Production of Natural Gas From Shale in Local Economies: A Resource Blessing or Curse?

By Jason P. Brown

The extraction of natural gas from shale and tight gas formations is one of the largest innovations in the U.S. energy sector in several decades. According to the Energy Information Agency's (EIA) 2013 Annual Energy Outlook, total U.S. recoverable natural gas resources were estimated to be 2,327 trillion cubic feet, up from 1,259 trillion cubic feet in 2000. Using projected annual growth in U.S. natural gas consumption, current U.S. reserves of natural gas represent an estimated 70 years' worth of supply. This energy boom has reversed a long downward trend in U.S. natural gas production. In the 1970s the U.S. energy sector seemingly conceded its decline and began investing in global markets to survive. That trend reversed course in the mid-2000s.

A key question is whether this now abundant and accessible natural resource has positive effects on local economic conditions. Some theories suggest resource abundance may increase local economic development through higher demand for labor in the energy sector and spillover spending in the local economy. Other theories, though, suggest industries not closely related to the resource extraction industry may be harmed as energy production expands. For example, labor demand by the extraction industry may be high enough to bid up local wages,

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which in turn could pull employees from other lower-paying jobs and make it difficult for other industries to survive. At the national and international level, this phenomenon has been referred to as the "natural resource curse," but the topic has received much less attention at the local level.

This article investigates how the recent boom in the U.S. natural gas industry has affected local economies in the central United States. Labor market conditions at the county level in a nine-state region are analyzed using econometric models to determine how employment and wages have responded to the rapid expansion of natural gas production from 2001 to 2011. The article finds a modest positive impact on local labor market outcomes in counties where natural gas production has increased, and little evidence of a natural resource curse.

Section I discusses factors leading to the shale boom in the natural gas industry and potential opportunities for the U.S. economy. Section II highlights factors that can lead to a natural resource curse or "blessing" and how those factors look different at the local and national levels. Section III describes the study region and discusses the empirical findings and evidence of a resource curse.

I. SHALE BOOM: A TALE OF TWO TECHNOLOGIES

Technologies pursued initially by two independent energy companies that were eventually brought together have forever changed the oil and gas industry. Production and proven reserves of natural gas have increased significantly since the mid-2000s. This increase has opened new possibilities for the U.S. economy.

Hydraulic fracturing and horizontal drilling

In the early 1980s, Mitchell Energy & Development Corporation, led by George P. Mitchell, drilled the first well in the Barnett Shale field in western Texas. Instead of encountering the typical, highly porous rock of conventional formations, Mitchell Energy encountered shale. Shale has the potential to hold vast amounts of natural gas; however, it is highly nonporous, which causes the gas to be trapped in the rock. Mitchell Energy experimented over 20 years with different techniques, and found that by using hydraulic fracturing (commonly referred to as "fracking") it was able to break apart the rock to free natural gas. Fracking consists of shooting a mixture of water, chemicals, and sand into wells to create fissures in rock formations that frees the trapped gas.

Over the same period, Devon Energy Corporation of Oklahoma City had been developing horizontal drilling techniques. Advances in controls and measurement allowed operators to drill to a certain depth, then drill further at an angle or even sideways, exposing more of the reservoir and allowing much greater recovery. In 2002, Devon acquired Mitchell Energy (Yergin). Devon combined its expertise of horizontal drilling with Mitchell Energy's knowledge of fracking. By 2003 Devon found a successful combination of the two technologies. Suddenly, natural gas that had been commercially inaccessible was now exploitable.

Expanded production and potential implications for the U.S. economy

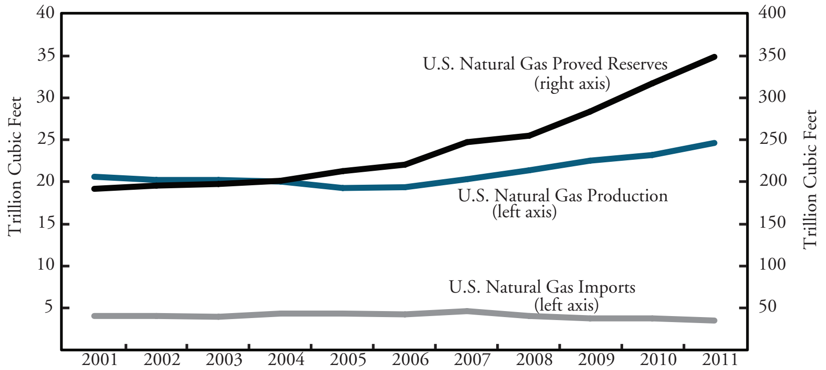
Higher natural gas prices in the mid-2000s and the combination of horizontal drilling with fracking changed the economics of natural gas production. New reserves from unconventional formations of shale and tight gas became economically profitable to tap.[1] Continued development of drilling and fracking techniques has increased production efficiencies, and today these unconventional wells have a low risk of being unproductive "dry holes." Prior to the advent of shale gas in the mid-2000s, total annual natural gas production in the United States was flat at about 19 trillion cubic feet to 20 trillion cubic feet (Chart 1). However, by 2011 total annual production had grown nearly 30 percent to 24.6 trillion cubic feet. Meanwhile, proved reserves increased sharply, while imports of natural gas remained flat.

Since the first major shale boom in the Barnett field, large-scale natural gas extraction has occurred in plays (groups of fields) around Woodford (Oklahoma); Fayetteville (Arkansas); Haynesville (Louisiana and Texas); Marcellus (Pennsylvania and West Virginia); and Eagle Ford (Texas). Activity has also boomed in the Niobrara shale in portions of Colorado, Kansas, Nebraska, and Wyoming, as well as in plays in other parts of the country.

A continued increase in domestic production could lead to improved net exports as the United States is currently a net importer of natural gas. The trend in net exports likely depends on the pace of converting traditional coal-fired power plants to gas-fired plants and possible conversion of vehicles to natural gas as a transportation fuel. Some

Chart 1

U.S. NATURAL GAS PRODUCTION, IMPORTS, AND PROVED RESERVES, 2001-2011



Source: Energy Information Agency.

natural gas may also be exported, but only a small percentage of U.S. consumption. Net exports of natural gas are expected to grow to 3.6 trillion cubic feet in 2040, representing only 12 percent of consumption (EIA). The federal government has approved three permits for liquefied natural gas export facilities within the last two years (U.S. Department of Energy). However, most of the projected growth in U.S. exports is expected to come from pipeline exports to Mexico.

The large domestic supply of natural gas has also revived debate about its effect on local economic conditions where production has occurred. Prior research on resource booms in coal-producing regions reported positive employment and earning effects during extraction and little reversal when extraction declined (Black and others). Similarly, the large increase in natural gas production has presented an opportunity to identify its impact on local economies in the United States.

II. NATURAL RESOURCE EXTRACTION: RESOURCE BLESSING OR CURSE?

Increased extraction can have positive or negative effects on a local economy where activity is occurring. These effects can be direct, through expanded local employment and wages due to more energy sector workers, or indirect through positive or negative spillovers. A special case of a negative spillover is the “natural resource curse,” which has different implications at local levels than at the national level.

Additionally, the rapid pace of gas extraction using unconventional techniques has raised concerns about potential effects on the environment and their associated cost.

Potential pathways of local effects from expansion of natural gas extraction

Natural gas extraction directly increases the employment and income of those working in the industry, particularly during exploration and drilling, but also during production. Expenditures on natural gas well construction and operations may also indirectly increase demand for other goods and services such as gravel, concrete, vehicles, fuel, hardware, and consumables. As a result, industries producing or selling these goods in the local economy may also increase employment and income. Land owners with mineral rights often receive lease and royalty payments, which they may spend in the local economy. Severance taxes paid on extracted natural gas can contribute to higher revenues for state and local governments. As residents and local governments receive such additional income, their spending in the local economy may rise in turn. Finally, the local economy may also benefit from increased spending by workers involved in construction or operations activities in the extraction sector.

Natural gas extraction may also have some drawbacks depending on the level and pace of activity. An influx of workers into a local area typically leads to higher demand for local housing. Natural gas activity often occurs in sparsely populated areas, especially in rural areas where the supply of housing is low. As a result, rental rates may rise, leaving people on low or fixed incomes unable to afford their housing. Increased truck traffic as a result of drilling may cause public infrastructure such as roads and bridges to degrade faster and require more maintenance. Local governments may find it difficult to respond to these needs. More generally, extraction may reduce the desire of people to reside, visit, or work in a community. That in turn would likely affect migration and commuting flows and income from tourism. All of these factors could affect the demand for land, with subsequent effects on property values, property tax revenues, and other aspects of the local economy. But perhaps most importantly, natural resource extraction could potentially lead to the "natural resource curse."

The mechanics of a resource curse at the local versus national level

Many prior studies have found that resource-rich countries tend to grow slower compared to resource-poor countries. This phenomenon has been called the "natural resource curse" (Corden and Neary). Multiple economic theories have been used to help explain the effect of natural resource extraction on economic development. Most current explanations for the curse have a crowding-out logic (Sachs and Warner 2001). The idea is that extracting natural resources reduces the level of other economic activity over time.[2]

At the local level, crowding out can occur when the increase in labor demand and local services from a booming sector leads to increases in relative wages and the cost of services. The increase in demand for labor in the extracting sector and the resulting increase in wages pulls workers from other sectors. Direct demand by firms and workers in the resource extracting sector may also increase local prices for goods and services, potentially creating a disadvantage for local businesses (Caselli and Michaels). Increased local price volatility may also deter local entry of new firms. Other parts of the local economy not closely related to the resource extraction industry may have limited ability to increase the wages they pay their employees or pass on the higher cost of services to other customers. For example, a worker in a food manufacturing plant may be able to get a higher wage by driving a truck hauling either water or fracking materials used in drilling. The food manufacturer may be unable to raise wages high enough to keep the worker. Similarly, a delivery-truck driver for a local retailer may also decide to move to the extraction sector if offered a higher wage. If the shock to local wages is large and persists long enough, other local businesses that are unable to pass the higher costs on to customers may be at a disadvantage or may be forced out of business. As a result, once the resource extraction slows or comes to an end, employees attracted to the industry may no longer have opportunities in prior jobs.

Prior findings on the local effects of a resource boom

Research on the effects of natural resources on local economic conditions has been thin compared to country-level research. Prior research at the county-level has produced mixed results. Similar to findings at the national level, James and Aadland found that U.S. counties that are more dependent on natural resources grow slower. However, Michaels and Weber (2012, 2013) found that greater oil or natural gas production generally increases employment and income in U.S. counties.

These prior studies suggest that natural resource abundance does not necessarily translate into natural resource dependence. Moreover, less clear is how much wealth created from resource abundance is captured at a local level, and thus can affect local economic development and growth. Related, the local distribution of benefits may be different from the distribution of costs. Given the multiple pathways of effect, assessing the local income and labor market outcomes of natural gas extraction is likely to require using multiple outcome measures.

Beyond income and labor market outcomes

The rapid pace of unconventional gas extraction has raised concerns about potential effects on the environment and their varied associated costs in different parts of the country. The environmental debate mostly has centered on water quality. Poorly cemented wells can leak and contaminate groundwater, as has been documented in Colorado, Ohio, and Pennsylvania (Lustgarten 2009a; Ohio Department of Natural Resources; Thyne). Flowback water not recaptured by drilling companies can contaminate surface water, as occurred in Dimrock, Pennsylvania (Lustgarten 2009b). But captured water requires treatment to remove dissolved solids. In areas with insufficient wastewater facilities, one disposal method has been to pump the water back underground. This approach, however, has been blamed for causing earthquakes (Fischetti).

Aside from water issues, diesel truck exhaust and emissions of volatile organic chemicals from natural gas processing plants can decrease air quality (Kargbo, Wilhelm, and Campbell). One study suggests that water and air contamination from unconventional gas development is associated with lower infant birth weight (Hill). However, it is unclear whether these environmental and health hazards from fracking are different from the possible health hazards of traditional drilling operations. More research is needed to determine any long-term environmental and health effects across multiple regions where extraction is occurring in shale and tight gas formations.

Although increased natural gas production may have many possible effects on local economies, a lack of data limits the scope of any analysis.

As a result, only labor market outcomes related to changes in employment, population, personal income, and wages are addressed in this analysis. These effects are discussed in the next section.

III. EMPIRICAL ANALYSIS OF A NINE-STATE REGION

Holding other local economic factors constant, local growth models can be used to estimate the effects of increased gas production on county-level employment, wages, and population. The models can help determine whether local effects have been positive or negative.

Much of the increase in U.S. natural gas production from 2001 to 2011 occurred in nine states in the central United States. In this region, county-level production data are available (Map 1) and show that production of natural gas increased in some counties.[3] These states together accounted for 70 percent of U.S. natural gas production in 2011. The nine-state region had a combined increase in production of 6,332 billion cubic feet, or nearly 50 percent. The increase in production was more dramatic in some states than others (as shown in both Chart 2 and Table 1). Arkansas and Louisiana saw sharp increases in annual production, while Colorado, Oklahoma, Wyoming, and Texas experienced more gradual growth.

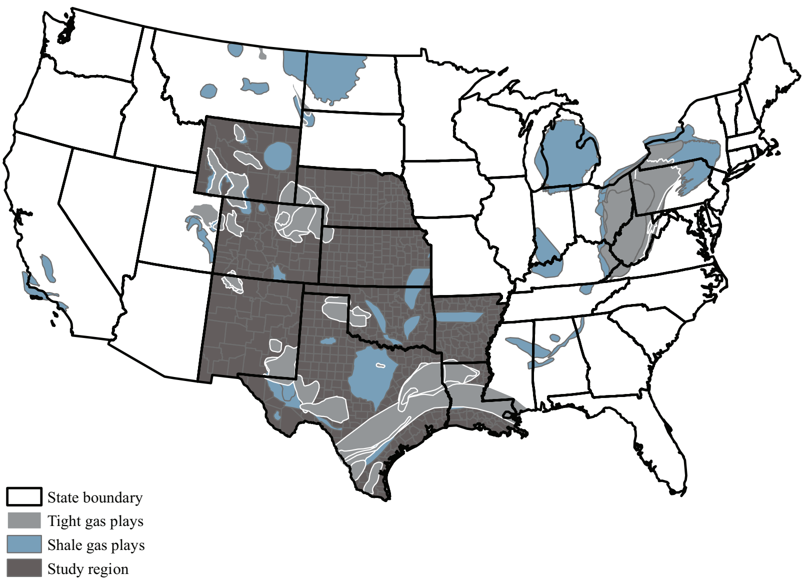
An initial comparison of counties

The analysis in this article focuses on 647 nonmetropolitan counties in the nine-state region and looks at the change in natural gas production from 2001 to 2011. Using nonmetropolitan counties creates a more homogenous sample and excludes counties with large cities from excessively influencing estimates of the effects of natural gas extraction on the local economy. Additionally, nonmetropolitan counties are arguably the population of interest. Crowding out of other sectors is more likely to appear in rural counties with thin labor markets compared to populated metropolitan counties with thicker labor markets (Weber 2013). Across the nonmetropolitan counties, the change in production was not uniform (Map 2). Counties with increased production tended to have higher coverage of shale or tight gas formations.

Counties in the sample may have experienced different trends in the local labor market depending on the change in natural gas production. For an initial comparison, counties were separated into three

Map 1

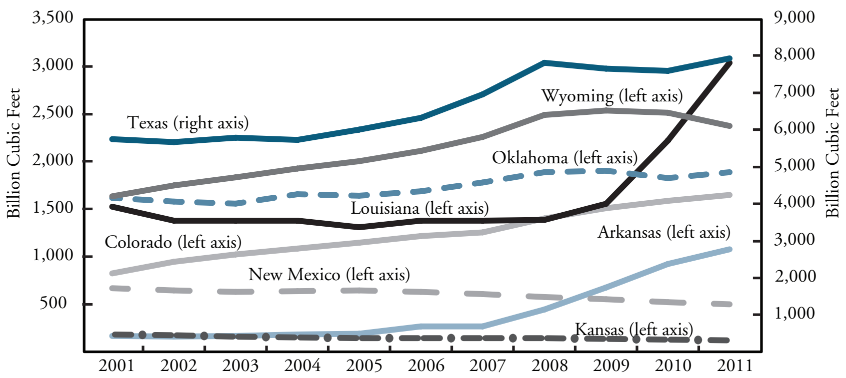
SHALE AND TIGHT GAS FORMATIONS



Source: Energy Information Agency.

Chart 2

NATURAL GAS PRODUCTION BY STATE



Source: Energy Information Agency.

Table 1

CHANGE IN NATURAL GAS PRODUCTION

In Billion Cubic Feet, 2001-2011

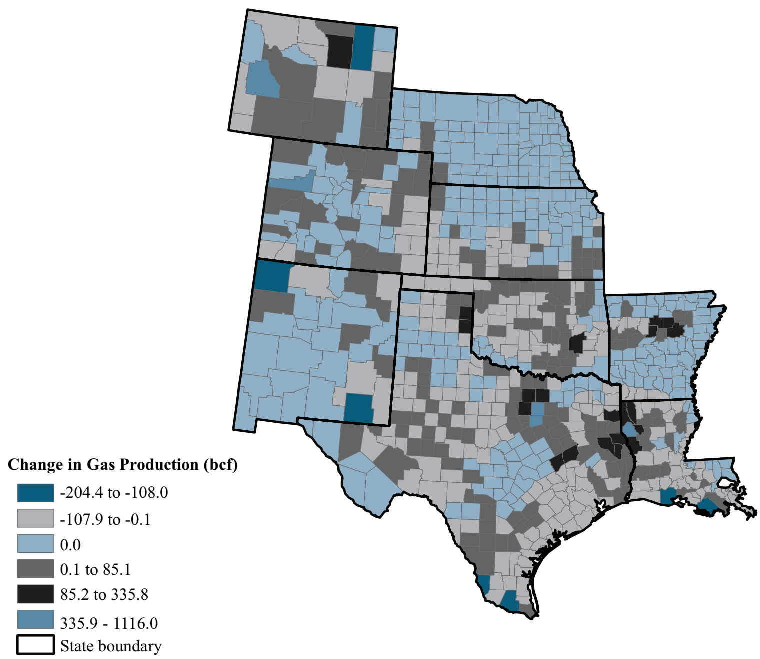
State	2001	2011	Change	Percent Change
Arkansas	167	1,077	910	544%
Colorado	825	1,649	824	100%
Kansas	481	310	-171	-36%
Louisiana*	1,525	2,969	1,444	95%
Nebraska	1.2	2	0.77	64%
New Mexico	1,712	1,288	-425	-25%
Oklahoma	1,615	1,889	273	17%
Texas*	5,752	7,911	2,159	38%
Wyoming	1,635	2,375	740	45%
Nine-state total	13,715	19,470	5,755	42%
U.S. total*	23,822	27,929	4,108	17%

* Excludes off-shore production
Source: Energy Information Administration.

Map 2

COUNTY-LEVEL CHANGE IN NATURAL GAS PRODUCTION

In Billion Cubic Feet, 2001-2011



Sources: Data collected from state agency websites; author's calculations.

Table 2

EMPLOYMENT SHARES BY COUNTY PRODUCTION CATEGORY

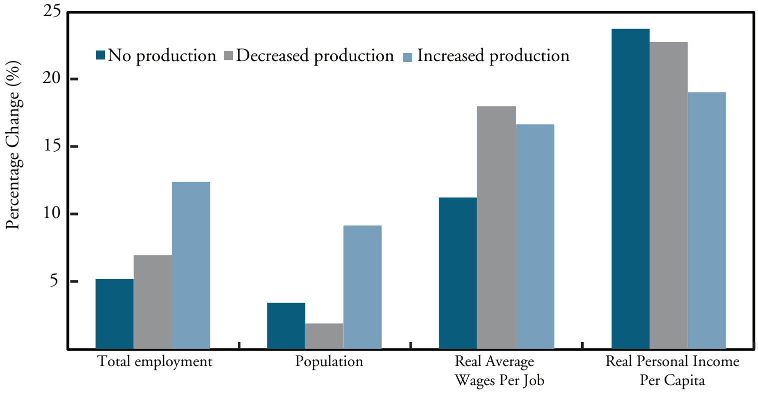
	No Production		Decreased Production		Increased Production	
Number of Counties	243		237		167	
	2001	2011	2001	2011	2001	2011
Mining share	0.8%	1.8%	4.0%	6.7%	3.2%	6.7%
Manufacturing share	8.9%	7.3%	7.1%	5.8%	8.5%	6.4%
Construction share	6.0%	5.4%	6.3%	5.9%	6.4%	5.8%
Transportation share	3.6%	3.8%	3.5%	3.5%	3.5%	3.8%
Retail share	10.3%	9.4%	9.9%	8.8%	10.5%	9.1%
Services share	30.5%	31.4%	28.9%	30.5%	29.2%	30.7%

Sources: Author's calculations using data from Bureau of Economic Analysis, REIS.

categories: those with no production, decreased production, and increased production. In addition, county employment was divided into six sectors: mining, manufacturing, construction, transportation, retail, and services. In this breakdown, employment in the gas extraction industry falls into the mining sector. It appears that counties with increased production relied more on mining employment as the share of mining employment increased over the decade from 3.2 percent to 6.7 percent (Table 2). While mining employment increased in the period, one reason that the mining share increased was a decrease in the level and share of manufacturing employment from 8.5 percent to 6.4 percent. Interpreting this as evidence of crowding out from increased natural gas production, however, would be misplaced as shown by similar trends in counties with no production or decreased production. These counties also experienced a declining share of manufacturing employment from 2001 to 2011. Moreover, the decline in the share of manufacturing employment was similar across all three categories.

Analysis of the data suggests that changes in natural gas production may partially explain differences in outcomes across counties with respect to changes in employment, population, real personal income, and real wages (Chart 3). Counties with increased production had faster growth in total employment (12.4 percent) and population (9.1 percent) compared to those where production declined (6.9 percent and 1.9 percent, respectively). Real personal income per capita grew faster in counties that had no production, while real average wages per job grew

Chart 3
CHANGE IN COUNTY-LEVEL OUTCOMES BY PRODUCTION CATEGORY, 2001-2011



Sources: Author's calculations using data from Bureau of Economic Analysis, REIS.

faster in counties that experienced a decline in production. However, growth in employment and real average wages per job was the lowest among counties in the sample that had no production, while population growth was lowest among counties with decreased production.

Empirical model and local economic factors

The multiple possible effects of natural gas extraction warrant using several outcome measures. Changes in these outcome variables are hypothesized to be affected by a county's socioeconomic and demographic characteristics and by the change in natural gas production in that county. Using an econometric model, changes in employment, real per capita income, real wages, and population (ΔY) at the county level are assumed to be affected by the county's own socioeconomic and demographic characteristics (X) measured in the base year, the county's change in natural gas production from 2001 to 2011, measured in billions of cubic feet (ΔG), and state-level fixed effects (S), as shown by:

$$(1)\,\Delta Y_{2011-2001} = \alpha + \beta \Delta G_{2011-2001} + X'_{2000}\beta + S'\gamma + \varepsilon,$$

where ε is an error term.

The change in natural gas production (ΔG) may be endogenous to the outcome variables of interest if a change in per capita income or employment in a county affects natural gas production. For example, increased income might enable local investors to invest in natural gas exploration and development. Endogeneity may also arise if the change in natural gas production is affected by unobserved factors that also affect the change in employment or per capita income. For example, increased natural gas production may be more likely to arise in communities that have fewer alternative economic opportunities or less ability to invest in such opportunities due to unobserved factors such as the quality of local resources, local leadership, or entrepreneurial capacity. In such cases, estimation using methods such as ordinary least squares (OLS) can result in biased estimates of the coefficients (α, β, γ) in Equation 1. For example, communities with fewer alternative economic opportunities may be more likely to invest or promote natural gas production. If so, communities with more production could have lower rates of growth than other communities, biasing downward an OLS-estimated economic effect of changes in natural gas production. Further details of the model are in the Appendix.

Labor market outcomes

Determining the effect of changes in natural gas production on local economic outcomes first requires estimating the relevance of shale and tight gas formations for gas production. Using a two-stage least squares regression to estimate Equation 1, results show that the percentage of a county covered by shale and tight gas formations was highly correlated with county-level changes in natural gas production from 2001 to 2011 (Table 3).[4,5]

The second-stage results show positive effects from increased natural gas production across several local economic outcomes. Each billion cubic feet of natural gas production was associated with 12.7 additional jobs in the county of production (Table 4).[6] Counties in the sample where production increased experienced an average increase of 41.5 billion cubic feet of gas and an estimated increase of 520 jobs. Relative to the level of employment in 2001, the average county experienced an implied 13-percent increase in employment from the increase in natural gas production. Summing across all counties in the

Table 3

RELEVANCE OF SHALE AND TIGHT GAS FORMATIONS

Dependant Variable: Δ Gas Production

	Coefficient	Robust S.E.	t-stat	p-value
Percent shale	34.96	8.96	3.90	0.000

F-test for excluded instrument	
F	15.23
p-value	0.000

Endogeneity Test	
χ-square	13.60
p-value	0.000

Note: Complete first-stage results are reported in Appendix Table A1.

Table 4

EFFECTS FROM CHANGES IN NATURAL GAS PRODUCTION, 2001-2011

Dependent Variables:

	Δ Total Employment	**Δ Mining Employment**	**Δ Manufacturing Employment**	**Δ Construction Employment**	**Δ Transportation Employment**
Δ Gas production (billion cubic feet)	12.72*** (4.70)	7.34*** (2.63)	-0.33 (1.06)	1.72* (0.94)	2.60*** (0.97)

	Δ Retail Employment	**Δ Services Employment**	**Δ Real Per Capita Income**	**Δ Real Average Wages**	**Δ Population**
Δ Gas production (billion cubic feet)	0.66 (0.97)	4.21* (2.37)	34.11 (22.34)	43.60** (18.22)	18.41*** (6.89)

* Significant at 90 percent level
** Significant at 95 percent level
*** Significant at 99 percent level
Notes: Robust standard errors are in parentheses. See Table A2 in the Appendix for the full set of results.

sample, the net predicted number of total jobs created as a result of natural gas production from 2001 to 2011 was 49,000.

Approximately half of the jobs created were in the mining sector, where an increase in a billion cubic feet of production led to 7.3 additional jobs. Summing across all counties in the sample, the predicted number of jobs created in the mining sector as a result of natural gas production was about 28,000 from 2001 to 2011. One interpretation of these results is that each natural gas-related mining job created 1.7 (12.7/7.3) total jobs or 0.7 nonmining jobs, which suggests that greater natural gas extraction did not lead to large economic spillovers from the mining sector to other sectors in the local economy. This finding is consistent with previously reported mining-nonmining employment multipliers at the state or local level (Perryman Group; L.C. Scott and Associates; Kelsey and others; Considine and others; Weber 2013).

As previously mentioned, the manufacturing sector has been cited as the most likely sector to be crowded out by expansion in natural resource extraction. A common assumption is that the manufacturing sector experiences an input price spike during an extraction boom, while its output price remains fixed. These conditions are expected to lead to the decline of the manufacturing sector. The results here suggest that increased natural gas production had little effect on county-level manufacturing employment. The manufacturing employment effect was small (-0.3 jobs per billion cubic feet) and, indeed, not statistically distinguishable from zero. Nonmanufacturing sectors were also investigated to test for crowding out effects. Construction, transportation, and services all experienced statistically significant net increases in employment. Construction gained 1.7 jobs per additional billion cubic feet in natural gas production; transportation gained 2.6 jobs; and services gained 4.2 jobs. The retail sector did not appear to be affected given that the estimated employment effects were small and not statistically different from zero.

Analysis of the personal income, compensation, and population results provides more evidence that increased natural gas production does not seem to have crowded out other sectors in the time period analyzed. Real average annual wages per job increased by $43 per billion cubic feet of production. For the average county in the sample that experienced increased natural gas production, the predicted increase in real average annual wages was $1,809 per job. Relative to wages in 2001, the average county experienced an implied 5.8-percent increase in the wage per job from increased natural gas production.

Changes in population were also affected by increased natural gas production. The results suggest that a county's population increased by 18 people with each billion cubic feet of production. Of the counties that saw increased production, the average county received a predicted influx of 760 people. Relative to 2001, the average county experienced an implied 13.5-percent increase in population. That the population effect is larger than the employment effect is not surprising. Prior research for metropolitan areas has shown that increased employment mostly is accounted for by worker in-migration (Rappaport 2012). If this finding applies to nonmetropolitan areas, the majority of jobs created in a county from natural gas activity may be filled by workers moving into the county. Some workers may move into the county with their families, which could also explain the larger population effects. An open question is whether people who moved into a county because of the boom in natural gas production will move out once production stops.

Little evidence of a local resource curse

The presence of a natural resource curse at a local level depends on relative wage and price differences caused by increased demand from the extracting sector. The evidence in this article suggests that for the region and period analyzed, large increases in natural gas production did not lead to a natural resource curse.

First, increases in gas production led to moderate increases in total employment. The ability to pull labor and people from outside of the county experiencing increased production was the primary reason.

Second, even with increases in relative prices, the manufacturing sector made up a small share of total employment in most counties. The results suggest that manufacturing employment was little affected by natural gas production.

Finally, an income effect leading to increased demand for non-manufacturing goods is necessary to generate relative increases in the prices of local goods and services. Most of the income effect appears to reflect wages relative to other income categories. Because most of the jobs created were in the mining sector, income effects spilling over from mining to other sectors were likely to be small.[7] The gas extraction workers may also be more likely to leave once natural gas production declines or ceases.

IV. CONCLUSION

The combination of fracking and horizontal drilling has opened natural gas reserves in once trapped shale and tight gas formations in several parts of the United States. As a result, domestic production has increased significantly in the last decade, reversing a decades-long downward trend in U.S. natural gas production and opened new possibilities for the U.S. economy. But the vast extraction of this natural resource also has implications for local economies. Prior research has suggested that national economies more reliant on natural resources tend to grow slower over time, but little work has been done on local economies.

This article finds that within the time frame and region under consideration, an increase in natural gas production has not been a natural resource curse for local economies. So far, local employment and wage effects have been positive, but modest. This is likely due in part to the ability of labor and people to move from county to county and the small share of manufacturing in the local economy. Despite the significant increase in natural gas production, it is unclear whether the local labor markets analyzed became more dependent on the mining sector and thus more at risk for a natural resource curse. Half of the jobs created from increased production have been in the mining sector, with little effect on nonmining sectors. And the largest wealth effect was seen in increases in average wages in the county. These benefits, however, may fade once local production begins to decline or if perceived or potential environmental costs become a reality.

APPENDIX

MODEL DETAILS AND CONTROL FACTORS

A common approach for dealing with endogeneity is instrumental variables (IV) estimation. The presence of shale or tight gas formations is likely a primary factor affecting the increase in natural gas production over the study period given that these formations were not previously exploitable until the advent of fracking and horizontal drilling technologies. Similar to Weber (2012, 2013), the percentage of a county covered by a shale or tight gas formation was calculated using Arc GIS and geographical information on shale and tight gas plays obtained from the Energy Information Agency. This measure was used as an instrument to explain the change in natural gas production (ΔG). Over the study period, sample counties completely covered by a shale or tight gas formation on average experienced an increase of 39 billion cubic feet in natural gas production, while counties without shale or tight gas formations had on average a decline in production of 2 billion cubic feet. The shale and tight gas formations are unlikely to be directly related to the outcome measures apart from affecting changes in natural gas production.[8]

Previous studies that have modeled changes in county-level employment, per capita income and average wages were referenced to determine what kinds of socioeconomic, demographic, and other control variables to include in the analysis (Table A1). The determinants of local economic demand include variables, such as the level of population and median household income (Deller and others). Recent research on rural places has concluded that remoteness to cities has implications for economic growth (Wu and Gopinath; Partridge and others). Distance to urban population centers of 100,000 people or more was calculated for each county using GIS methods.

Urban agglomeration economies have also been shown to affect changes in per capita income, in particular where urban and rural areas are interdependent (Castle and others). Urban agglomeration is measured using population density. Following Rappaport (2008), population density is constructed as a population-weighted average of smaller area densities. Economic structure as it relates to regional specialization has also been shown to be of importance (Kim). For example, the rise and fall of industrial sectors have implications for economic development in a county, depending on its industrial composition. Industrial composition is accounted for by the share of employment in major industries such as agriculture, forestry, fishing and hunting, construction, manufacturing, and the mining sector in the county.

Consistent with modern economic growth theory, as the stock of human capital increases in a county, income is expected to grow (Rupasingha and others). Human capital is measured by the percentage of the adult population with associate and bachelor's degrees. Labor accessibility has also been shown to contribute to economic growth in a region (Partridge and Rickman). Here, it is measured using a county's unemployment rate.

Natural gas activity has been regulated and taxed to differing degrees by states. Most often a severance tax is levied on the gas extracted. These policies likely influence relative differences in natural gas production across states. As a result, state fixed effects were also included in the model to control for differences in unobserved state policies or conditions that might change economic outcomes as well natural gas production.[9]

Table A1

SAMPLE COUNTY-LEVEL DESCRIPTIVE STATISTICS

Variable	Mean	Standard Deviation
Natural gas production (billion cubic feet), 2001	17.29	53.92
Change in natural gas production, 2001-2011	5.96	66.22
Agricultural share of employment, 2001[1]	0.19	0.11
Construction share of employment, 2001[1]	0.06	0.03
Manufacturing share of employment, 2001[1]	0.08	0.07
Mining share of employment, 2001[1]	0.03	0.04
Unemployment rate, 2000[2]	4.18	1.72
Percent of adult population with associate degree, 2000[3]	4.94	2.11
Percent of adult population with bachelor's degree, 2000[3]	10.71	4.41
Population, 2000[1]	16,951.6	16,394
Population density, 2000[4]	738.77	460.17
Distance to nearest urban center of 100,000 or more (miles)[4]	106	82.25
Median household income, 2000 (2011 $)[3]	40,759	7,635

Note: Based on 647 observations.
Sources: [1]Bureau of Economic Analysis, [2]REIS; [3]Bureau of Labor Statistics; U.S. Census Bureau, 2000 Decennial Census; [4]author's calculations.

Table A2
COMPLETE RESULTS FROM FIRST-STAGE REGRESSION

Dependant Variable: ∆ Gas Production

	Coefficient	Robust S.E.	t-stat	p-value
Percent shale	34.96	8.96	3.90	0.000
Agriculture share	-18.72	24.72	-0.76	0.449
Construction share	341.7	196.55	1.74	0.083
Manufacturing share	13.62	37.95	0.36	0.720
Mining share	-152.64	71.64	-2.13	0.033
Unemployment rate (percent)	-2.33	1.26	-1.86	0.064
Household income	-0.001	0.0003	-2.04	0.042
Population	-0.0002	0.0002	-1.08	0.279
Population density	-0.004	0.005	-0.83	0.404
Associate (percent)	0.70	1.05	0.66	0.507
Bachelor's (percent)	0.31	0.51	0.60	0.550
Distance to urban	0.021	0.027	0.78	0.434
Colorado	-10.15	10.76	-0.94	0.346
Kansas	-8.73	8.70	-1.00	0.316
Louisiana	12.33	30.64	0.40	0.688
Nebraska	-14.84	9.40	-1.58	0.115
New Mexico	-22.81	12.19	-1.87	0.062
Oklahoma	-11.58	9.01	-1.29	0.199
Texas	-15.9	9.94	-1.60	0.110
Wyoming	24.93	34.46	0.72	0.470
intercept	27.26	21.42	1.27	0.204

N	647	Adj. R^2	0.09

F-test for excluded instrument	
F	15.23
p-value	0.000

Endogeneity Test	
χ-square	13.45
p-value	0.000

Source: Author's calculations.

Table A3

COMPLETE RESULTS FROM SECOND-STAGE REGRESSION

	Dependant Variables:									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Δ Total employment	**Δ Mining employment**	**Δ Manufacturing employment**	**Δ Construction employment**	**Δ Transport employment**	**Δ Retail employment**	**Δ Services employment**	**Δ Per Capita Income**	**Δ Average Wages**	**Δ Population**
Δ Gas Production	12.72***	7.341***	-0.326	1.720*	2.596***	0.657	4.209*	34.11	43.60**	18.41***
	(4.703)	(2.630)	(1.060)	(0.944)	(0.966)	(0.640)	(2.367)	(22.34)	(18.22)	(6.892)
Agriculture Share	1,507.8*	190.8	2.706	-195.3	44.47	185.9**	1,349.0***	5,952.5	4,014.7	3,378.5**
	(825.6)	(313.5)	(138.8)	(134.9)	(117.4)	(93.11)	(403.1)	(4,730.1)	(2,696.1)	(1,456.2)
Construction Share	-2,317.1	-2,633.6*	164.0	-2,857.2***	-871.6	397.2	63.17	3,612.5	-16,569.6	3,421.9
	(2871.0)	(1461.8)	(712.2)	(777.8)	(655.1)	(489.4)	(1,537.6)	(14,776.1)	(10,115.6)	(4,126.1)
Manufacturing Share	-5,079.4***	-765.1**	-2456.1***	-12.12	-51.42	-211.0	-971.6**	-10,055.1***	-8,366.4***	-3701.5**
	(1,192.6)	(353.3)	(426.4)	(181.4)	(209.0)	(146.9)	(495.3)	(3513.2)	(3,209.9)	(1,553.8)
Mining Share	8,541.5***	4,504.4***	166.7	604.5	772.4**	515.7**	2,107.5***	30,694.3***	47,460.8***	4,397.5
	(2,251.2)	(1,161.7)	(354.8)	(420.2)	(342.8)	(214.0)	(710.5)	(8,232.9)	(10,377.6)	(3,318.4)
Unemployment Rate(percent)	80.88	3.403	16.50*	-20.43**	4.825	5.375	80.03*	-249.7	227.9	21.72
	(58.63)	(14.63)	(8.778)	(8.473)	(5.693)	(8.678)	(47.41)	(383.4)	(174.9)	(93.78)
Median Household Income	0.0341***	0.0154**	0.00734***	-0.000769	0.00426**	0.00104	0.0112**	-0.0834	0.0374	0.0531***
	(0.0121)	(0.00614)	(0.00235)	(0.00305)	(0.00203)	(0.00176)	(0.00518)	(0.0673)	(0.0342)	(0.0181)
Population	0.0654***	0.0132***	-0.00888***	-0.000561	0.00230	-0.000848	0.0315***	-0.0123	-0.0168	0.137***
	(0.00954)	(0.00328)	(0.00176)	(0.00129)	(0.00149)	(0.00120)	(0.00514)	(0.0152)	(0.0153)	(0.0210)

Table A3 continued

	Dependant Variables:									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Δ Total employment	**Δ Mining employment**	**Δ Manufacturing employment**	**Δ Construction employment**	**Δ Transport employment**	**Δ Retail employment**	**Δ Services employment**	**Δ Per Capita Inc.**	**Δ Average Wages**	**Δ Population**
Population Density	0.0143	0.0595	0.0357	-0.0226	0.0168	0.00739	0.0650	0.0387	1.227**	-0.472**
	(0.169)	(0.0577)	(0.0428)	(0.0258)	(0.0281)	(0.0244)	(0.0745)	(0.558)	(0.595)	(0.213)
Associate Degree (Percent)	-53.25	-9.929	-0.0158	-2.144	-2.129	0.410	-21.48	249.9	1.149	-205.7***
	(41.25)	(15.15)	(7.812)	(5.925)	(5.396)	(3.872)	(16.95)	(208.3)	(201.3)	(51.71)
Bachelor's Degree (Percent)	11.35	-7.619	-9.272***	-13.12***	-4.540*	-0.0188	21.38***	25.53	-12.81	54.58**
	(15.75)	(6.594)	(3.245)	(4.363)	(2.670)	(2.715)	(8.247)	(104.8)	(62.16)	(21.92)
Distance to Urban Population	-0.271	-0.225	-0.0911	0.112	-0.0858	-0.193*	-0.226	0.0907	-1.125	-1.952**
	(0.638)	(0.259)	(0.184)	(0.129)	(0.115)	(0.106)	(0.291)	(3.018)	(2.042)	(0.847)
Colorado	547.9	79.62	139.0	1.282	3.528	-43.07	-138.7	-2,312.1	-460.4	1,427.7**
	(347.9)	(120.9)	(87.85)	(61.23)	(63.67)	(41.39)	(163.8)	(1,410.8)	(1,069.3)	(656.3)
Kansas	315.8	16.31	186.9**	82.72*	64.10	-66.80*	-175.9	3,132.3***	-632.0	510.9
	(267.2)	(90.44)	(91.16)	(43.21)	(48.09)	(35.25)	(135.0)	(1,145.1)	(862.0)	(434.6)

Table A3 continued

	Dependant Variables:									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Δ Total employment	**Δ Mining employment**	**Δ Manufacturing employment**	**Δ Construction employment**	**Δ Transport employment**	**Δ Retail employment**	**Δ Services employment**	**Δ Per Capita Inc.**	**Δ Average Wages**	**Δ Population**
Louisiana	56.70	-301.4	209.0**	78.29	-52.46	-5.025	-181.4	1,077.8	556.4	-1,205.6*
	(429.8)	(214.5)	(106.4)	(77.13)	(104.6)	(40.10)	(223.4)	(1480.6)	(1,407.9)	(719.3)
Nebraska	649.0*	47.30	171.0*	99.68**	175.0***	-12.85	-108.4	5,513.6***	588.1	1,208.2**
	(337.6)	(101.1)	(88.69)	(47.47)	(55.66)	(37.93)	(153.7)	(1,404.7)	(1,220.9)	(479.4)
New Mexico	570.6	270.4	262.8**	186.1**	96.05	59.76	-226.5	1,220.0	694.2	813.5
	(407.3)	(167.1)	(109.0)	(73.98)	(72.67)	(49.99)	(209.0)	(1,305.9)	(9,73.7)	(621.0)
Oklahoma	219.8	192.6	212.8**	74.37*	43.50	-41.77	-288.7*	-1,267.6	905.6	124.6
	(275.9)	(117.3)	(89.33)	(43.51)	(56.55)	(34.48)	(151.5)	(779.5)	(659.5)	(472.9)

Table A3 continued

	Dependant Variables:									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Δ Total employment	**Δ Mining employment**	**Δ Manufacturing employment**	**Δ Construction employment**	**Δ Transport employment**	**Δ Retail employment**	**Δ Services employment**	**Δ Per Capita Inc.**	**Δ Average Wages**	**Δ Population**
Texas	551.8**	51.01	164.2**	173.0***	119.2**	-10.09	-121.9	709.1	1,216.2**	711.8*
	(233.8)	(79.12)	(82.09)	(42.14)	(50.49)	(36.61)	(122.8)	(682.1)	(569.9)	(396.5)
Wyoming	737.9	-4.877	128.6	194.3**	9.162	-95.87*	-213.0	-937.3	-272.9	1,536.0**
	(494.4)	(284.3)	(96.16)	(89.21)	(97.68)	(50.14)	(192.4)	(1,943.1)	(1,892.2)	(759.7)
Intercept	-2,429.8***	-536.8*	-262.8**	363.9**	-204.3**	-110.2	-1,256.2***	6,786.1	637.0	-3,999.1***
	(656.9)	(276.7)	(124.4)	(166.1)	(93.87)	(92.90)	(392.5)	(4,808.6)	(2,536.8)	(1,032.5)
N	647	647	647	647	647	647	647	647	647	647
cor(y, yhat)	0.598	0.415	0.616	0.343	0.268	0.232	0.575	0.419	0.409	0.629
F	9.913	5.384	8.36	3.271	2.879	3.643	7.606	9.984	6.322	11.44

* Significant at 90 percent level
** Significant at 95 percent level
*** Significant at 99 percent level
Note: Robust standard errors are reported in parentheses.
Source: Author's calculations.

ENDNOTES

[1]Shale gas is a field in which natural gas accumulation is locked in tiny bubblelike pockets within layered sedimentary rock such as shale. While shale gas is trapped in rock, tight gas describes natural gas that is dispersed within low-porosity silt or sand areas that create a tight-fitting environment for the gas.

[2]Manufactured exports are typically identified as the product that gets crowded out (Sachs and Warner 1995, 1999). At the national level, exports from the natural resource sector may cause the exporting country's exchange rate to appreciate, which in turn puts domestic manufacturers that export at a comparative disadvantage since their products become relatively more expensive. Canadian manufacturing appears to have recently experienced this comparative disadvantage with the boom in the production and export of oil sands (Beine, Bos, and Coulombe).

[3]Annual county-level production data were collected from state agency websites: Arkansas Oil and Gas Commission (*http://www.aogc.state.ar.us/*); Colorado Oil and Gas Conservation Commission (*http://cogcc.state.co.us/*); Kansas Geological Survey (*http://www.kgs.ku.edu/PRS/petro/interactive.html*); Louisiana Department of Natural Resources (*http://sonris.com/*); Nebraska Energy Office (*http://www.neo.ne.gov/statshtml/index3c.html*); New Mexico Tech (*http://www.emnrd.state.nm.us/OCD/statistics.html*); Oklahoma Corporation Commission Oil and Gas Division (*http://www.occeweb.com/og/annualreports.htm*); Railroad Commission of Texas (*http://webapps.rrc.state.tx.us/PDQ/generalReportAction.do*); Wyoming Oil and Gas Conservation Commission (*http://wogcc.state.wy.us/*).

[4]Complete results from the first-stage regression are shown in Appendix Table A1.

[5]Test results show that the change in natural gas production is endogenous and that the instrument (% shale) is a strong instrument. The implication is that IV-2SLS estimation is preferred over OLS. One possible concern might be that what is known about the geological formations in a particular county depends on historical exploration and the subsequent investment that was made to obtain that information. This may call into question the exogeneity of the instrument used. However, if the shale or tight gas formations are in the county, but not known, production is less likely to have occurred since energy companies drill where they think the gas is most likely located.

[6]One possible concern might be that counties with increased natural gas production were already growing faster than counties that did not have increased gas production prior to 2001. A double difference model allows for differences in prior trends. A double difference model was estimated, where the second difference in the outcome variables was from 1990 to 2001. The results where quantitatively similar to the first difference model, but the parameter estimates where less precise for some outcome measures.

[7]Local residents who own mineral rights may capture some of the wealth. Unfortunately, information at the local level on royalty and lease payments is not readily available.

[8]While it is not possible to test for the exogeneity of a single instrumental variable, a series of auxiliary regressions all confirmed that the percentage of a county covered by shale or tight gas formations was not correlated with any of the outcome variables measured in 1990.

[9]Arkansas serves as the omitted category in the state fixed effects.

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