A decade of natural gas development: The makings of a resource curse?☆

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ABSTRACT

Many studies find that areas more dependent on natural resources grow more slowly – a relationship known as the resource curse. For counties in the south-central U.S., I find little evidence of an emerging curse from greater natural gas production in the 2000s. Each gas-related mining job created more than one nonmining job, indicating that counties did not become more dependent on mining as measured by employment. Increases in population largely mitigated a rise in earnings per job and crowding out. Furthermore, changes in the adult population by education level reveal that greater production did not lead to a less educated population.

1. Introduction

In the 2000s natural gas production from shale formations increased tenfold in the U.S. and growth in production is expected to continue in what The Economist magazine and others have called the ‘shale gas revolution’ (Economist Intelligence Unit, 2011). According to the U.S. Energy Information Administration, “The production of natural gas from shale formations has rejuvenated the natural gas...
industry in the United States” (EIA, 2011). The industry has expanded drilling in a broad swath of the country, from Pennsylvania to Texas to Wyoming.

A large cross-country literature documents how economies based on natural resources grow more slowly than other economies in what is broadly known as the resource curse (Sachs and Warner, 2001; Auty, 2001; Van der Ploeg, 2011). Similar within-country evidence has also emerged. Papyrakis and Gerlagh (2007) find that U.S. states with a greater dependence on natural resources (measured by the share of output accounted for by the natural resource sector) grew slower than other states. James and Aadland (2011) find the same for U.S. counties. In contrast – at least at first glance, Weber (2012) finds that greater natural gas production increased employment and income in counties in three Western states. Over his study period, participation in a natural gas boom added 1780 jobs and 69 million dollars in wage and salary income to the average county.

The findings of Weber (2012) do not exclude the possibility of a current or future resource curse where the shale gas industry has grown. If workers are unwilling to move to areas with development, the industry’s growth may cause wages to appreciate and crowd out other sectors with more potential for sustained growth. In addition, the industry could simply have few linkages to the nonmining economy. The increase in employment in gas-boom counties in Weber (2012) may therefore have occurred primarily or even entirely in the mining sector and increased dependence on mining. If the common empirical finding that economies more dependent on natural resources grow more slowly reflects a true causal effect (e.g. James and Aadland, 2011), then gas-boom counties may grow more slowly in the long run despite the short-term employment gains.

I study whether the shale gas industry has created conditions symptomatic of the resource curse. Specifically, I look for evidence of increased dependence on the mining sector, higher earnings per job, and declines in the educational attainment of the adult population in counties in the south-central U.S. Many counties in the four-state region of Texas, Louisiana, Arkansas, and Oklahoma experienced a wave of natural gas drilling in the 2000s. As a result, the four states accounted for two-thirds of the increase in onshore natural gas production in the U.S. from 2000 to 2010.

For nonmetropolitan counties in the region, I find little evidence of an emerging resource curse from greater natural gas production. Increases in population in gas producing counties prevented a large increase in earnings per job and a statistically discernible crowding out of manufacturing. Each gas-related mining job was associated with 1.4 additional nonmining jobs in the county where production occurred, indicating that natural gas development had a largely neutral effect on resource dependence as measured by employment. Furthermore, the change in the adult population with different education levels indicates that extraction did not lead to a less educated workforce.

2. The boom in natural gas drilling

2.1. Cost-reducing technology meets higher natural gas prices

The growth in natural gas production stems from higher energy prices and the refinement of two complementary technologies, hydraulic fracturing and horizontal drilling. The technologies permit extraction of unconventional gas – gas trapped in hard rock formations like shale and that require unconventional methods to profitably exploit. Hydraulic fracturing involves injecting a mix of chemicals and water deep into the ground to open fissures in rock. Fracturing is not new, having been first used commercially in Texas and Oklahoma in 1949 (Montgomery and Smith, 2010). Innovation in drilling horizontally has occurred more recently and partly reflects earlier public investments in research. Spurred by high energy prices in the late 1970s and 1980s and concerns about domestic supplies, the U.S. government funded research on extracting gas from hard rock formations. The research has been recognized as having lowered the cost of drilling horizontal wells capable of drawing gas over a large area (King, 2010; National Energy Technology Laboratory, 2011). This in turn reduced the number of wells needed to exploit a given area. As costs fell, the productivity advantage of horizontal wells encouraged their use (EIA, 1993).

In the 1990s, several companies experimented with combining hydraulic fracturing with horizontal drilling in the Barnett Shale in Texas (National Energy Technology Laboratory, 2011). This occurred
Table 1

<table>
<thead>
<tr>
<th>State</th>
<th>2000</th>
<th>2010</th>
<th>Increase</th>
<th>Percent increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arkansas</td>
<td>172</td>
<td>927</td>
<td>755</td>
<td>439</td>
</tr>
<tr>
<td>Louisiana</td>
<td>1343</td>
<td>2091</td>
<td>748</td>
<td>56</td>
</tr>
<tr>
<td>Oklahoma</td>
<td>1613</td>
<td>1827</td>
<td>214</td>
<td>13</td>
</tr>
<tr>
<td>Texas</td>
<td>5682</td>
<td>7565</td>
<td>1883</td>
<td>33</td>
</tr>
<tr>
<td>Four-state total</td>
<td>8810</td>
<td>12,410</td>
<td>3600</td>
<td>41</td>
</tr>
<tr>
<td>U.S. total</td>
<td>18,474</td>
<td>23,960</td>
<td>5486</td>
<td>30</td>
</tr>
</tbody>
</table>

Note: The data are from the Energy Information Administration.

despite wellhead gas prices in the 1990s that averaged just $1.92 per thousand cubic feet.¹ When prices increased markedly in the 2000s, averaging $5.19 over the decade, hydraulic fracturing and horizontal drilling expanded rapidly in Texas and elsewhere.

2.2. Drilling hotspots and state policy responses

Companies have used fracturing and horizontal drilling to exploit previously untapped gas reservoirs in Colorado, Wyoming, the south central U.S., and more recently in Pennsylvania and Ohio. The Barnett Shale in Texas has been the most exploited shale gas reservoir, but production from formations in Arkansas and Louisiana also spiked during the decade. In 2010, Texas, Louisiana, Arkansas, and Oklahoma accounted for more than half of onshore natural gas production in the U.S. and as mentioned in Section 1, the states accounted for two-thirds of the growth in U.S. onshore production from 2000 to 2010 (Table 1). Of the four states, Arkansas saw the largest percent increase, with a more than fourfold increase. Texas had the largest absolute increase, with production expanding by 1883 billion cubic feet or roughly 9.7 billion dollars (=5,190,000 × 1883 billion cubic feet).

States have much discretion over taxing and regulating gas extraction, and policies vary markedly. Major producing states (e.g., Texas, Wyoming, Colorado, Louisiana, Oklahoma) permit hydraulic fracturing (“fracking”) but apply a severance tax on gas extracted. Comparatively, Pennsylvania permits fracturing but in lieu of a severance tax it started applying an impact fee on wells in 2012. Because of environmental and health concerns, nearby New York has had a moratorium on fracking since December of 2010 (Hoye, 2010). North Carolina and Vermont have adopted a similar policy and California and Maryland are considering doing so.

3. Natural gas development: the makings of a resource curse?

Much of the empirical resource-curse literature, including several studies cited in the introduction, relates resource dependency to economic growth. But resource dependence is best treated as a potential consequence of resource extraction, not as an explanatory variable. As highlighted by Brunnschweiler and Bulte (2008), common measures of resource dependency like the share of earnings accounted for by the natural resource sector reflect the weakness of the nonresource sector as much as they reflect growth in resource extraction. Van der Ploeg (2011) describes how resource extraction may make industrial sectors less competitive; encourage rent seeking, corruption, and conflict; reduce savings rates; and cause governments to overspend. An almost necessary consequence of the first two effects is a weaker nonresource sector and by extension greater dependence on natural resources.

The link between natural gas extraction and resource dependence should be examined empirically, not assumed. Indeed, greater extraction could even decrease resource dependency. The natural gas industry may have strong linkages with the nonmining sector (which I use as synonymous for the sector not based on natural resources) and consequently create more jobs and earnings in the nonmining

¹ Natural gas prices for states and the U.S. are available at the website of the Energy Information Administration: http://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm.
sector than in the mining sector. Hirschman (1958) long ago emphasized such linkages as central to an industry’s potential to create broad-based economic growth. Model-based estimates from a study by IHS Global Insight suggest that the shale-gas industry had higher employment multipliers than finance and construction (IHS Global Insight, 2011). The study cites the industry’s intensive use of capital and its strong linkages to the construction, fabricated metals, and chemical sectors.

Aside from direct production linkages with the nonmining sector, natural gas extraction may have strong links to consumer demand. Employees in the shale-gas sector reportedly earn more than $23 dollars an hour (IHS Global Insight, 2011). Gas development also generates substantial payments to landowners with mineral rights. Landowners provide access to natural gas through leases with drilling companies that often involve a one-time lease payment and a flow royalty payments based on production. A survey of firms drilling in the Haynesville shale in Louisiana revealed that they spent $1.2 billion in lease and royalty payments in 2009 (Scott and Associates, 2010). A survey of landowners in two counties in Pennsylvania showed that they consumed roughly 10 percent of the payments received in 2009 (Kelsey et al., 2011). Spent at the same rate, the more than a billion dollars in lease and royalty payments to landowners in the Haynesville Shale alone would have increased consumer spending by 100 million dollars.

The intuition that growth in resource extraction increases an area’s dependence on natural resources may nonetheless hold. For one, the natural gas industry may have weaker linkages than what has been reported. Looking at the 1970s coal boom in Appalachia, Black et al. (2005) find that each coal mining job created only a quarter of a local sector job and no traded sector jobs. A flurry of drilling and royalty payments could also crowd out other sectors. Increased demand from the booming natural gas sector may raise prices for apartments and haircuts (nontradable goods and services) but not for shoes (tradable), whose price is set by the world market. Furthermore, wage appreciation caused by greater demand for labor erodes the competitiveness of the nonbooming tradable good sector (Corden and Neary, 1982). On the national level, greater exports by a booming natural resource sector may also cause the exchange rate to appreciate, thereby lowering the competitiveness of other exporters. This appears to have happened in Canada where currency appreciation from energy production eroded the competitiveness of manufacturing (Beine et al., 2012).

The prospect that greater extraction could increase or decrease economic dependence on natural resources as measured by the share of employment (or other outcomes) raises the question of whether such measures accurately capture resource dependence. Admittedly, they have limitations: a job at a masonry business that pours concrete for drilling pads may vanish when drilling slows even though the job is classified as a nonmining job. Growth in the gas industry, however, may help the masonry business expand, gain economies of scale, and compete for clients in other industries. Unless its product or service is very industry-specific, a decline in drilling may simply cause a firm to expand in other niches. The masonry business, for example, might turn to residential projects.

3.1. Natural gas development and education

Because human capital is often cited a cause of higher long-term growth, a decline in educational attainment is another sign of the making of a resource curse. Both Papyrakis and Gerlagh (2007) and Walker (2013) present evidence from the U.S. for a strong link between natural resources, low education, and low growth. If resource industries increase the wages of low-skilled workers more than those of high-skilled workers, it reduces the incentive for local residents to invest in education. If a recent high school graduate can earn nearly as much as a college graduate by pouring concrete, he probably will forgo college.

For areas with an abrupt increase in drilling, changes in the stock of skill in the local population probably come from labor migration. Resource extraction may primarily increase the demand for low or semi-skilled workers – think people with a commercial driver’s license. In contrast, the environmental risks and costs of resource extraction may cause more skilled workers – the creative class of scientists, engineers, and artists likely to spur innovation and growth (Florida, 2002) – to move away, or if they did not live there in the first place, to never come. The environmental Kuznets curve implies that as incomes increase, people demand more environmental amenities. There is some evidence that
unconventional gas drilling affects newborn health and lowers the values of homes that rely on well water (Muehlenbachs et al., 2012; Hill, 2012).

4. Sample counties

The analysis focuses on the 362 nonmetropolitan counties in Arkansas, Louisiana, Oklahoma, and Texas. Using nonmetropolitan counties creates a more homogenous sample and precludes a few counties with large cities from excessively influencing estimates from a linear model. Moreover, nonmetropolitan counties are arguably the population of interest. Symptoms of a resource curse are more likely to appear in rural counties with thin labor markets than in populated metropolitan counties.

Data on employment, earnings per job, and total population come from the Regional Economic Accounts of the Bureau of Economic Analysis (BEA). Earnings per job is calculated as total wage and salary disbursements divided by total wage and salary jobs. A challenge with the publically available BEA data is that mining and manufacturing employment (but not total employment) is suppressed for observations where the number of establishments creates confidentiality problems. In cases of suppression, values are imputed based on a 2002 dataset created by Isserman and Westervelt (2006) who used the establishment size categories and the geographical and industrial hierarchy of the Census Bureau’s County Business Patterns data to impute employment values for all counties and industries. Manufacturing and mining employment values for 1995, 2000, and 2010 for suppressed counties are then estimated by applying state-specific industry growth rates to the data imputed by Isserman and Westervelt. In the empirical section the results are checked for sensitivity to different approaches to suppression.

For 2000, data on the number of people in the county with different levels of education come from the Census Bureau Census of Population; for the end-period population by education level, I use the 2007–2011 average from the American Community Survey. The website of the Energy Information Administration provides GIS data on unconventional gas formations (shale, sandstone or “tight”, and coalbed formations). Data on gas production by county by year come from state organizations involved in monitoring oil and gas development.2

The average sample county produced 15.6 billion cubic feet of gas in 2000, and over the next nine years production increased by 6.8 billion cubic feet. The median county, however, produced less than a billion cubic feet in 2000 and saw no growth in the ensuing years. The innovation in drilling technology and higher prices in the 2000s should have primarily affected counties with unconventional gas. To illustrate the link between unconventional gas formations and growth in production, I divide sample counties into three groups based on the percent of the county covering an unconventional gas formation. The sample contains 138 non-gas counties, defined as having no unconventional gas formations; 82 fringe counties, where 0.1–49.9 percent of the county covers an unconventional gas formation; and 142 gas counties, where 50 percent or more covers a formation. The appendix has a map of counties shaded by group.

For each group of counties Fig. 1 shows the average production from 1995 to 2010. In the late 1990s, gas counties consistently produced more gas than the other two groups, but production for all groups was flat until the early 2000s when it increased dramatically in gas counties, was steady in fringe counties, and fell slightly in non-gas counties. From 2003 to 2010, average production in gas counties increased by roughly 20 billion cubic feet.

5. Empirical approach

One approach to studying the effects of natural gas development would be to look at a first-differenced model relating the change in natural gas production with, for example, the change in

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2 These agencies are the Arkansas Oil and Gas Conservation Commission, the Kansas Geological Survey, the Louisiana Department of Natural Resources, the Mississippi Oil and Gas Board, GO-TECH at the New Mexico Institute of Mining and Technology, the Oklahoma Corporation Commission, and the Texas Railroad Commission. Of the counties outside of the four-state region, there is only evidence of gas production in the counties in Mississippi, New Mexico, and Kansas. Data for counties outside of the four-state region but in the commuting zones of sample counties are incorporated in calculating spatially lagged variables.
employment. A weakness of the first-differenced model is that it requires that counties with natural gas drilling in the 2000s did not have a distinct prior trend in employment growth. Supposing that they did, and representing the prior trend with $v_{gas}$, consider the model

$$\Delta Y_{00–10} = \alpha + \beta \Delta Gas_{00–10} + v_{gas} + \epsilon_{00–10}$$  \hspace{1cm} (1a)$$

As long as the unobserved term $v_{gas}$ is time invariant, it can be eliminated by differencing with the analogous equation from the preceding period. Because gas production data are not available for all states going back to 1990, I define the prior period equation as covering 1995 to 2000:

$$\Delta Y_{95–00} = \theta + \beta \Delta Gas_{95–00} + v_{gas} + \epsilon_{95–00}$$  \hspace{1cm} (1b)$$

Subtracting (1b) from (1a) yields

$$\Delta Y_{00–10, 95–00} = \eta + \beta \Delta Gas_{00–10, 95–00} + \epsilon_{00–10, 95–00}$$  \hspace{1cm} (2)$$

Thus, the dependent variable is defined as “change in $Y$, 2000–2010” (the period of development) minus “change in $Y$, 1995–2000”. The key independent variable – the change in natural gas production in billions of cubic feet – is defined similarly. Subtracting the change in the pre-development period accounts for any time-invariant trend uniquely affecting counties that were to experience gas development.

Studies of extractive booms have repeatedly speculated that labor market effects likely extend beyond the localities where extraction occurs (Black et al., 2005; Michaels, 2010; Weber, 2012). If natural gas extraction creates the conditions for a resource curse in the county of production, it may create similar conditions in neighboring counties. In a similar vein, a prolonged resource boom in one area could cause the booming area to draw capital and labor from peripheral areas, creating and perpetuating geographic disparities in economic growth (Myrdal, 1957).

A common approach to modeling local spillovers is to include spatially lagged variables as regressors. The lag is created by multiplying a spatial weights matrix with the variable to be lagged, which for each county gives the weighted average of neighboring counties. The Spatial Durbin model is common in the literature and includes a spatially lagged dependent variable ($Wy$) and spatially lagged covariates ($WX$) and is estimated by maximum likelihood (Anselin, 1988). The spatial autoregressive model is another approach and consists of including $Wy$ instrumented by lagged covariates ($WX$) (Kelejian and Prucha, 1999).
Recent work, however, shows that the Durbin model and the spatial autoregressive model lead to a similar reduced form equation involving $X$ and $WX$ that only differs in how many spatial lags it includes – the neighbors, the neighbors of the neighbors, and so forth (Pinkse and Slade, 2010; Gibbons and Overman, 2012). Furthermore, compared to the peer effects literature, the spatial econometrics literature has given little heed to the reflection problem highlighted by Manski’s (1993) seminal paper on peer or neighborhood effects. A county’s outcomes may move with the average outcome of neighboring counties for reasons other than spillovers of economic activity. Gibbons and Overman (2012) recommend that applied empirical work on spatial relationships focus less on parsing out the effects of $Wy$ from $WX$ and more on identifying causal responses to changes in a spatially lagged covariate of interest.

I therefore include in the empirical model the average change in natural gas production of a county’s contiguous neighbors. I also include several control variables and their spatially lagged versions (averages of the county’s contiguous neighbors):

$$
\Delta Y_{00–10.95–00} = \eta + \beta(\Delta Gas_{00–10.95–00}) + \rho W(\Delta Gas_{00–10.95–00}) + X_{94}\theta + WX_{94}\theta^r + \epsilon_{00–10.95–00}
$$

where $W$ is the spatial weights matrix that permits calculating the average of contiguous counties and $X$ includes the control variables. Because spatial spillovers decline with distance, using contiguous counties provides a good opportunity for a statistically precise estimate of the spillover. The $X$ used to calculate spatial lags includes metropolitan counties and counties that share a commuting zone with a sample county, even if they are outside the four-state region.\(^3\)

Included in $X$ are income per capita, population density, and the percent of total employment accounted for by the mining, construction, manufacturing, and agricultural sectors. I also include the county’s driving distance (in driving time using the existing roads) to the nearest city of 100,000 and state dummy variables to control for state–specific growth trends. The $X^s$ vector includes the same variables as the $X$ vector except for the state dummies and the driving distance variable, which already reflect spatial relationships. All continuous control variables except the driving distance variable correspond to 1994.

5.1. Estimation and identification

Growth in gas production and its spatial lag may be correlated with omitted variables that affect labor markets. Gas companies may drill more in economically depressed areas where they can lease land for less. The Center for Business and Economic Research (2008) found that prior to an expansion in drilling, counties in the Fayetteville Shale in Arkansas had lower growth in wages per employee than the state as a whole. This is consistent with Weber (2012) who finds higher employment and income effects from a gas boom when using instrumental variables than when using OLS.

The double-differencing explained earlier allows for areas that experienced much drilling in the 2000s to have had a different trend prior to the drilling. It does not address all sources of endogeneity. Even if counties with drilling in the 2000s had a prior trend similar to other counties, gas companies may still have chosen to drill in counties that were to experience better (or worse) growth in the 2000s. Similar to Weber (2012), I address such potential endogeneity by using the location of unconventional gas reservoirs and its spatial lag to instrument for the growth in gas production and its spatial lag.\(^4\) The instruments are correlated with growth in gas production because unconventional gas accounted for most production growth in the region. They are also likely to be correlated with the outcomes

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\(^3\) Commuting zones are groupings of counties with relatively integrated labor markets as evidenced by where people live and work. Tolbert and Sizer (1996) describe the creation of commuting zones based on the 1990 Census journey-to-work data, which are the commuting zones used in this study. The average commuting zone in the U.S. (and the study region) contains about four counties.

\(^4\) To avoid giving a small neighboring county the same weight as a large county in calculating the spatial lag of Percent Gas, I calculate the total area of contiguous counties and the total area covering unconventional gas formations separately. The spatial lag variable $W \times (\text{Percent Gas})$ is the division of these two areas.
of interest only through their correlation with gas production. Without drilling there is no apparent reason why gas trapped two miles underground and once thought to be infeasible to extract should be correlated with labor market outcomes on the surface.

Regressions with $\Delta \text{Gas}_{2000-10.95-00}$ and its spatial lag as the dependent variable reveal a strong correlation between Percent Gas and growth in natural gas production (Table 2). Compared with counties with no unconventional gas formations (Percent Gas = 0), counties completely covering such a formation (Percent Gas = 1) saw gas production increase by 34 billion cubic feet from 2000 to 2010 relative to the prior five years. The coefficient for the spatial lag is similar, at 29 billion cubic feet. By comparison, the average county in the four-state region saw production increase by only 7 billion cubic feet.

Angrist and Pischke, 2009 (p. 218) explain how to test for an instrument’s strength to ensure that each endogenous regressor has at least one unique, excluded instrument sufficiently correlated with the regressor to ensure identification. The key is to test the strength of the correlation between the excluded instrument and the regressor that it is instrumenting for after partialing out variation captured by other covariates, the instrumented value of other endogenous regressors, and other excluded instruments. I use the Angrist and Pischke approach to calculate the $F$-statistic for the relationship between Percent Gas and $\Delta \text{Gas}_{2000-10.95-00}$ and between the spatial lags of both variables. The $F$-statistic for the relevance of Percent gas and $W \times (\text{Percent gas})$ is 15.8 and 17.1 indicating sufficient instrument strength to alleviate concerns about weak instrument bias (Stock and Yogo, 2005) (Table 3).

With the same number of excluded instruments and endogenous regressors, GMM estimation reverts to traditional Two Stage Least Squares, which I use for estimation. The standard errors reflect a robust covariance matrix that allows for arbitrary heteroskedasticity.

### 6. Production and employment, population, and earnings per job

I use Eq. (3) to estimate the effect of gas production on total, mining, and manufacturing employment and then on total population and earning per job. I find that each billion cubic feet in gas production created 18.5 total jobs in the county of production (Table 4). The total employment estimate is similar to that from a simple but recent analysis (ending in 2011) in Weber (2013), which gives an employment effect of 22 jobs per billion cubic feet. The coefficient on the spatial lag of gas production suggests that gas production in neighboring counties had little effect on employment in the county in question. The point estimate of the coefficient is small and statistically insignificant.
Table 3
Instrument relevance.

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\Delta$ Gas</th>
<th>$W \times (\Delta$ Gas)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Gas</td>
<td>34.2***</td>
<td>−1.3</td>
</tr>
<tr>
<td></td>
<td>(8.6)</td>
<td>(3.6)</td>
</tr>
<tr>
<td>$W \times (\text{Percent Gas})$</td>
<td>2.7</td>
<td>29.3***</td>
</tr>
<tr>
<td></td>
<td>(8.5)</td>
<td>(7.3)</td>
</tr>
<tr>
<td>Controls for state</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Other control variables</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Spatial lags of control variables</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Adjusted $R^2$</td>
<td>0.079</td>
<td>0.066</td>
</tr>
<tr>
<td>Observations</td>
<td>361</td>
<td>361</td>
</tr>
</tbody>
</table>

Notes: Robust standard errors are in parenthesis. The spatial weights matrix $W$ is row normalized and based on contiguous counties. The change in natural gas production is in billions of cubic feet. The control variables include the mean driving distance to a city of 100,000 or more, income per capita, population density of the county, and the percent of total employment accounted for by the mining, construction, manufacturing, and agricultural sectors. The sample includes all nonmetro counties in the four states, less one county which was excluded for its extreme change in earnings per job, which was negative and four times more negative than the next closest observation.

* Statistical significance at the ten percent level.
** Statistical significance at the five percent level.
*** Statistical significance at the one percent level.

Of the 18.5 total jobs created, 7.5 of them were in the mining sector. Combined with the total employment effect, the estimates imply that each gas-related mining job created 2.4 total jobs (18.5/7.5). (The bootstrapped 95 percent confidence interval based on the percentile method is 1.03–6.4). Put differently, each gas-related mining job created 1.4 nonmining jobs, implying that greater natural gas extraction did not increase a county’s dependence on mining.

Although the multiplier suggests that extraction had a robust effect on the nonmining economy, it also suggests that several Input–Output studies of natural gas development may have overstated the industry’s employment effect – a conclusion consistent with Weber (2012). A widely cited study by IHS Global Insight implies that in 2010 each mining job associated with the industry supported more than 9 nonmining jobs somewhere in the country. Other studies at the state or substate level have produced similar mining–nonmining employment multipliers (Perryman Group, 2008; Scott and Associates, 2010; Kelsey et al., 2011; Considine et al., 2011).

Table 4
Employment, population, and earning per job effects of greater natural gas production.

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\Delta$ Total employment</th>
<th>$\Delta$ Mining employment</th>
<th>$\Delta$ Manufacturing employment</th>
<th>$\Delta$ Population</th>
<th>$\Delta$ Earnings per job</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta$ $\text{Gas}$</td>
<td>18.5***</td>
<td>7.5***</td>
<td>−0.4</td>
<td>25.2***</td>
<td>30.1***</td>
</tr>
<tr>
<td></td>
<td>(6.4)</td>
<td>(3.1)</td>
<td>(2.4)</td>
<td>(9.1)</td>
<td>(17.8)</td>
</tr>
<tr>
<td>$W \times (\Delta$ Gas)</td>
<td>3.5</td>
<td>0.3</td>
<td>1.4</td>
<td>−1.5</td>
<td>−65.4*</td>
</tr>
<tr>
<td></td>
<td>(10.7)</td>
<td>(3.7)</td>
<td>(5.7)</td>
<td>(13.6)</td>
<td>(32.9)</td>
</tr>
<tr>
<td>Controls for state</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Other control variables</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Spatial lags of control variables</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>Observations</td>
<td>361</td>
<td>361</td>
<td>361</td>
<td>361</td>
<td>361</td>
</tr>
</tbody>
</table>

Notes: Robust standard errors are in parenthesis. The change in employment and natural gas production is the change from 2000 to 2010 less the change from 1995 to 2000. The change in natural gas production is in billions of cubic feet. The spatial weights matrix $W$ is row normalized and based on contiguous counties. The sample includes all nonmetro counties in the four states, less one county which was excluded for its extreme change in average earnings per job, which was negative and four times more negative than the next closest observation.

* Statistical significance at the ten percent level.
** Statistical significance at the five percent level.
*** Statistical significance at the one percent level.
The local multiplier estimated here is probably an upper bound estimate for a local multiplier. The four-state region has a long-standing natural gas industry and pioneered fracking and horizontal drilling, meaning that its supply chain is the most developed of any region in the U.S. The employment multiplier is probably lower in other regions. Furthermore, local employment multipliers are not necessarily lower than their state or national counterparts. Moretti (2010) argues that local multipliers provide an upper bound on national multipliers because labor supply is more inelastic at the national level, causing greater crowding out.

Of all sectors, natural gas extraction is most likely to crowd out manufacturing – the classic tradable sector whose input prices may increase without a corresponding increase in output prices. It appears that greater gas production does little to crowd out manufacturing employment. The population and earning per job results provide one explanation. An increase in population accompanied the increase in employment, with each billion cubic feet of gas attracting 25 people. The employment and population effects imply that each job attracted 1.3 persons. This does not mean that unemployment increased; each job would have drawn several people if each worker brought several non-working dependents. That the population effect is only slightly larger than the employment effect is consistent with anecdotal evidence that natural gas drilling relies heavily on young, transient workers who do not have families or do not move them to drilling locations. Similar to the prior results, there is no evidence that a boom in gas production in contiguous counties affected population, although it may have attracted as many people as it caused to move.

The increase in employment and population accompanied a statistically weak increase in earning per job, that is, wage and salary disbursements per wage and salary job. Each billion cubic feet in gas led to an increase in $30 per job per year. For the county at the 90th percent for the change in gas production (a change of 22 billion cubic feet), production would have increased earnings per job by about $660 dollars or 2.4 percent of earnings per job in 1994. Interestingly, the coefficient on the spatial lag implies that gas production in neighboring counties caused a decline in earnings per job. This is counter-intuitive since an increase in earnings in one county would presumably draw labor from nearby, forcing employers to pay more to retain workers. From the employment results, we know that there was no systematically positive spatial employment or population spillover. Still, the composition of the population may have changed, with higher skilled workers moving to production areas and lower skilled workers moving to peripheral areas with lower housing costs. The type of jobs may have also changed in neighboring counties, with part-time jobs in convenience stores replacing higher-paying full-time jobs.

6.1. Robustness of the employment, population, and earnings per job estimates

As mentioned, manufacturing and mining employment are suppressed for some counties and required imputation. Manufacturing employment is suppressed in at least one year in a quarter of sample counties. For mining, the number is around 50 percent, reflecting that many counties have very little mining employment. Imputation introduces measurement error, which if uncorrelated with the actual manufacturing or mining employment, will attenuate coefficient estimates to zero and inflate standard errors. Bias from classical measurement error, however, is addressed by instrumenting for the imprecisely measured variable. Even so, I estimate mining and manufacturing employment results using two approaches to suppressed counties: first, by giving suppressed counties the lowest observed employment level in that year and second, by excluding them.

The estimates are robust to the two approaches. For mining employment, the alternative approaches to suppression give similar estimates, 8.0 and 7.9 jobs per each billion cubic feet (Table A1). This is close to the previous estimate of 7.5 jobs. Turning to manufacturing employment, the simple imputation method gives a negative effect of −1.9; excluding suppressed counties gives a small positive effect of 0.1. Both estimates are small and statistically insignificant and together they bound the initial estimate of −0.4. The apparent robustness of the results is understandable: many
suppressed counties are suppressed in all periods, suggesting that employment in the sector in question is small in levels and growth and would therefore contribute little to identification of the coefficients.

An arguably strong assumption made when double differencing the dependent variable is that the unobserved time trend $u_{gas}$ in Eq. (1a) persists unchanged from the prior period to the period of gas development. A way to allow for the trend to weaken would be to use a model with a lagged (and differenced) dependent variable. But a differenced lagged dependent variable would be correlated with the error term by construction. Another approach is to estimate a first-differenced model using the change from 2000 to 2010. This approach assumes that any prior trend over the 1995–2000 period does not persist into the 2000–2010 period.

In two plausible cases the first and double-differenced estimates bracket the true effects. Let $u_{gas, 95–00}$ and $u_{gas, 00–10}$ indicate trends in the first and second period unique to counties that experienced drilling in the 2000s. If a prior positive trend weakens but remains positive ($u_{gas, 95–00} > u_{gas, 00–10} > 0$), the double-differenced model understates the effect of gas production, and the first-differenced model overstates it. Conversely, if a prior negative trend weakens (independent of the effect of drilling) but remains negative ($u_{gas, 95–00} < u_{gas, 00–10} < 0$), the double-differenced model overstates the effect, and the first-differenced model understates it. In both cases, the true effect lies somewhere in the middle.

I therefore estimate a first-differenced model, where the outcome is the change from 2000 to 2010 and all control variables take on their 1999 values. The first-differenced estimates for the effect of a billion cubic feet of gas on employment are similar to the double-differenced estimates: for example, 20.6 total jobs compared to 18.5 and 8.0 mining jobs compared to 7.5 (Table A2). Combining the first-differenced total and mining employment results imply that each gas-related mining job created 1.6 nonmining jobs compared to the double-differenced estimate of 1.4. The effect on earnings per job is also similar: 30.7 dollars per job per year compared to 30.1.

For population, the first-differenced estimate is noticeably larger, 37.5 compared to 25.2. If counties with drilling in the 2000s had a prior trend of higher than average population growth but the trend weakened in the 2000s, then the true effect on population lies somewhere between 25.2 and 37.5 people per billion cubic feet.

6.2. Production and local employment: a lagged relationship?

Much of the local economic effects of natural gas development are thought to occur when companies drill wells and lay pipelines. Because production starts immediately after the well is fracked and declines exponentially afterwards, there should be a strong correlation between employment related to drilling activity and growth in production. But if production lags drilling by a year or more, potentially because wells are not immediately brought into production after they are drilled, then production in one year may have a larger correlation with employment in the prior year than in the current year. I therefore estimate the total employment effect using 2010 as the end point for the change in gas production but using 2009 and then 2008 and so forth for the end point for employment. I find that the total employment effect is largest when the same end year is used for employment and production. As the end point for the change in employment is move backward the estimated employment effect declines (Table A3).

7. Educational attainment in the adult population

To see if greater gas extraction potentially jeopardizes long-run growth by leading to a less skilled labor force, I look at changes in the adult population (age 25 and older) with an educational attainment of less than a high school; only high school; some college; and college or more. The change is between 2000, which is based on the Census of Population, and the 2007–2011 average value based on the
Table 5  
Natural gas production and the adult population, by educational attainment.  

<table>
<thead>
<tr>
<th>Variable</th>
<th>( \Delta ) Adult population</th>
<th>( \Delta ) Adult population</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Less than HS</td>
<td>HS only</td>
</tr>
<tr>
<td>( \Delta \text{Gas} )</td>
<td>21.6***</td>
<td>−1.3</td>
</tr>
<tr>
<td>(7.4)</td>
<td>(2.5)</td>
<td>(4.1)</td>
</tr>
<tr>
<td>( W \times (\Delta \text{Gas}) )</td>
<td>−4.7</td>
<td>4.2</td>
</tr>
<tr>
<td>(12.0)</td>
<td>(4.9)</td>
<td>(7.1)</td>
</tr>
<tr>
<td>Controls for state</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Other control variables</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Spatial lags of control variables</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>361</td>
<td>361</td>
</tr>
</tbody>
</table>

Notes: Robust standard errors are in parenthesis. For the change in population, the change from the 2000 value from the Census of Population to the 2007–2011 average value from the American Community Survey. The change in gas production is from 2000 to 2010 and is in billions of cubic feet. The spatial weights matrix \( W \) is row normalized and based on contiguous counties. The sample includes all nonmetro counties in the four states, less one county which was excluded for its extreme change in earnings per job, which was negative and four times the magnitude of the next closest observation.

* Statistical significance at the ten percent level.
** Statistical significance at the five percent level.
*** Statistical significance at the one percent level.

American Community Survey, which has insufficient coverage for a reliable county estimate in one year. The model estimated is

\[
\Delta \text{Adult } o_{j,p}^{\text{educ}} = \tau + \delta( \Delta \text{Gas}_{j,00–10} ) + \lambda W( \Delta \text{Gas}_{j,00–10} ) X_{94} \pi + W( X_{94} ) \pi + \epsilon
\]  

Incorporating 1990 data on population by educational attainment would permit another differencing analogous to that of the previous two models but natural gas production data does not go back to 1990 for all states. Despite the lack of differencing the effect of extraction on the adult population is consistent with the prior estimate for total population: each billion cubic feet of gas attracted slightly more than 21 people ages 25 and older, compared with 25 people in the general population (Table 5).

Gas production had, if anything, a small negative effect on the number of adults with less than a high school education. This is notable because in 2000 this group accounted for 30 percent of the adult population in the average county (see Table 2). In contrast, each billion cubic feet of gas drew 11.5 people with only a high school education. The high school educated adult population accounted for more than half of the total change even though it accounted for just 34 percent of the adult population in the average county. The point estimate for the change in adults with some college and those with college indicates the each group’s share of the increase is in line with their share of the adult population.

The estimated effects are consistent with what is known about the workforce associated with natural gas extraction – that the majority of laborers are low or semi-skilled in terms of formal education. It is worth highlighting that even though the total adult population increased, the point estimate for the number of people with less than a high school education is negative. One interpretation is that higher rents may have encouraged lower income, less educated adults to move away or to never come. On the other end of the education spectrum, greater extraction did not cause more educated workers, broadly understood as those with a college education or more, to move or to stay away at a rate higher than counties with a smaller increase in gas production.

8. Conclusion

Natural gas drilling will likely expand in several areas of the United States in the coming decade. The common empirical finding of lower economic growth in areas with greater dependence on natural resources raises the possibility that drilling will undermine the long-term economic prospects for a large swath of the country. For the south-central U.S., a decade of natural gas expansion appears to have
not generated the conditions associated with the resource curse – a finding consistent with Michaels’ 2009 study which showed that oil abundance promoted long-term growth in the 20th century in the same region. Any crowding out is sufficiently small that each gas-related mining job created at least one nonmining job, implying that extraction has not systematically increased the dependence of local economies on mining for employment. Furthermore, greater extraction did not erode the human capital stock; it may have even improved it by increasing the semi-skilled population (high school and some college).

At the same time, local labor market effects are only part of the economic consequences of extractive industries. The resource curse may in fact operate through other channels such as destabilizing local and state government revenues and expenditures or creating health and environmental problems that eventually manifest themselves. A nascent empirical literature is beginning to explore the environmental and health consequences of the recent wave of natural gas extraction (Muehlenbachs et al., 2012; Gopalakrishnan and Klaiber, 2013; Hill, 2012) but the externalized costs, who bears them, and how long they linger are still largely unquantified. The wide dispersion of unconventional oil and gas endowments across the U.S. and the world and projections of continued high oil prices imply that these questions will occupy public policy discussions in many places for many years, suggesting high returns to such a research agenda.

Appendix A.

See Fig. A1 and Tables A1–A3.

Fig. A1. Counties by percent of the county covering an unconventional gas formation. Note: GIS data on unconventional gas formations is from the Energy Information Administration.
Table A1
Other approaches to suppression of mining and manufacturing employment.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Δ Mining employment</th>
<th>Δ Manufacturing employment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Simple imputation</td>
<td>Excluding suppressed counties</td>
</tr>
<tr>
<td>Δ Gas</td>
<td>8.0***</td>
<td>7.9*</td>
</tr>
<tr>
<td></td>
<td>(3.1)</td>
<td>(3.9)</td>
</tr>
<tr>
<td>W × (Δ Gas)</td>
<td>−0.2</td>
<td>−3.3</td>
</tr>
<tr>
<td></td>
<td>(3.6)</td>
<td>(8.1)</td>
</tr>
<tr>
<td>Controls for state</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Other control variables</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Spatial lags of control variables</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>361</td>
<td>163</td>
</tr>
</tbody>
</table>

Notes: Robust standard errors are in parenthesis. The “Simple Imputation” column refers to the results when suppressed counties are given the minimum observed value for the year in question. For example, a county where mining employment is suppressed in 2000 is given the minimum unsuppressed value observed in 2000. The change in employment and natural gas production is the change from 2000 to 2010 less the change from 1995 to 2000. The change in natural gas production is in billions of cubic feet. The spatial weights matrix W is row normalized and based on contiguous counties. The sample includes all nonmetro counties in the four states, less one county which was excluded for its extreme change in earnings per job, which was negative and four times the magnitude of the next closest observation.

* Statistical significance at the ten percent level.

** Statistical significance at the five percent level.

*** Statistical significance at the one percent level.

Table A2
First-differenced estimates: employment, population, and earning per job.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Δ Total employment</th>
<th>Δ Mining employment</th>
<th>Δ Manufacturing employment</th>
<th>Δ Population</th>
<th>Δ Earnings per job</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δ Gas</td>
<td>20.6</td>
<td>8.0</td>
<td>−1.3</td>
<td>37.5***</td>
<td>30.7</td>
</tr>
<tr>
<td></td>
<td>(7.1)</td>
<td>(2.9)</td>
<td>(1.8)</td>
<td>(12.1)</td>
<td>(16.4)</td>
</tr>
<tr>
<td>W × (Δ Gas)</td>
<td>−11.0</td>
<td>−1.0</td>
<td>0.6</td>
<td>0.9</td>
<td>−71.0*</td>
</tr>
<tr>
<td></td>
<td>(13.0)</td>
<td>(3.2)</td>
<td>(4.4)</td>
<td>(19.1)</td>
<td>(33.0)</td>
</tr>
<tr>
<td>Controls for state</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Other control variables</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Spatial lags of control variables</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>361</td>
<td>361</td>
<td>361</td>
<td>361</td>
<td>361</td>
</tr>
</tbody>
</table>

Notes: Robust standard errors are in parenthesis. All outcome variables are defined as the change from 2000 to 2010. The change in gas production is also defined as the change from 2000 to 2010 and is in billions of cubic feet. The control variables are taken at their 1999 values. The spatial weights matrix W is row normalized and based on contiguous counties. The sample includes all nonmetro counties in the four states, less one county which was excluded for its extreme change in earnings per job, which was negative and four times the magnitude of the next closest observation.

* Statistical significance at the ten percent level.

** Statistical significance at the five percent level.

*** Statistical significance at the one percent level.
Table A3
Does the largest employment effect occur before production growth?

<table>
<thead>
<tr>
<th>Variable</th>
<th>Change in employment ([(end year–2000)–(2000–1995)], where the end year is . . .</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δ Gas ([2010–2000)–(2000–1995)]</td>
<td>18.5**</td>
</tr>
<tr>
<td>W × Δ Gas</td>
<td>3.5</td>
</tr>
<tr>
<td>Controls for state</td>
<td>Yes</td>
</tr>
<tr>
<td>Other control variables</td>
<td>Yes</td>
</tr>
<tr>
<td>Spatial lags of control variables</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>361</td>
</tr>
</tbody>
</table>

Notes: Robust standard errors are in parenthesis. The change in employment and natural gas production is the change from 2000 to 2010 less the change from 1995 to 2000. The end period used to calculate the change in employment is different in each column. For example, the change in employment in the furthest right column is defined as the change from 2000 to 2006 minus the change from 1995 to 2000. The change in natural gas production is in billions of cubic feet. The spatial weights matrix W is row normalized and based on contiguous counties. The sample includes all nonmetro counties in the four states, less one county which was excluded for its extreme change in earnings per job, which was negative and four times the magnitude of the next closest observation.

*Statistical significance at the ten percent level.
**Statistical significance at the five percent level.
***Statistical significance at the one percent level.

References


