Boomtowns and the Nimbleness of the Housing Market:

The Impact of Shale Oil and Gas Drilling on Local Housing Markets

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Abstract

Recent drilling innovations allowing access to unconventional resources like tight oil and shale gas have spurred a number of drilling booms around the United States. One side effect is rising housing prices caused by migrating oil and gas industry workers who create a positive housing demand shock. Initial research has examined the effect of these shale drilling booms on rental prices and home valuations, but thus far the effect of the price signal on housing supply has not been investigated. Using two-way fixed effects estimators I analyze the effect of shale drilling operations on population, home and hotel construction in the Marcellus, Bakken and Fayetteville Shale regions, finding that a housing boom accompanies the drilling boom. The size of the impact tends to increase as the considered region becomes more rural and remote.

Introduction

The recent conjoining of multiple drilling innovations, including hydraulic fracturing and horizontal drilling, has initiated a revolution in oil and gas drilling. These technologies allow the extraction of vast amounts of previously uneconomical resources. The first major implementation of this drilling method occurred in the Barnett Shale region near Fort Worth, Texas in the early 2000's (citation). Subsequent drilling booms have been observed in the Haynesville Shale (Texas and Louisiana), Fayetteville Shale (Arkansas), Marcellus Shale (Pennsylvania and West Virginia), Bakken Shale (North Dakota and Montana), Permian Basin (Texas), and the Eagle Ford Shale (Texas) regions. Future drilling booms may occur in the Utica Shale (Ohio), Mancos Shale (New Mexico), and Niobrara Shale (Colorado), among many other regions currently being explored.

These booms create spillover effects into the local economy in the drilling region. The size of the boomtown effects depend on the specific nature of the resource and aspects of the local region, including the population, employment, industry composition, and connectedness with other population centers. Three impacts have been commonly mentioned by local officials in media reports from the regions experiencing these drilling booms. The itinerant population of drilling industry workers competes with each other and the local population for temporary housing, bidding up the price of rental properties in the process. Local roadways suffer deterioration and congestion due to a substantial increase in truck traffic hauling drilling supplies and extracted resources. Lastly, the influx of drilling industry workers strains the physical and institutional infrastructure providing public services. This report focuses on the response of the local housing market to the increased housing price signal.

Background and Motivation

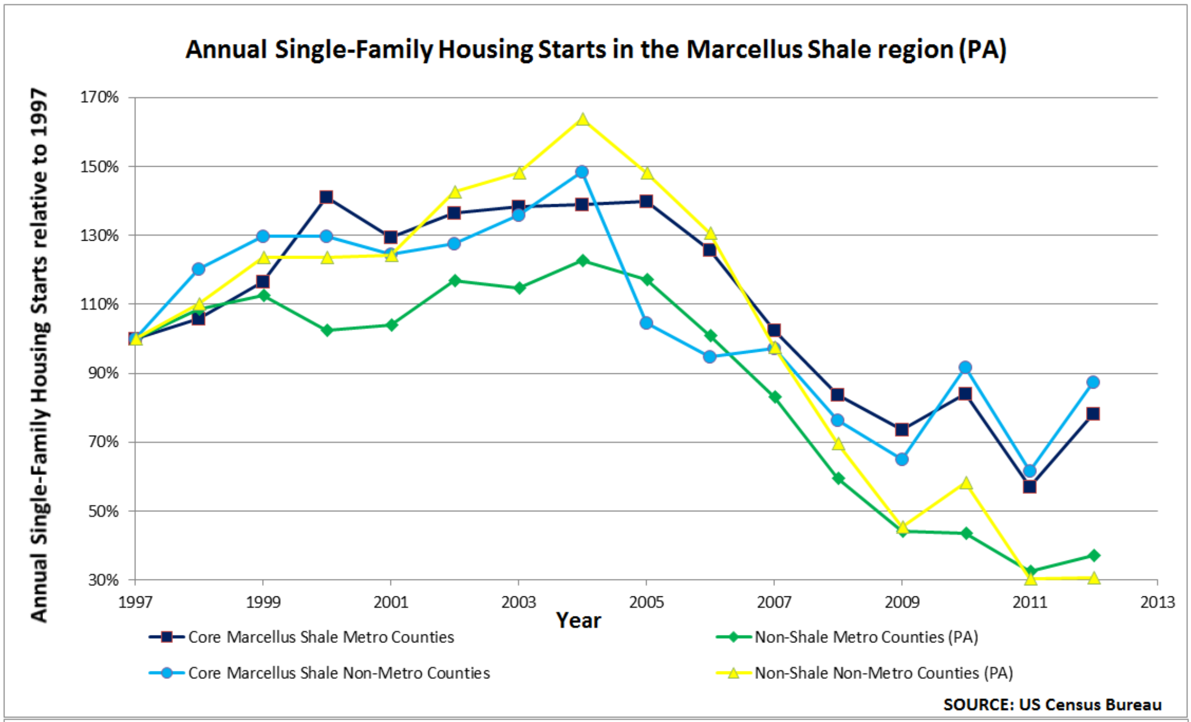
The story of an unexpected and valuable resource discovery leading a flood of entrepreneurs to an isolated region to exploit that commodity is a common narrative in popular literature, especially with regard to the settling of the American frontier. The accompanying boomtown economy is similarly iconic. The occurrence of boomtowns has dwindled as the last unknown frontiers have been explored, however. The exception to this rule has been those areas rich in commodities which experience ebbs and flows of demand based upon market prices.

Oil and natural gas are good examples of such commodities. Conventional oil and gas resources exist as discrete subsurface reservoirs where the resource is trapped in porous geologic formations by surrounding low-permeability formations. Some reservoirs in a given oil or gas field are easier to extract resources from than others and therefore exhibit a lower production cost. The lowest cost reservoirs are exploited first and when market prices rise there is a rush to tap the higher cost reservoirs, creating multiple temporary boomtowns over long time cycles. The Permian Basin in Texas is a good example of such an area, having experienced drilling booms starting in the 1940's, 1970's, and 2000's.

The combination of drilling technologies unlocking access to unconventional[1] shale oil and gas resources may create such similar 'generational' boomtowns following the initial surge in drilling. Each shale well is expected to provide substantive production for 30 years (US EIA, 2013) and as well production volumes decline they can be re-fractured stimulate further production. The potential for sequential drilling booms depends on the contemporary market price of oil and gas and the recoverability of the remaining resources. Since the shale drilling booms seen so far have occurred with relatively low recovery factors[2], there is a reasonable likelihood that future drilling innovations which allow recovery of greater amounts of the in-place resource will incentivize multiple boom periods. In addition, shale regions have 'sweet spots' of high production volumes, similar to conventional reservoirs. These areas are targeted first for drilling, leaving the less economical areas available to be drilled in the future when commodity prices are more favorable.

Because of the large number of regions with unconventional resources, their widespread occurrence throughout each region, and the potential for multiple booming periods to occur as commodity prices and drilling innovations allow, an understanding of the specific effects of unconventional resource drilling booms on the local economy is important. This knowledge will allow local leaders and entrepreneurs to more deftly navigate the impact of the boom and bust, providing for better governmental policy and business decisions to maximize the economic benefits and mitigate the social costs. A quantitative analysis and comparison between the regions can also provide a greater understanding of how a region's connectivity with nearby population centers affects its experience of the boomtown effects.

This paper focuses specifically on the impact of drilling booms on housing construction. Many media reports have indicated that apartment rent prices have doubled or tripled in the most intense drilling areas, leading for calls for state and federal governments to implement need-based housing assistance. Pennsylvania's Housing Affordability and Rehabilitation Enhancement (PHARE) Fund is an example of such legislation. However, programs subsidized by the legislation were not funded until early 2013, two years after the peak of drilling in the Marcellus Shale region. Therefore, the legislation likely did not exert downward pressure on local housing prices until three years after the time of greatest need. Meanwhile, recent policy studies (Farren et al. 2013; Partridge et al. 2013; Farren 2014) have indicated that a contemporaneous housing construction boom has accompanied previous drilling booms, indicating that the housing market may be responding more nimbly to price signals than anticipated. Figures 1 through 3 illustrate the housing market response in the Marcellus, Bakken, and Fayetteville Shale regions. In each region there is a substantial increase in home and hotel construction in primary drilling counties compared to non-drilling counties. A quantification of the size and speed of the private market's response to housing price signals will serve to both better inform policy and illuminate the responsiveness of home construction to positive price shocks.



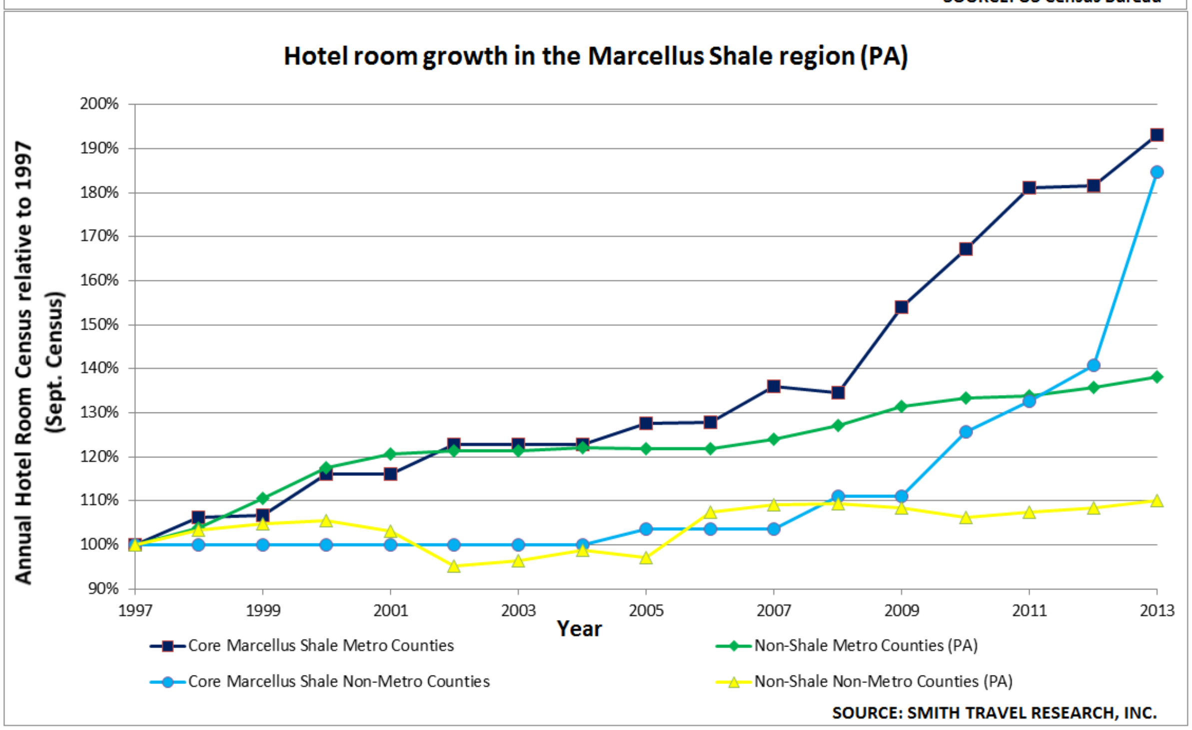
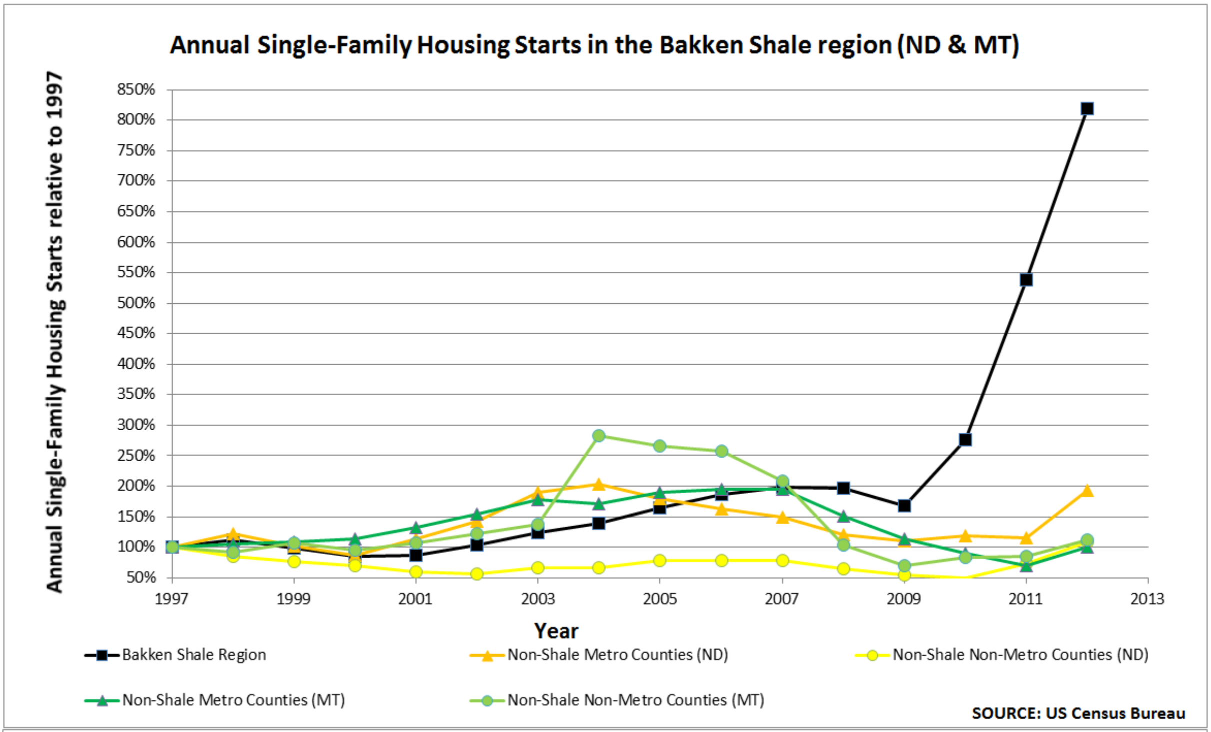


Figure 1: Housing Development during the Drilling Boom in the Marcellus Shale



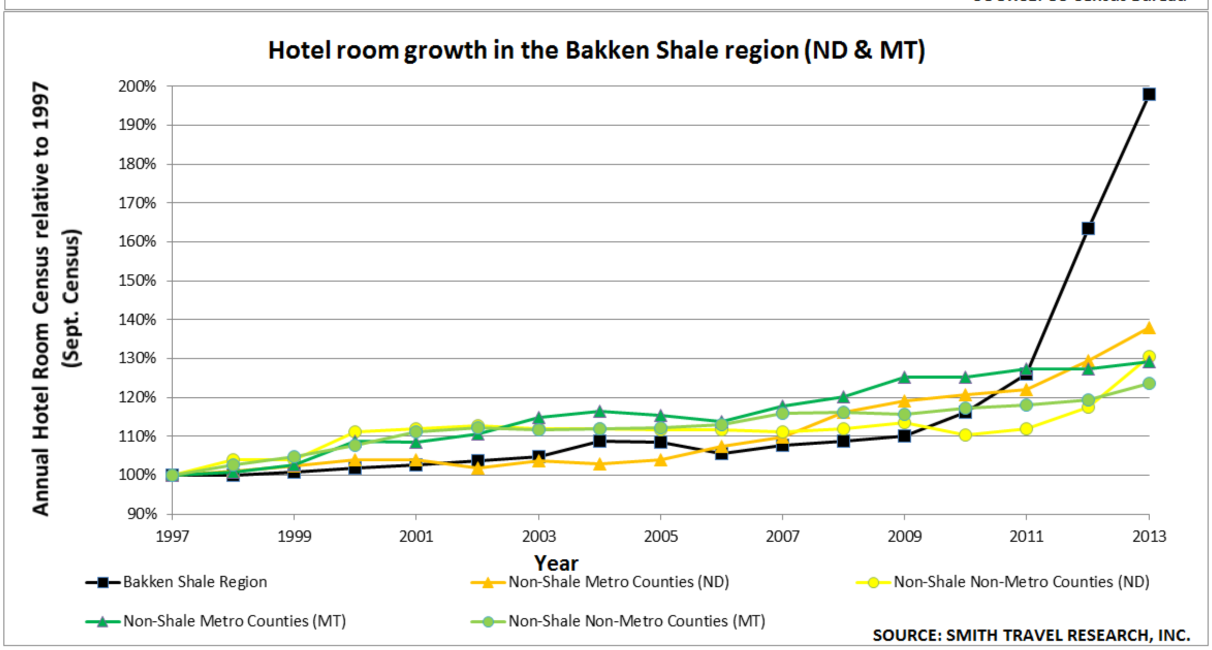
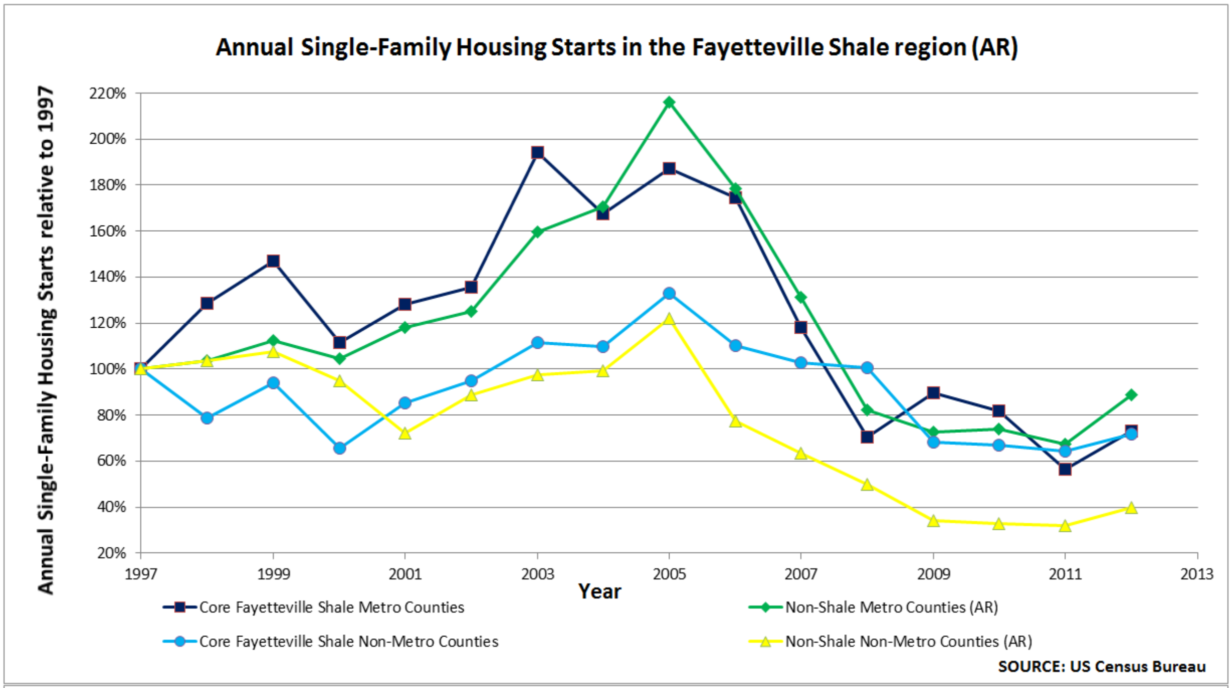


Figure 2: Housing Development during the Drilling Boom in the Bakken Shale



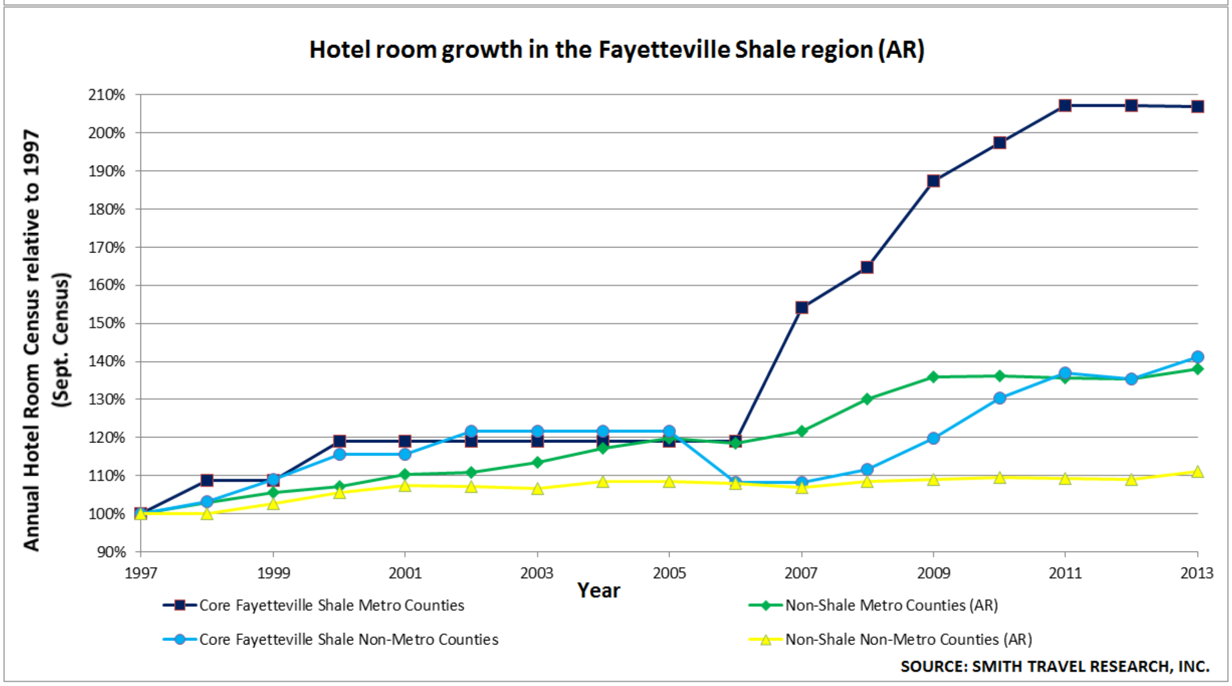


Figure 3: Housing Development during the Drilling Boom in the Fayetteville Shale

Literature Review

There is a general lack of literature investigating the connection between boomtown economies and housing supply, though some affiliated literature provides illumination of the subject. Randall and Ironside (1996) find that a given community's experience with a booming energy industry depends on the relative isolation of the community, the degree of resource dependency, and its specific labor market characteristics. In particular, it is important to account for the differences in production cycle and the corresponding effects on the local population that unconventional resources such as shale oil create, since they are different than those of traditional oil drilling (Headwaters Economics 2012). Farren et al. (2013) and Partridge et al. (2013) investigate the potential for shale gas drilling activities in the Marcellus shale region to have impacts on the local housing market, finding that the Fair Market Rent rose in counties with the most drilling activity and that each well drilled was associated with 2.5 new residential housing permits in the county.

A portion of the relevant literature looks at the impacts of natural resource extraction on property values. Boxall, Chan, and McMillan (2005) find that natural gas development in Alberta, Canada decreases residential property values nearby, potentially through degrading the local environmental amenities. Kelsey, Adams, and Milchak (2012), find that the scale of shale gas drilling in the Marcellus Shale region is not associated with changes in the total market value in drilling townships during the initial years of the boom. Muehlenbachs, Spiller and Timmins (2012; 2014) investigate this same effect on individual residential properties, finding that nearby shale gas wells have a net negative effect on home value, a similar result to Boxall et al. Gopalakrishnan and Klaiber (2014) find that the drilling activities associated with nearby shale gas wells in the Marcellus region caused substantial reductions in home sale prices, but that these effects were short-term and faded with distance. James and James (2014) find similar reductions in home sale prices in Colorado's Niobrara region were associated with existing wells rather than wells under construction.

Conceptual Framework

Shale gas and oil development proceeds in several general stages. Each region and energy firm proceeds through the stages individually, based on when the region-specific technologies are discovered that enable economical resource extraction. This means that it can be hard to specifically delimit the timing of each stage for each region, but these classifications are useful as a conceptual framework to understand the shale oil or gas drilling boom cycle.

The preliminary stage is the 'Innovator Stage'. During this time period geologists, petroleum engineers, and entrepreneurs are involved in trying to find new resources or innovate new methods of extracting known but hard-to-reach deposits of oil and gas. Once these individuals are successful, the process moves into the 'Landmen Stage'[3] during which drilling rights are procured by the oil and gas firms. Some initial drilling will occur during the Innovator and Landmen Stages as companies search for best drilling methods to use, but I characterize the primary period of intense drilling as the 'Roughneck Stage'[4]. During this stage, wellpads are constructed, wells are drilled, and the pipeline and oil-/gas-field infrastructure is built. This stage is likely to continue until the most economically attractive resource have been tapped, which can be influenced by actual well production volumes or changes in market prices which make another resource more attractive[5]. The final stage is the 'Asset Manager Stage' where most of the drilling has been completed and energy industry activities have shifted to management and maintenance of continued production from the mature oil- or gas-field.

The different stages of a drilling boom have different impacts on the local housing market in the drilling region. The Innovator Stage likely has the least effect, as it involves a relatively small increase in demand for housing relative to an equivalent community where no gas or oil exploration is occurring. This demand is likely to be for short-term housing in preference to long-term housing unless an established oil and gas industry exists in the region. The Landmen Stage should substantially increase the demand for itinerant (hotels) and short-term housing (apartments) as each drilling firm needs to send numerous agents to the region to pore over paper copies of property sale records going back for decades to determine if the mineral rights were ever severed from the land rights and the current owner of the sub-surface minerals. The drilling rig workers of the Roughneck Stage will likely have similar housing demands to the landmen, although by this point in the development process oil and gas company managers may also be moving to the region seeking long-term housing (apartments and houses). Long-term housing demand will also increase during the Asset Manager Stage due to the permanent, career-oriented positions are created locally by the oil and gas companies to supervise production operations and also because of increased demand from residents with greater availability of employment opportunities and larger incomes from mineral royalties or the booming economy incentivize them to seek housing locally.

There is good potential for these stages to overlap, meaning that the increased demands for itinerant and short-term housing may combine and that the demand for long-term housing may occur simultaneously. This could be motivated by firms' rush to capitalize on the recent higher-than-average market prices of oil and gas which made the expensive hydraulically-fractured horizontal wells economical in the first place.

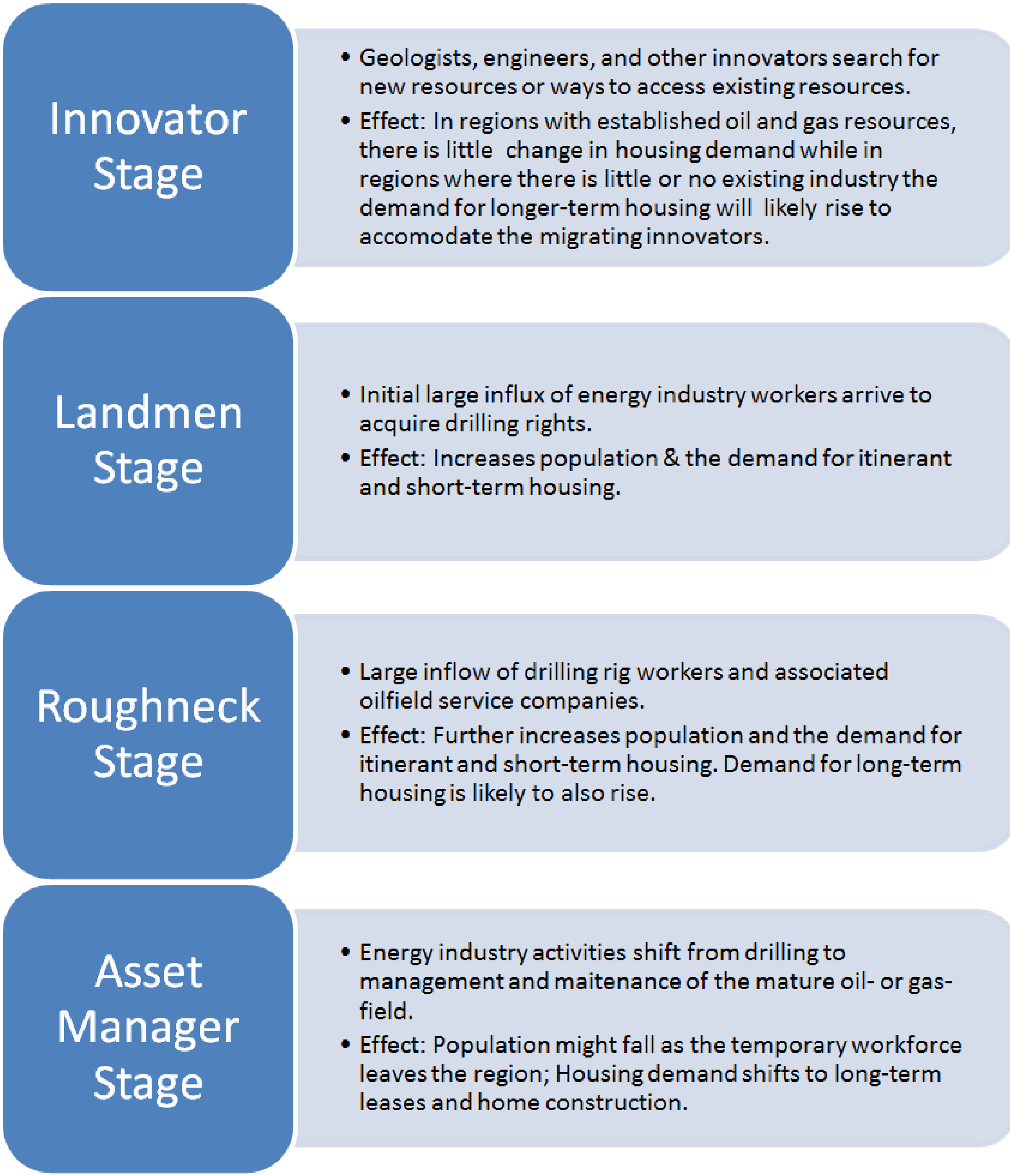


Figure 4: Stages of Shale Oil and Gas Development

Analytical Framework

I use a county-level analysis with two-way fixed effects panel regression estimators to estimate the impact of nearby shale drilling operations on measures associated with increases in housing demand (population) and supply (home and hotel construction). Fixed effects panel regression assists in the control (on average) of unobserved, unchanging, county-specific heterogeneity which would bias the analysis. This is important because some regions under consideration have established oil and gas industries already in place, which could potentially change their response from those areas which do not (those counties with established industries likely already have a locally-based workforce, reducing their need to import workers and reducing the housing market impact). Additionally, the shale drilling booms have occurred at approximately the same time as the US housing crisis, economic recession and recovery, meaning that time fixed effects are needed to account for unobserved, macroeconomic shocks to local housing markets which would otherwise be correlated with drilling operations. Robust standard errors are clustered by county to help control for autocorrelation issues.

The baseline model takes the form

$$Y_{i,t} = \alpha + \beta_1 X_i + \Delta_i'\beta_2 + Z_i'\beta_3 + T_t'\beta_4 + \varepsilon \qquad (1)$$

where Y_i corresponds to the housing market measure in question. The county population is used as a proxy for housing demand while the number of residential unit construction permits approved (single-unit and multi-unit buildings) and the total number of hotel rooms are used as measures of housing supply. X_i corresponds to the shale drilling metric (shale development-related employment or the number of shale wells drilled) and Δ_i is a set of variables which would influence the local housing market (median household income, poverty rate, expected employment growth, and the county population for the housing supply analyses). Z_i and T_t are the county and yearly fixed-effect variables.

It is possible that low levels of shale drilling are not sufficient to have a noticeable effect on the local housing market because the incoming oil and gas industry workers might simply utilize any surplus housing available. Conversely, large amounts of drilling are likely to overwhelm the surplus supply and incentivize local home and hotel construction to meet the increased demand. In order to account for the potential of non-linear effects of shale development on the housing market – as found in Farren et al. (2013) – I also use the primary explanatory variables in quadratic form:

$$Y_{i,t} = \alpha + \beta_5 X_i + \beta_6 X_i^2 + \Delta_i'\beta_7 + Z_i'\beta_8 + T_t'\beta_9 + \varepsilon \tag{2}$$

Both the linear and quadratic models are regressed in level and log-log form.

Identification Strategy

The implicit assumption used in this analysis is that oil and gas industry workers desire to minimize their travel time from their home to the drilling area, all other things being equal. This would increase housing demand in counties with higher levels of drilling and would incentivize producers to increase the housing supply in these counties. Countering this tendency is the public perception of negative environmental impacts caused by hydraulic fracturing. Previous research has showed that housing values near gas wells were negatively affected by the wells' proximity (Boxall, Chan, and McMillan, 2005), especially homes which used well water (Muehlenbachs, Spiller, and Timmins 2012; Gopalakrishnan and Klaiber 2014) or were located in agricultural settings (Gopalakrishnan and Klaiber 2014). James and James (2014) in a national analysis found that property values near active shale wells generally decreased on a county-wide basis. The perceived environmental disamenity from living in a county experiencing intense shale drilling operations could limit housing growth and perhaps push it into nearby non-drilling counties instead.

The primary explanatory variables I use to estimate the impact of shale drilling booms on the housing market are the county-specific employment in industries associated with the shale drilling boom[6] and the number of oil and gas wells drilled that target shale resources. If oil and gas industry workers are living largely in the same counties as they are drilling shale wells, then the two analyses should show positive correlations with the housing supply variables. If instead oil and gas industry workers are avoiding living in drilling counties by commuting from non-drilling counties, then the estimated coefficients should show a negative correlation with the housing supply variables. If the wells-based analyses show a positive correlation with housing supply while the employment-based analyses return indeterminate effects this could be a sign that housing market effects are spilling over to nearby counties from the primary drilling counties.

To properly identify the various shale booms' effects on the local housing market it is important to control to the greatest extent possible for other major factors affecting housing supply and demand. The time- and spatially-varying factors chosen for this purpose are the population. median household income, the poverty rate, and expected employment growth rate. These variables capture the changes in gross demand and the ability to purchase housing while the county and annual help control for long-run differences between different counties' housing market and temporal effects, such as the 2007 bursting of the US housing bubble.

Data

The analysis uses a panel data set consisting of annual, county-specific observations spanning from 1997 through 2011. Three regions that have experienced shale booms are investigated; the Marcellus Shale (Pennsylvania, West Virginia, Ohio, and New York), the Bakken Shale (North Dakota and Montana), and the Fayetteville Shale (Arkansas). The data on increases in housing supply come various federal, state, and private industry sources. Information on the number of shale wells drilled per county is available on a state-by-state basis, generally from each state's Department of Environmental Protection or the Office of Oil and Gas Management or their equivalent. Annual county-level measures of population and median household income are available through the BEA. The number of single- and multiple-unit residential building permits approved is available from the U.S. Census Bureau[7]. Poverty measurements are provided by the Small Area and Income Poverty Estimates (SAIPE) program through the US Census Bureau. Counts of urban and rural populations are also available through the Census Bureau. Monthly census information on the number of hotel rooms by county is obtained from Smith Travel Research (STR), Inc. Lastly, high-quality employment data by industry is available from EMSI (Economic Modeling Specialists Intl.), an economic data clearinghouse and consulting firm[8].

Results

Population

The result of the population-focused regression which was the most comparable between regions is shown in Table 1. The regressions of the county population on the shale development employment metric showed generally strong and consistent results. The linear model indicated that each new job associated with shale drilling operations was correlated with a population increase of between three to ten persons. Since there are many oilfield service industries that follow oil and gas drilling operations, this general result is not surprising, although the coefficient estimate of 9.7 in the Fayetteville Shale is surprisingly large. One explanation is that since the comparison is between drilling counties and other non-drilling counties in the same state, this number may indicate that persons in Arkansas were leaving non-drilling counties and moving to drilling counties, which partially double-count the migration of the same person. Alternately, the population of most counties in Arkansas may have been generally decreasing during this time period and the shale drilling operations countered this trend in some counties. Even more interesting are the results of the quadratic model, which returned a much tighter range of coefficient estimates. Under this model, each new shale development job was associated with an increase of between 4.4 and 5.5 total persons in the county population.

Hotel Construction

The increase in the number of shale development jobs was also the best predictor of the increase in hotel rooms in the same county (see Table 2). These regressions showed surprisingly strong explanatory power, which may have more to do with the general trend of hotel construction across all counties rather than the explanatory strength of shale development employment. The three regression returned similar results in the linear model, where each 100 additional shale development jobs were associated with an increase of four to fifteen new hotel rooms in the same year. The Bakken Shale estimate was especially precise while the others were not. This may indicate that hotel development is likely to occur in the same county as shale drilling when there are no large population centers in nearby counties to serve as attractions for commercial, social, and public amenities (ie: through local stores, restaurants, bars, public utility service, etc.). In contrast, the Marcellus estimate was imprecise while the Fayetteville estimate became negative and highly precise in the quadratic model. Given that the Fayetteville Shale region is immediately adjacent to Little Rock, Arkansas, it is likely that most of the hotel growth occurred in the metro area and that oil and gas industry workers commuted to the counties north of the city where the drilling was occurring. Examining Figure 3 provides additional support for this hypothesis.

Home Construction

Tables 3 and 4 show the results of the regression of the number of shale wells drilled each year on the number of building permits approved for private homes. The regressions investigating the increase in multi-unit (apartment-style) residential structures provided relatively little explanatory power and are not reported.

The regressions of private home construction permits approved to the annual wells drilled in the same county showed the best predictive power in the Marcellus Shale region. Similar to previous research (Farren et al., 2013; Partridge et al., 2013), each Marcellus well was association with about 1.7 housing permits, although this value decreased with increasing amounts of shale wells since the estimated quadratic coefficient is negative. The Bakken and Fayetteville regions returned much less precise estimates, but it is interesting to note that the relationship of their quadratic form estimated coefficients was the opposite of the Marcellus Shale – for larger amounts of wells drilled the number of homes built accelerated.

The logarithmically-transformed regressions show the best results in the regressions of the log of private home construction permits approved on the level measure of shale wells drilled. The results clearer than in the level-level regression. Both the Marcellus and Bakken

Shale regions show very precise coefficient estimates while the scale of the Fayetteville Shale estimates are similar to the Marcellus Shale coefficient estimates, but much less precise. Each 100 shale wells drilled in the Marcellus Shale region are associated with a 30 percent increase in housing construction, while the same number of wells drilled in the Bakken Shale region are associated with a 126 percent increase in housing construction in that county that same year. In short, these results fit the expected hypothesis that rural shale regions would experience greater housing market impacts than suburban regions and that remote regions would experience even larger impacts than the rural regions.

Future Work

These results represent a preliminary analysis of the potential of shale oil and gas drilling booms to impact the local housing market, especially through stimulating housing construction. However, the issue of spillover effects from drilling counties to nearby non-drilling counties has not yet been addressed and likely obscures an accurate estimation of the effects. Similarly, controlling for the relative size of the boom through interactions of the primary explanatory variables (shale development employment and shale wells drilled) with the area that the county covers and size of the local population will also likely help provide better estimates of the actual impact. Utilizing propensity score matching to better compare shale drilling counties with proper counterfactuals should also provide more accurate results. Lastly, the regressions utilized here were limited by the availability of employment data and so do not include the post-boom drilling slowdown in the Marcellus Shale region or the continued acceleration of drilling in the Bakken Shale. A subsequent analysis of the full wax and wane of the Marcellus boom and including the peak of the Bakken drilling will likely provide more precise estimates.

Conclusion

Although there was not a strong trend across the results supporting the hypothesis that the housing market impacts from shale booms in remote drilling areas would be larger than those in rural areas, which would themselves be larger than the effects on suburban areas, the results did show that the largest estimated impacts, in a relative sense, occurred in the remote Bakken region while the suburban Fayetteville region produced the least-accurate/most-difficult-to-interpret effects. Further, more sophisticated, analysis will likely clear up some of the ambiguity, but the general hypothesis that shale drilling operations have spurred localized housing construction booms has been validated.

	Marcellus-Utica		Bakken		Fayetteville	
	Population	Population	Population	Population	Population	Population
Shale Dev. Employment	3.774	5.027**	2.806*	5.47**	9.701**	4.427
	(2.391)	(2.419)	(1.607)	(2.125)	(3.917)	(5.526)
(Shale Dev. Employment)^2		-4.7e-05		-3.5e-04**		.0012
		(5.5e-05)		(1.7e-04)		(.0016)
Median Household Income	1.528***	1.539***	-.0421	-.0659	1.185***	1.214***
	(.2828)	(.2861)	(.0381)	(.0403)	(.4281)	(.4373)
Poverty	757***	768.6***	198.7*	196.1*	368**	354.6**
	(268.6)	(268.4)	(101.7)	(99.76)	(159.7)	(158.5)
Expected Employment Growth Rate	-393.3*	-423.6**	-557.9***	-549.7***	-1016***	-1005***
	(216.9)	(205.9)	(188.3)	(184)	(300.5)	(303)
R-squared	0.210	0.212	0.202	0.221	0.382	0.392
Ad. R-squared	0.207	0.208	0.193	0.212	0.372	0.381
F	3.911	3.742	2.015	1.74	2.418	2.721
Observations	4080	4080	1635	1635	1125	1125
Breakeven Point	-	1,069,574	-	15,629	-	N/A

(Standard errors shown in parantheses) * = p<0.1 ** = p<0.05 *** = p<0.01

Table 1: Two-way Fixed Effects Regression of County Population on Shale Development Employment

	Marcellus-Utica		Bakken		Fayetteville	
	Hotel Rooms	Hotel Rooms	Hotel Rooms	Hotel Rooms	Hotel Rooms	Hotel Rooms
Shale Dev. Employment	.1456	.0253	.0364***	.0369	.0568	-.1493**
	(.0925)	(.1259)	(.0112)	(.0306)	(.0347)	(.0638)
(Shale Dev. Employment)^2		5.1e-06		-6.1e-08		5.0e-05***
		(7.5e-06)		(3.0e-06)		(1.5e-05)
Population	-.0058	-.0042	.0294	.0294	.0497*	.0526*
	(.0069)	(.0082)	(.0182)	(.0181)	(.0278)	(.0268)
Population Density	2.516**	2.232	-10.24	-10.23	-18.08	-21.06
	(1.273)	(1.585)	(34.41)	(34.29)	(19.52)	(18.91)
Median Household Income	.0349***	.0324***	-5.7e-04	-5.8e-04	-.0072	-.0048
	(.0115)	(.0124)	(9.7e-04)	(9.6e-04)	(.0052)	(.0049)
Poverty	16.86*	14.37*	5.766**	5.767**	-.1152	-.3097
	(8.799)	(7.642)	(2.85)	(2.853)	(2.603)	(2.446)
Expected Employment Growth Rate	-24.53**	-21.23*	-.1061	-.1072	12.09*	10.82*
	(11.82)	(12.85)	(2.479)	(2.473)	(6.229)	(5.591)
R-squared	0.363	0.369	0.62	0.62	0.757	0.771
Ad. R-squared	0.360	0.366	0.614	0.613	0.752	0.766
F	17.41	110.8	27.56	30.86	22.11	41.4
Observations	3885	3885	1290	1290	1016	1016
Breakeven Point	-	N/A	-	6,049,180	-	2,986

(Standard errors shown in parantheses) * = p<0.1 ** = p<0.05 *** = p<0.01

Table 2: Two-way Fixed Effects Regression of the Number of Hotel Rooms per County on Shale Development Employment

	Marcellus-Utica		Bakken		Fayetteville	
	Houses	Houses	Houses	Houses	Houses	Houses
Shale Wells Drilled	.633*** (.2166)	1.692** (.7281)	.2596 (.2425)	-.1649 (.2183)	.0728 (.0809)	-.4468 (.5936)
$(\text{Shale Wells Drilled})^2$		-0.0039* (0.0021)		.0015 (.0013)		.0025 (.0026)
Population	-.0111** (.005)	-.011** (.005)	-.0032 (.0048)	-.0034 (.0048)	-.009 (.0056)	-0.0098* (0.005)
Population Density	.4838*** (.1846)	.4844*** (.1843)	14.39 (11.34)	14.54 (11.3)	3.243 (4.676)	3.979 (4.222)
Median Household Income	-.0096 (.0076)	-.0097 (.0076)	.0038*** (.0011)	.0039*** (.0011)	.018** (.0081)	.0179** (.0081)
Poverty	-10.15* (6.088)	-9.958 (6.05)	2.042** (.9863)	1.962** (.9802)	1.063 (1.733)	1.055 (1.732)
Expected Employment Growth Rate	32.07*** (6.091)	31.49*** (6.01)	7.891* (4.683)	7.854* (4.681)	18.37 (11.37)	18.35 (11.37)
R-squared	0.325	0.326	0.119	0.122	0.126	0.126
Adj. R-squared	0.322	0.322	0.108	0.11	0.109	0.109
F	11.57	10.98	2.717	2.679	20.66	20.64
Observations	4050	4050	1635	1635	1095	1095
Breakeven Point		434		110		179

(Standard errors shown in parantheses) * = p<0.1 ** = p<0.05 *** = p<0.01

Table 3: Two-way Fixed Effects Regression of the Number of Approved New Housing Construction Permits on the Number of Shale Wells Drilled

	Marcellus-Utica		Bakken		Fayetteville	
	log(Houses)	log(Houses)	log(Houses)	log(Houses)	log(Houses)	log(Houses)
Shale Wells Drilled	.0017*** (4.5e-04)	.003* (.0016)	.0053*** (.0014)	.0126*** (.0044)	.0038 (.0027)	-.0025 (.0051)
(Shale Wells Drilled)^2		-4.9e-06 (5.1e-06)		-2.7e-05** (1.2e-05)		3.0e-05 (1.8e-05)
log(Population)	-	-	.8705 (.5334)	.9277* (.5368)	-	-
log(Population Density)	-.1215 (.5101)	-.1069 (.5142)	-	-	1.4*** (.4772)	1.483*** (.4819)
log(Median Household Income)	1.691*** (.5207)	1.679*** (.5236)	1.824*** (.4773)	1.767*** (.4695)	1.341 (.853)	1.267 (.8567)
Poverty	.0058 (.0124)	.0059 (.0125)	.0131 (.0111)	.0143 (.0111)	-0.0299* (0.0161)	-0.03* (0.0164)
Expected Employment Growth Rate	.081*** (.0226)	.0803*** (.0225)	.0754** (.0308)	.0762** (.0307)	.0252 (.0525)	.024 (.0524)
R-squared	0.433	0.433	0.116	0.123	0.271	0.274
Ad. R-squared	0.43	0.43	0.106	0.112	0.259	0.261
F	72.04	68.27	7.608	10.7	10.25	10.09
Observations	4080	4080	1635	1635	1125	1125
Breakeven Point	-	612	-	467	-	83

(Standard errors shown in parantheses) * = p<0.1 ** = p<0.05 *** = p<0.01

Table 4: Two-way Fixed Effects Regression of the Logged Number of Approved New Housing Construction Permits on the Number of Shale Wells Drilled

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[1] Shale oil and gas represent 'unconventional' resources. These resources are characterized by 'tight' rock formations through which oil and gas do not readily flow – as opposed to conventionally targeted formations which are more porous – and exist over a larger geographical area than the more discrete reservoirs which typify conventional resources. They also generally contain much larger volumes of oil and gas than conventional resources. Horizontal drilling allows a single well to access a much larger area of the rock formation than a standard vertical well, which is important given the limited porosity of the rock. Hydraulic fracturing then breaks the rock, allowing the trapped oil and gas to move through the cracks to the well bore and then to the surface.

[2] The recovery factor is defined as the ratio of technically recoverable oil or gas (given current technology) in a reservoir relative to the total estimated oil or gas in the reservoir. For shale gas the recovery factor can vary between 15 to 35 percent and for shale oil the recovery factor has been estimated to be between 1 and 10 percent (US EIA, 2013techrecover). In contrast, conventional oil field recovery factors range from 30 to 40 percent while the gas recovery factor can be as high as 80 percent (MIT, 2011).

[3] Landmen are employed by the oil and gas industry to determine the current holders of mineral rights in the drilling region, procure those rights, and arrange drilling contracts with local landowners.

[4] Roughnecks, colloquially, is an all-encompassing term referring to oil and gas drilling rig workers of all skill levels and responsibilities.

[5] Similar to the collapse of the natural gas drilling boom and the shifting of drilling assets to the oil-producing Bakken and Eagle Ford Shales and the Permian Basin when natural gas prices fell in 2009.

[6] The specific NAICS industry codes I utilized to capture shale development employment effects are the same as used by Farren et al. (2013): 2111-Oil and Gas Extraction; 2131-Support Activities for Mining; 5413 –Architectural, Engineering, and Related Services; 2389–Other Specialty Trade Contractors; 3331–Agriculture, Construction, and Mining Machinery Manufacturing; 4862–Pipeline Transportation of Natural Gas; 2371–Utility System Construction

[7] This data is made available through the C. William Swank Rural-Urban Policy Program at Ohio State University.

[8] This data is made available through a grant funded by the Appalachian Research Initiative for Environmental Science (ARIES), part of the Virginia Center for Coal and Energy Research at Virginia Tech.