surprisingly large share of the land in the U.S. The 2007 Census of Agriculture showed that 55 percent of the nonurban land of the 48 lower states was owned or operated by farms (ERS-USDA 2013).

Our variable of interest is the self-reported market value of the land and buildings owned by the farm divided by the total acres owned. We employ other variables collected through the Census, including the farm's sales by commodity type and whether the farm operator lives on the farm. Because of undercoverage and nonresponse in the Census of Agriculture, all farms have a statistical weight indicating how many farm it represents in the population. We use this weight in our empirics.

Table 1 shows descriptive statistics for the sample of farms observed in at least two Census of Agriculture between 1992 and 2012 and received the version of the questionnaire asking for farm real estate values. The number of farms in 2007 and 2012 is much higher than in prior years because all farms in 2007 and 2012 received the questionnaire collecting farm real estate values. Because we estimate different effects of shale development for residence farms and livestock farms, which we define later, we also report the number and percent of the sample each group represents.

Shale Development and Farm Real Estate Appreciation: Empirical Approach and Findings

We estimate how the average logarithmic 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

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

In this specification the β_t terms show how the difference between farm real estate values two has changed over time, conditional on year (Y_t) and farm (φ_i) fixed effects. For the year fixed effects, the excluded year is 1992 (the model is estimated using data from the 1992, 1997, 2002, 2007, and 2012 Censuses of Agriculture). The farm fixed effect implies that only farms observed in at least two Censuses contribute to identification of parameters other than the farm fixed effect.

Our identification strategy follows other studies on extractive booms that exploit changing macro conditions (prices or technology) that affected different regions based on 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, geology is the characteristic used to delineate shale and nonshale farms; for the Marcellus the Pennsylvania-New York border, which corresponds to different policy regimes, provides the delineation. Identification of the effect of shale development rests on the assumption that time trends that affect farm real estate values did not affect areas that eventually had shale development (*Shale*=1) differently than areas that never had development (*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 in New York border counties differently than those on the Pennsylvania side. But given the similar proximity to urban areas of shale and nonshale counties in the Barnett and those on the PA-NY border, we believe that this is unlikely. Moreover, the empirical results will show that farms in the different groups experienced a similar trend in appreciation prior to shale development, providing a reason to expect similar trends in the absence of development.

Do self-reported land values incorporate subsurface rights at all?

We find evidence that to some extent, farmers include their oil and gas rights in the self-reported value of their farm real estate. For the Barnett Shale, where split estates are more common, natural gas development had a small positive effect on farm real estate values over time (Table 2). This is evidenced by the coefficients on the $Shale \ x \ Y_t$ interaction terms. In the northeastern part of the Marcellus Shale, where split estates are less common, we find much greater appreciation in the Pennsylvania counties, which experienced intense leasing and drilling, compared to adjacent counties on the New York side. At a similar stage of development (2012 in Pennsylvania and 2007 in the Barnett), the estimated shale effect for farms in the Marcellus is a 48 percent increase (0.39 log points) in real estate values compared to a 9 percent increase in the Barnett.

In addition to statistics presented in Fitzgerald (2014) we provide further evidence that split estates are common in Texas. In Texas, oil and gas rights are treated as real property like land and houses. Once an oil or gas well begins producing, the rights associated with it are assessed a value annually, upon which the owner pays local property taxes.[1] Weber, Burnett, and Xiarchos (2014) show how the oil and gas property tax base increased by more than $80,000 per student in Barnett Shale school districts relative to districts just outside of the shale. The Census of Agriculture collects information on all property taxes paid by farmers. If they commonly own their oil and gas rights, we should see an increase in property taxes paid per acre owned in shale

[1] More details on oil and gas property tax assessments in Texas can be found through the Tarrant Appraisal District website (www.tad.org) and in particular: https://www.tad.org/ftp_data/DataFiles/MineralInterestTermsDefinitions.pdf.

areas relative to nonshale areas. It is possible that school districts and local governments in the shale area lowered property tax rates as the tax base expanded, causing the total tax collections to return to pre-drilling levels. It is unlikely, however, that this would have occurred before an initial tax revenue windfall, which we should observe in our data in the form of greater tax payments at some point.

The fixed effects model with the log of property taxes paid per acre owned as the dependent variable provides little evidence that farmers in the Barnett Shale area began paying more taxes compared to those outside the shale as development matured (Table 2). If oil and gas right ownership were common among farmers there, we would expect tax payments to increase precipitously during peak drilling, since taxes are only assessed once production begins. Yet the coefficient on the *Shale x* Y_t interaction actually decreases from 2002 to 2007 when drilling and production increased substantially.

A similar analysis for the Marcellus is not indicative of the ubiquity of split estates because oil and gas rights are not taxed in Pennsylvania.[2] Indeed, we find that property taxes paid by farms on the Pennsylvania side changed little over time relative to properties on the New York side. This finding also gives us confidence that the differential appreciation 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 the leasing and drilling periods?

The second question our empirics inform is how the effect of shale gas development changes over the leasing and drilling stages of development. For farms in both the Barnett and Marcellus

[2] A 2002 decision by the Pennsylvania Supreme Court interpreted the state's assessment laws to exclude oil and gas (Pepe, 2009).

Shales, most appreciation occurred with leasing. Little if any additional appreciation occurred as wells were drilled and production began.

In the Barnett, farm real estate values evolved similarly from 1992 to 1997 in shale and nonshale areas. Real estate then increased in shale areas relative to nonshale areas in subsequent years. The largest period-to-period appreciation occurred from 1997 to 2002 when the coefficient on the $Shale\ x\ Y_t$ interaction went from -0.022 to 0.090, an increase of 0.112 log points. Neither of these coefficient estimates, however, are statistically distinguishable from zero. Only the Shale x 2012 coefficient is statistically significant and only at the 10 percent level.

The higher appreciation in the Barnett Shale from 1997 to 2002 corresponds to the period when leasing intensified. The weak evidence of additional appreciation from 2007 to 2012 may reflect investment of oil and gas wealth into land and buildings. Alternatively, Weber, Burnett, and Xiarchos (2014) find that increases in the value of oil and gas rights caused an increase in the property tax base in shale areas, helping to increase residential property values in shale areas relative to nonshale areas in the Dallas-Fort Worth region. Such increases in local property tax revenue may have also contributed to greater appreciation of farm real estate, either through greater demand for residential development or through lower property tax rates.

As with the Barnett Shale sample, farm real estate values initially evolved similarly in Pennsylvania and New York border counties up to 2002. In 2007, when most land would have been leased, farm real estate in shale areas appreciated by nearly 50 percent (0.39 log points) more than in nonshale areas. The higher values on the Pennsylvania side then persisted through 2012.

Our findings suggest that having lease offers in hand matters for landowners to value their land and the attached rights. In 2007 and 2008 there was no clear moratorium on fracking in

New York. The difference between Pennsylvania and New York around this time was that the rush to lease land started in Pennsylvania and only began spilling into New York near the end of 2007 (Wilber 2012, p. 48). In spite of property owners in the three New York counties likely owning oil and gas rights in the Marcellus Shale similar to their counterparts across the state line, less leasing on the New York side as of 2007 caused landowners there to place a low value on their oil and gas rights. This suggests that land owners were conservative in reporting of land values and did not assign much value to their oil and gas rights without lease offers in hand.

How common are split estates?

The property tax data suggest that split estates are common in the Barnett. Using quantile regressions we provide further evidence that split estates are more common in the Barnett Shale than the northeastern part of the Marcellus Shale, though there may be other reasons why the effect of shale development is different for the two regions.

Equation (4) does not control for whether a property has the oil and gas rights attached to it. Initially, these rights would have been almost worthless but would then gain tremendous value as technology and prices evolved to make drilling in shale profitable. The changing value of these rights are embedded in the residual because they vary across properties in the shale area. The shale indicator variable does not control for the rights because ownership of them varies across farms within the shale group. Quantile regressions permit estimating different effects for different quantiles based on a farm's residual. Quantile regressions with panel data are hard to interpret since an observation could change quantiles over time based on its residual. We therefore convert our panel data into a cross sectional model of the form:

$$(5)\quad \Delta \ln(value\ per\ acre)_t = \lambda_1 + \lambda_2 Shale_i + \boldsymbol{\lambda_3 X_{t-1}} + \upsilon_{it}$$

where $\Delta \ln(value\ per\ acre)_t = \ln(value\ per\ acre)_t - \ln(value\ per\ acre)_{t-1}$. The vector $\boldsymbol{X_{t-1}}$ includes several property characteristics potentially correlated with appreciation: the logarithmic of property taxes paid per acre owned, the log of the total acres owned, an indicator variable for whether the farm operator lives 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 in the farm.

The results in the prior section suggest that shale areas appreciate most during the land leasing period of development. For the Barnett sample we therefore specify t-1 as 1997, which is prior to when interest in the Shale grew, and t as 2002, when leasing occurred. Leasing in the northeastern Marcellus Shale 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 (5), we estimate the difference in appreciation between shale and nonshale areas at the 25th quantile (λ_2^{25}) by finding the parameters , $\lambda_1^{25}, \lambda_2^{25}$, and λ_3^{25}that minimize the sum of the absolute difference between the actual and predicated values, where observations with positive residuals are weighted by 0.25 and those with negative residuals are weighted by 0.75 (see equation 7.1 on p. 213 in Cameron and Trivedi, 2009). We estimate coefficients at the 25th, 50th (median), and 75th quantiles and, for comparison, at the mean.

The point estimates on the shale variable in the quantiles regressions for the Barnett show greater appreciation for farms at the 75th quantile than at the mean or median (Table 3). But, even at the 75th quantile the point estimate for the coefficient on the shale variable has a wide confidence interval and is not statistically distinguishable from zero. This provides further evidence of the ubiquity of split estates. We also note that the estimated shale effect is larger at the 25th quantile than at the mean or median, which does not match our prediction that properties with higher than average unobservable characteristics (presumably with the oil and gas rights) should appreciate more than other properties. Nonetheless, all of the point estimates for the coefficient on the shale variable have wide confidence intervals and are not statistically distinguishable from zero.

The Marcellus results better match our predictions: the effect of being in the shale area (the Pennsylvania side) was largest for farms in the 75th quantile, next largest in the 50th quantile, and smallest in the 25th quantile. We observe a statistically significant effect of shale leasing at the 75th and 50th quantile and at the mean but not at the 25th quantile based on unobserved characteristics. This may mean that the majority of farms in the Marcellus study area own the oil and gas beneath them. It could also suggest that resource richness, and therefore interest in leasing, is spread fairly uniformly across Tioga, Bradford, and Susquehanna counties. This is consistent with maps showing a broad swath of drilling occurring throughout these three counties. Drilling in the Barnett Shale counties was less uniform, with more drilling on the side of the counties closer to Fort Worth.[3]

How has shale gas development affected the value of rural residence and livestock properties relative to other properties?

As mentioned previously, the value of real estate in livestock farms and residence farms may be more sensitive to the disamenities from shale development. We define a livestock farm as one reporting more than 75 percent of sales from livestock, with a minimum of $10,000 in livestock sales. The USDA has traditionally used a farm typology that groups farms into Residence,

[3] For a map of cumulative natural gas wells drilled in Pennsylvania visit this site at the Energy Information Administration: http://www.eia.gov/todayinenergy/detail.cfm?id=6390. For the Barnett Shale, visit: http://www.eia.gov/todayinenergy/detail.cfm?id=2170.

Intermediate, and Commercial farms. Following this typology, we define a residence farm as any farm with less than $250,000 in agricultural sales and whose principal operator does not identify farming as their primary occupation and lived on the farm at least once in the census year.[4] The classification of a residence farm does not depend on acreage, so it should not be confused as a term for small farms. Large farms with little agricultural production can be termed residence farm, while productive small farms would not. We then estimate a modified version of Equation (5) augmented with a dummy variable indicating a livestock or residence farm and its interaction with the shale dummy variable:

(6.1) $$\Delta \ln(value\ per\ acre)_{it} = \pi_1 + \pi_2 Shale_i + \pi_2 Livestock_i + \pi_3 (Shale_i x Livestock_i) + \boldsymbol{\pi_4 X_{t-1}} + \nu_{it}$$

(6.2) $$\Delta \ln(value\ per\ acre)_{it} = \theta_1 + \theta_2 Shale_i + \theta_2 Residence_i + \theta_3 (Shale_i x Residence_i) + \boldsymbol{\theta_4 X_{t-1}} + \eta_{it}$$

As in Equation (5), this is a cross-sectional analysis focusing on the difference in the log value per acre before and after the leasing period. For the Barnett, t equals 2002 and t-1 equals 1997; for the Marcellus t equals 2007 and t-1 equals 2002. We estimate equations (6.1) and (6.2) separately instead of as a single equation including indicator variables for shale, livestock, residence, and their interactions, since we are limited in sample size to farms in both censuses in question for each study area. Including all interactions at once would result in just a few farms identifying the shale effect for residence livestock farms, for example.

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

The point estimate of the effect of being in the shale was less for livestock farms than for other farms in both the Barnett and Marcellus Shale samples (Table 4). In the Barnett, the shale effect was negative for livestock properties; for the Marcellus, the effect was positive but smaller for livestock farms than nonlivestock farms. In both cases, however, the point estimates are statistically insignificant. Less appreciation (or depreciation) over the leasing period for properties used to raise livestock instead of grow crops may indicate that livestock farmers are less likely to own their oil and gas rights. Alternatively, farmers may perceive that drilling poses a risk to the farm's water, lowering its value as a livestock farm.

For both the Barnett and Marcellus Shale samples we also find that the effect of being in the shale was larger for residence farms than for other farms. The point estimate of the coefficient on the *Shale x Residence* interaction is similar in both cases (0.43 and 0.45), though less precise in the Barnett sample (standard error of 0.28 compared to 0.20). The finding is the opposite of our prediction that the value of residence farms would be more sensitive to the disamenities for drilling (or expected drilling). As with nonlivestock farms, residence farms may be more likely to own their oil and gas rights. Perhaps prior interest in oil or gas development and therefore splitting of estates, focused on larger tracts of accessible land which is where larger farms tend to be located. Alternatively, farmers are potentially less able than residence landowners to move away in the event land or water are accidentally contaminated, which may make the former less willing to sign leases.

How has shale gas development affected land values in southwestern Pennsylvania where split estates are supposedly common?

Southwestern Pennsylvania experienced a similar wave of drilling beginning around 2005, slightly earlier than in northeastern Pennsylvania. Southwestern Pennsylvania does have a history of energy development, which is likely associated with more split estates as in the Barnett. We perform a brief analysis on the shale counties of Washington and Greene, which lie southwest of Pittsburgh. We chose Beaver and Lawrence counties just northwest of Pittsburgh as the most suitable comparison counties. While they are both Marcellus shale counties, only parts lie within the high formation pressure area that gives drillers higher production rates. Thus, they experienced much lower levels of drilling. Over the 2002 to 2012 period, 87 and 55 wells were drilled in Beaver and Lawrence, compared with 2,207 and 2,826 wells in Greene and Washington (PA DEP 2014).

Our fixed effects regression results indicate no significant effect of shale development on property values over our study period, only a significant negative effect from 1997 to 2002 (results not shown). The lack of significant effect otherwise is consistent with the weak effect in the Barnett Shale in Texas, where split estates are common. We have no plausible explanation for the relative depreciation in the shale counties or appreciation in the non-shale counties from 1997 to 2002. The quantile regression results are more in line with those in northeastern Pennsylvania, where splits estates are uncommon. Combined, our results fit the general assessment that split estates are most common in Texas, least common in northeastern Pennsylvania, and somewhat common in southwestern Pennsylvania. This gives some credence to our method of assessing the prevalence of split estates through a combination of panel fixed effects and quantile regression.

Conclusion - What We Have and Have Not Learned from Land Values

Shale gas development affects self-reported farm real estate values, indicating that to some extent farmers include their oil and gas rights in the market value of their land. Researchers using self-reported land values in the 2000s and more recently should be aware that oil and gas right ownership and development may cause large changes in values in certain areas and may be correlated with variables of interest. Moreover, if land values are conceptually envisioned to exclude subsurface rights, then the inclusion of them by respondents implies that land value estimates based on reported data will be too. To the extent that the frequency with which farmers own their oil and gas rights varies by region – and our findings suggest that it does – differences in land values across space may also be biased.

Appreciation occurs during the land leasing period, not when most drilling happens. The little to no additional appreciation in the drilling period may reflect several competing forces. On one hand, investment of royalty income in improvements to land or buildings, greater local public revenues and overall greater demand for land should cause appreciation during the peak drilling phase. On the other hand, other factors could cause depreciation: well productivity can decline exponentially shortly after being drilled and drilling can produce environmental disamenities and affect the land's suitability for the uses that give it value.

The nature of our data means that we can estimate only the long-term net effect of shale development on land values. We do not know if specific channels are at work and, if so, how much they contribute to appreciation or depreciation. Isolating the importance of various channels would provide a richer description of the effects of development. Land values will continue to be interesting to track in coming years as they will reveal how the combined effect of the above mentioned causal channels evolve as shale development matures. Our last year of analysis, 2012, was near the Barnett's peak; production continued to grow after 2012 in the Marcellus.

The effect of development on property values appears to vary by property type, though our samples are too small to provide rigorous and fine-grained breakouts. For both the Barnett and the Marcellus we find that residence farm properties appreciated more as land was leased. In contrast, for both regions point estimates suggest that livestock farms appreciated less than other farms in the shale, though the difference was not statistically significant in either case. This is an area fertile for research and one where regional differences will matter. Water scarcity in the west may reduce the value of farms dependent on ground or surface water for growing crops or raising livestock. In the east, water quality may matter more and mostly for livestock farms since most crops are rain-fed.

In all of the questions raised, a continued empirical challenge is the lack of data on oil and gas right ownership. It remains a glaring omitted variable in any study of property values and oil and gas development. This is true for self-reported data or sales data. For self-reported data it is necessary to know if oil and gas rights are present and if they are included in the reported land value; for sales data, it is important to know if they were initially present and, if so, if they were conveyed to the buyer. Our empirics provide indirect evidence that the frequency of split estates is more common in the Barnett Shale than in the northeastern part of the Marcellus Shale. Ownership may also be correlated with characteristics of the property that make it more or less valuable, such as accessibility and distance to urban centers. Ownership data would therefore aid in identifying environmental disamenities from drilling apart from changes in oil and gas right ownership or valuation.

Tables

Table 1. Summary Statistics

	Texas - Barnett				PA/NY - Marcellus			
	Shale		Non-Shale		PA		NY	
Farm Real Estate Value	$/Acre	N	$/Acre	N	$/Acre	N	$/Acre	N
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	$/Acre	N	$/Acre	N	$/Acre	N	$/Acre	N
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
Residence Farms	%	N	%	N	%	N	%	N
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	%	N	%	N	%	N	%	N
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 observed in at least two Censuses of Agriculture from 1992 to 2012 and that received the census questionnaire asking for real estate values are included. Real estate values and property taxes are per acre of land owned by the farm. Residence farms are defined as any farm with less than $250,000 in agricultural sales and whose principal operator does not identify farming as their 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. The increase in the number of farms in 2007 and 2012 reflects changes in the 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, whose influence is mitigated by using a log specification in our empirical model.

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

	Texas - Barnett		PA/NY - Marcellus	
Dependent Variable	Log(value/acre)	Log(property tax payments/acre)	Log(value/acre)	Log(property tax payments 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	FE	FE	FE	FE
Number of observations	25,529	24,719	8,904	8,700
Number 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, * p<0.1. Robust standard errors clustered by farm in parentheses. FE denotes farm-level fixed effects. The excluded year is 1992. In the Pennsylvania – Marcellus analysis, the variable *Shale* equals 0 for the farms in the New York border counties. Although they are in the Marcellus Shale, state policy has precluded shale development.

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)				PA/NY - Marcellus (t=2007, t-1=2002)			
	Mean	25th	50th	75th	Mean	25th	50th	75th
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 payments/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 R2	0.076				0.104			

Note: *** p<0.01, ** p<0.05, * p<0.1. Standard errors for the mean regressions 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 difference with different five-year periods chosen for the Barnett and Marcellus depending on the start of the leasing period. In the Pennsylvania – Marcellus analysis, the variable *Shale* equals 0 for the farms in the New York border counties. Although they are in the Marcellus Shale, state policy has precluded shale development.

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 payments/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 R2	0.053	0.054	0.132	0.120

Note: *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses. This is a cross-sectional analysis. L. designates a five-year lag, 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 period. In the Pennsylvania – Marcellus analysis, the variable *Shale* equals 0 for the farms in the New York border counties. Although they are in the Marcellus Shale, state policy has precluded shale development.

Figures

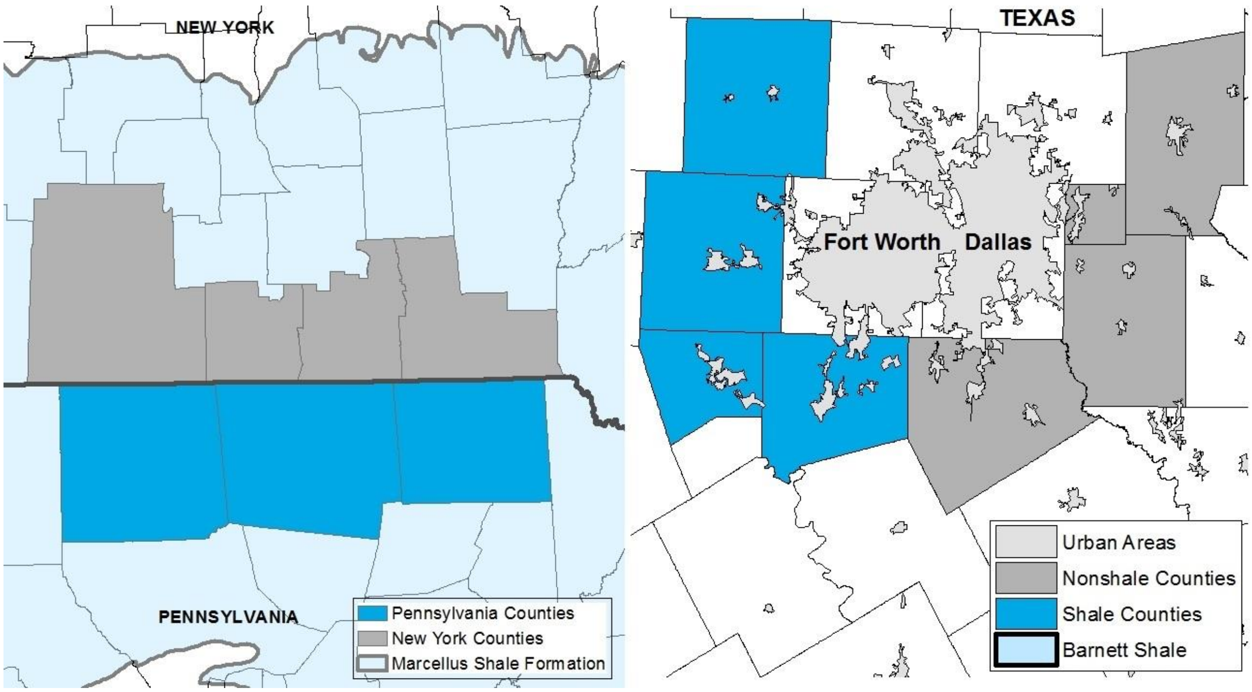

Figure 1. Study Regions and Counties

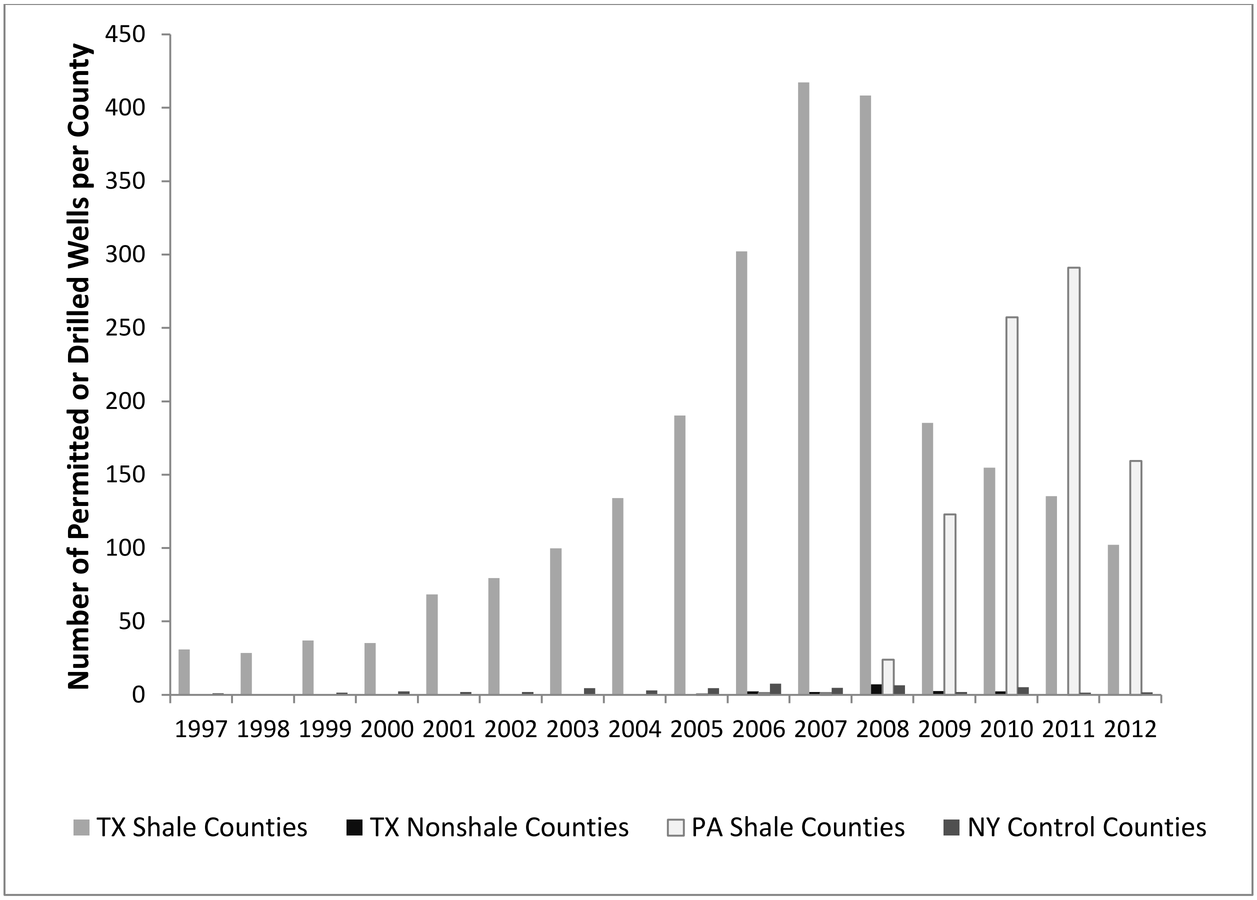

Figure 2. Shale Gas Development, 1997-2012

Source: Pennsylvania Department of Environmental Protection; New York Department of Environmental Conservation; Railroad Commission of Texas.
Note: Only unconventional wells are considered, which are those 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 when the well was drilled. For Texas, the year corresponds to when the well permit was approved, excluding permits that were never drilled. The TX Shale and Nonshale Counties and the PA Shale and NY Control Counties correspond to the counties in the map in Figure 1.

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