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Abstract

The recovery of the US manufacturing sector following the 2008–2009 economic recession has coincided with a sharp drop in natural gas prices. Popular discussion has often attributed a large portion of the manufacturing recovery to this drop in gas prices, but little rigorous analysis has been conducted on this issue. We use confidential plant-level data to estimate the manufacturing employment effects of changes in natural gas and other energy prices. Previous analyses have used aggregated data and failed to control for multiple drivers of employment dynamics, such as other input costs and proximity to product demand. We show that controlling for these factors substantially diminishes the effects of natural gas and electricity prices on manufacturing employment. Accounting for the direct effects of natural gas prices as well as the indirect effects via electricity prices, we estimate that the decline in natural gas prices between 2007 and 2012 raised overall manufacturing employment by 0.6 percent. For industries in the top quartile of the gas intensity distribution, the natural gas price drop raised employment by three times as much—that is, 1.8 percent.

Key Words: energy boom, employment effects, US manufacturing, natural gas prices

JEL Codes: Q43, J23, D24

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1. Introduction

Despite long-term declines in its relative share of employment and output, US manufacturing has rebounded sharply from the 2008–9 recession. In fact, this is the first recession where the sector has fully recovered its share of output since the early 1980s (Celasun et al. 2014). Internationally, the United States represents about 20 percent of global manufacturing—roughly the same share as China. Even though employment in domestic manufacturing has not fully returned to prerecession levels, the sector still accounts for more than half of the high-wage blue-collar jobs in the country (McKinsey Global Institute 2012).

The recovery of the manufacturing sector has coincided with a sharp drop in natural gas prices (EIA 2013a). Declining production costs, particularly from shale formations, have dramatically increased output and estimated reserves and reduced gas prices for consumers. Between 2007 and 2012, real natural gas prices declined by about 50 percent. Since 2005, domestic natural gas production has increased by 50 percent, reaching 2.8 trillion cubic feet (tcf) in 2016. In one year alone, 2011, the US Energy Information Administration (EIA) more than doubled its estimates of technically recoverable shale gas to 827 tcf. Subsequently, estimates have been revised upward several times, with recent estimates suggesting the United States may have more than 1,100 tcf of technically recoverable shale gas resources (EIA 2013b). Combined with its estimates of non–shale gas resources, EIA projects that the United States has more than 100 years of technically recoverable natural gas reserves overall (EIA 2017).

Few experts dispute that the US economy is benefiting from higher natural gas production and lower prices. GDP growth, employment expansion in the natural gas production sector, lower electricity and natural gas prices, improvements in trade balance, and increases in tax revenues are all among the commonly articulated gains. The manufacturing sector consumes natural gas directly as a fuel and indirectly through its use in electricity generation. Both the electricity and manufacturing sectors have increased their gas consumption substantively, with few gains in the residential and commercial sectors.

Based on standard microeconomic theory, a decline in the price of an input, such as natural gas, reduces marginal production costs, increases output, and reduces output prices. The output increase raises employment, and the decrease in natural gas price relative to wages can increase or decrease employment depending on whether natural gas and employment are complements or substitutes in production. The size, location, and timing of the job gains are unclear and are the subject of considerable debate in policy circles. This is particularly true when looking granularly at individual industries or at particular regions of the country.

Lower natural gas prices have also generated a policy debate about future natural gas exports. Low prices in the United States relative to other countries have increased the profitability of exporting natural gas, either by pipeline or by ship in liquefied form. At the same time, an increase in gas exports would boost US prices, benefiting natural gas producers but harming consumers, particularly gas-intensive industries. These opposing effects are the basis for a vigorous policy debate over whether exports should be allowed to grow rapidly or growth should be restrained.

Several recent studies have attempted to estimate the effects of the recent decline in natural gas prices on manufacturing employment. These estimates suggest that the manufacturing employment gains from the gas price declines are potentially quite large—as much as 9.1 percent for industries in the top decile of energy intensity and up to 30 percent for the most energy-intensive industry (fertilizer manufacturing).[1] However, these papers rely on aggregated data and pay virtually no attention to other factors that may be correlated with natural gas prices and also affect employment, such as skilled labor availability, proximity to intermediate inputs, or other location-specific variables.

To assess the effects of natural gas prices on the recovery of the manufacturing sector and to characterize the potential effects of expanding natural gas exports, we attempt to make several advances over the recent literature in this paper. First, we analyze the effects of natural gas prices on local (county-level) employment, defined at a highly disaggregated industrial level. This detail enables an analysis of the aggregate and geographic effects of natural gas price declines, in contrast to the other studies, which have relied on national-level data. The use of county-level data allows us to make a second advance—namely, the consideration of other location-specific factors, such as proximity to key inputs. This approach builds on the literature on agglomeration and industry dynamics (e.g., Ellison and Glaeser 1997). Accounting for these factors is not possible using aggregated data, and these factors turn out to be correlated with natural gas prices. Consequently, controlling for the location-specific factors substantially reduces the estimated effects of the observed natural gas price declines on employment.

We use confidential plant-level Census information to develop a reduced-form panel data model linking manufacturing employment to natural gas and electricity prices, controlling for other factors that may affect growth, and estimate long-term (five-year) effects. We find that natural gas prices have a statistically significant effect on county-level employment, with effects typically increasing with natural gas intensity. Consistent with the findings of previous studies such as Kahn and Mansur (2013), electricity prices also affect employment, which suggests that natural gas prices affect manufacturing employment both directly and indirectly. Similarly to other studies, our estimates include the effects of both expanding production and substitution between natural gas and labor induced by changes in natural gas prices.

The resulting model estimates, in turn, are used to simulate the employment gains arising from the 50 percent natural gas price decline that occurred between 2007 and 2012. We find that the drop in natural gas prices raised overall manufacturing employment by 0.6 percent. These estimates of the gas price–induced gains are smaller than those reported in other recent studies, which is at least partly explained by our controlling for the agglomeration factors. Our estimated employment impacts are also small relative to the observed swings in aggregate manufacturing employment over the period: either the aggregate decline of 17.8 percent between 2007 and 2012 or the aggregate increase of 6.1 percent in the post-recession period between 2010 and 2012.

Although natural gas prices had modest effects on aggregate manufacturing employment, they did have substantial effects on employment in gas-intensive industries. The decline in natural gas prices between 2007 and 2012 increased employment by 1.8 percent in the relatively gas-intensive industries (i.e., those in the top quartile of the

[1] These calculations exclude indirect effects associated with industries providing materials directly used in oil and gas production, such as the increased output of steel mills to produce the casing used on drilling rigs.

gas intensity distribution), which is three times greater than the estimate for the entire manufacturing sector, reflecting the importance of natural gas as an input for the gas-intensive industries. Like the aggregate estimate, this estimate is smaller than that reported in other recent studies.[2] In both the 2007–12 and 2010–12 periods, the gas-intensive industries experienced consistently higher employment growth than the manufacturing average. Overall, the decline in natural gas prices explains more than half the faster employment growth rates observed in the gas-intensive industries. Thus natural gas prices explain only a small portion of the aggregate employment changes but large shares of cross-industry variation in employment growth during these time periods.

Increases in natural gas exports are expected to have relatively small impacts on natural gas prices, raising them somewhere between 3 and 9 percent (EIA 2014). Consequently, simulations of our model suggest that higher exports would have relatively small impacts on overall manufacturing employment, reducing employment by 0.1 to 0.3 percent across all industries, depending on the magnitude of the export-induced price change. For the gas-intensive industries, the employment reductions would be 0.2 to 0.5 percent.

Section 2 of the paper reviews the recent literature on the link between domestic natural gas prices and manufacturing employment. Sections 3 and 4 describe the modeling setup and plant-level data. The model estimates and simulation results are presented in sections 5 and 6. Section 7 offers concluding observations.

2. Literature Review

Several studies examine the effects of electricity or aggregate energy prices on manufacturing employment or output, including Kahn and Mansur (2013) and Aldy and Pizer (2015). The recent decline in natural gas prices has stimulated a more recent literature on the specific linkages between domestic natural gas prices and US manufacturing activity, measured by employment, output, or other variables.[3] Hausman and Kellogg (2015) analyze 230 manufacturing industries using published Census of Manufactures data disaggregated to the six-digit North American Industry Classification System (NAICS) level for the years 2002, 2007, and 2012, combined with industry-level measures of natural gas intensity (including both direct gas purchases and indirect inputs into electricity calculated at the national level) from Bureau of Economic Analysis 2007 input-output tables.

Focusing on the most gas-intensive industries, which they define as those in the top decile of intensity across the manufacturing sector, Hausman and Kellogg (2015) take two approaches to estimating the counterfactual employment changes for these industries. First, they assume that if gas prices had not fallen after 2007, the 2007–12 employment growth rates for gas-intensive industries would have been the same as employment growth for other industries. Using this counterfactual yields a net employment gain for gas-intensive industries of 3.4 percent. As an alternative counterfactual, they control for the 2002–7 difference in employment growth rates between gas-intensive and other industries.

[2] The specific differences reported here also reflect a slightly wider range of industries in the gas-intensive group.

[3] Focusing on local economies that experience increases in natural gas production, Weber (2014) and Allcott and Keniston (2017) estimate the effects of natural gas prices on employment and wages in nonproduction industries.

This counterfactual yields an employment gain of 9.1 percent for the gas-intensive industries. In other calculations, they define the gas-intensive industries as those in the top quintile (rather than the top decile). Using the second approach to estimate the counterfactual for the top quintile yields an employment gain of 11 percent. When they focus exclusively on the single most gas-intensive industry, fertilizer manufacturing (NAICS 325310), the comparable gain is 14 percent. Overall, their results show relatively large gains for gas-intensive industries associated with the natural gas price declines, ranging from 3.4 to 14 percent over the period 2007–12.

Melick (2014) adopts a somewhat different strategy for estimating the link between domestic natural gas prices and US manufacturing employment. He develops a regression model using published four-digit NAICS codes rather than the more disaggregated six-digit data used by Hausman and Kellogg, which results in a sample of approximately 80 industries. However, his data goes back further in time, to 1991. Importantly, Melick's focus is on the differences in domestic natural gas prices (measured as the average price at the Henry Hub, a commonly used benchmark price) and the gas price in Europe for 2006 (measured at Germany's eastern border). He finds that the fall in US natural gas prices since 2006 is associated with a 2–3 percent increase in activity for the entire manufacturing sector, with much larger effects of 30 percent or more for the most energy-intensive industries. Although his model includes both current and lagged terms, which allows for at least some consideration of the longer-term effects, he notes that since firms typically add production only gradually, his analysis may not capture the full effect of the decrease in US gas prices.

Celasun et al. (2014) compare aggregate US manufacturing output with that of other developed countries in a repeated cross section covering the period 2001–13. They focus on intercountry differences in three factors: natural gas prices, unit labor costs, and exchange rates. While all three variables are statistically significant and positively affect US employment, variation in natural gas prices contributes the least to changes in output. Overall, they find that a doubling of the natural gas price differential in favor of the United States would increase total US manufacturing production by 1.5 percent.

Kirat (2016) estimates the response of several measures of manufacturing output and employment to natural gas prices, using panel data that allow each industry's response to vary with its energy intensity. Domestic natural gas prices are measured vis-à-vis prices in Europe. With this framework, Kirat finds that the decline in relative US prices has led to an increase in total US manufacturing activity of nearly 2 percent.

All of these papers estimate the effects of natural gas prices on national employment, but they do not provide any information about the regional effects. Moreover, the papers do not consider other factors that could potentially affect manufacturing employment and may be correlated with natural gas prices. The omission of these factors could lead to over- or underestimation of the effects of reduced natural gas prices on employment. The literatures on industry agglomeration (e.g., Ellison and Glaeser 1997; Ellison et al. 2010) and industry life cycles (the growth and contraction of industries over time) identify multiple variables that affect the evolution of industry employment over time and explain its geographic distribution. Dumais et al. (2002) show that changes in industry-level economic activity depend on factors besides energy prices, such as proximity to intermediate inputs and the availability of skilled labor. There is also evidence that energy-intensive industries tend to cluster geographically. These literatures suggest that additional factors must be considered when predicting the regional and temporal effects of energy prices on employment.

Our approach goes beyond existing studies to generate industry-specific estimates of the temporal and geographic effects on manufacturing employment of energy prices. We develop a model that also accounts for the effects of energy prices and other factors, such as environmental regulation, on local (county-level) employment by industry. Recognizing the literature on industry life cycles and agglomeration, we explicitly control for factors such as the availability of skilled labor and other inputs.

3. Model

We model the impact of natural gas prices on employment using a sample that includes all manufacturing industries. The unit of observation is a unique industry-county-year combination, where j indexes industries, c indexes counties, and y indexes years. Our econometric model is similar to the models used in the agglomeration literature (e.g., Ellison and Glaeser 1999). Specifically, employment for a given industry, county, and year depends on input costs and product demand. For example, a decrease in input costs in one county, relative to costs in other counties, decreases production costs for plants located in that county. Plants located in that county can reduce their product prices relative to competitors in other counties, increasing demand for their output. Consequently, employment in the county and industry increases, both because production expands at plants that existed before the input cost decrease and also because new plants enter after the cost decline. The cost decrease in the first county may also reduce employment in other counties because plants located in those counties face higher relative input costs than they did before the cost decline.

One expects these employment effects to be larger for more intensive users of the input. For example, a decline in average wages of skilled workers in one county should have larger employment effects for skilled worker–intensive industries than for other industries. The logic extends to aggregate input cost shocks, which reduces input costs for US plants relative to foreign competitors.

Product demand may also affect county by industry employment. For example, proximity to consumers can affect employment because of the cost of shipping a plant's output to consumers. An increase in consumers of a particular product in one county can increase employment of producers of the product in that county, as well as in nearby counties, because those plants can supply consumers at lower total costs (including shipping costs) than plants located farther away from the consumers.

In the particular case of natural gas prices, one expects a decrease in aggregate natural gas prices to increase aggregate employment, particularly in gas-intensive industries, because input costs decline relative to foreign competitors. Moreover, the increase in employment following a gas price decrease should be largest in counties that experience the greatest price declines.

Following Hausman and Kellogg (2015), we focus on changes in energy prices and employment over five-year intervals. This time span captures plant-level responses that may include adjustments in capital equipment, as well as plant entry and exit. This contrasts with the agglomeration literature, which estimates the equation in levels rather than first differences. In our model, taking first differences turns out to be important for removing trends. Similarly to Greenstone (2002), we estimate a simple linear regression of manufacturing employment growth on energy prices, regulation, and other factors:

$$\Delta lnE_{jcy} = \beta_j^0 + \beta^e s_j^e \Delta lnP_{jcy}^e + \beta_j^g s_j^g \Delta lnP_{cy}^g + \beta_j^r R_{cy} + \beta_j^x \Delta X_{jcy} + \varepsilon_{jcy} \quad (1)$$

where ΔlnE_{jcy} is the change in log employment between years $y-1$ and y; ΔlnP^{e}_{jcy} and ΔlnP^{g}_{cy} are the changes in electricity and natural gas prices; s^{e}_{j} and s^{g}_{j} are the industry's cost shares of electricity and natural gas; R_{cy} includes county attainment status for local air pollutants, as discussed below; X_{jcy} is a vector of agglomeration drivers; ε_{jcy} is an error term; and each β is an industry-specific coefficient to be estimated. Following Ellison and Glaeser (1999), X_{jcy} includes both cost and demand factors—proximity to inputs, consumers, skilled labor, and others—that is, the factors other than energy prices that the agglomeration literature suggests affect employment levels. We provide further details on these variables below in the data section. We also include county-year interactions in X_{jcy} to control for macroeconomic shocks to county-level employment.[4]

Our main focus is on the coefficients on the electricity and natural gas cost share–price interactions. Because the equation is in first differences, the coefficients are identified by differential shocks to energy prices across counties, combined with variation in cost shares across industries. The equation includes the main effects of the cost shares and prices as well as the interactions. The main effects control for differential trends in employment growth that are correlated with the cost shares, as well as the average effects of natural gas price shocks on employment. We expect that a given price shock has a large employment effect for industries with a larger cost share, causing the coefficient on the interaction term to be negative. The coefficient would equal negative one if all industries had a Cobb-Douglas production function (Linn 2008), implying that a 1 percent natural gas price change would cause a percentage change in employment equal to the natural gas cost share. The coefficient can differ from one, relaxing the Cobb-Douglas assumption. The identifying assumption in equation (1) is that natural gas or electricity price shocks would not affect employment in a hypothetical industry that does not use any natural gas or electricity. This is a milder assumption than that made in Hausman and Kellogg (2015), who assume that natural gas prices do not affect low-intensity users.

This specification allows for heterogeneous effects of electricity and natural gas prices across industries—that is, larger effects for industries with higher cost shares. Estimating a single coefficient on the interaction term imposes a functional relationship between energy prices and employment, analogous to the assumption in Aldy and Pizer (2015). Because of our focus on natural gas prices, we partially relax this assumption for natural gas by grouping together the industries by their energy cost share and allowing the coefficients to vary across groups. We estimate this version using a spline, which highlights changes in coefficients across groups.

[4] The county-year interactions turn out to be important for identifying the energy price coefficients, as omitting the interactions yields positive energy price coefficients in some specifications that we estimated. However, if we estimate the preferred model but omit the county-year interactions, the simulated effects of the 2007–12 natural gas price decline are similar to those reported using our preferred model that includes these interactions.

The controls for attainment status and agglomeration drivers are important for the identification of the employment effects of electricity and natural gas prices. Greenstone (2002) and other studies have documented the negative employment effects of environmental regulation under the Clean Air Act, which sets standards for pollution levels and compels counties failing to meet the air quality requirements, known as nonattainment areas, to reduce emissions. Because many energy-intensive industries are also heavily polluting, energy prices could affect employment across industries in similar ways to tighter pollution regulations. Thus we use attainment status as a proxy for environmental stringency; we expect negative employment effects for counties that are not in attainment.

The agglomeration variables control for demand and supply side factors that could affect industry location, such as proximity to consumers of the industry's output and availability of inputs. These variables could be correlated with energy prices for a variety of reasons—for example, a county may have low natural gas prices because gas is particularly abundant in that area or it may have large resources of other inputs such as timber. If energy price shocks are correlated with wage shocks, omitting controls for wages of skilled workers would yield biased estimates of the energy price coefficients. We include the agglomeration variables in a similar manner as the energy price variables, typically interacting local changes in factor availability with the industry's intensity of use for that factor (e.g., interacting the change in the fraction of college graduates in the county over the period with the fraction of the industry's workforce in executive or professional jobs).

4. Data

The primary data source for our analysis is the confidential plant-level data collected by the US Census Bureau in the Census of Manufactures (CMF), which is carried out every five years. These data have been collected into the Longitudinal Business Database described by Jarmin and Miranda (2002). We use the CMF records from 1972 through 2012. They provide information on total employment and total value of shipments for each manufacturing plant. We aggregate these data by county and four-digit NAICS industry.[5] We examine the changes in employment and output over the five-year period between censuses, measured by the change in the natural logarithmic values of these variables between the starting and ending years of the period. We include in our analysis all years of data for any county-NAICS4 cell that ever had manufacturing employment during the 1972–2012 period. (We use NAICS4 to indicate an industry defined at the four-digit level, which is more aggregated than a NAICS6 industry.) To account for the fact that some industry-county-year cells have zero employment, we add 1 to employment before taking the log.[6]

Our main explanatory variables relate to energy prices and energy usage, specifically for natural gas and electricity. The CMF

[5] Before 1997, the Census used Standard Industrial Classification (SIC) industry definitions. If a plant that operated before 1997 continued operating after 1997, we use its later NAICS code; otherwise, we use an SIC-NAICS concordance to assign a NAICS code. A few industries (notably publishing) moved into or out of manufacturing during the 1997 SIC-NAICS change; since we do not have data for them over the whole period, they are excluded from the analysis.

[6] We have estimated alternative versions of equation (1) that add other constants to employment before taking the log. The coefficient estimates are qualitatively similar, for example, if we use 10 rather than 1.

provides plant-level information on electricity expenditures and quantities, which we use to calculate a county-level average electricity price in each year, aggregating expenditures and quantities across all plants in the county and dividing expenditures by quantities. If a particular county does not have any CMF records in a given year, we substitute the state-level average electricity price based on all CMF plants in the state.

Since the CMF data do not distinguish between natural gas and other fuels, we need alternative data sources for natural gas. Some other Census data sets provide plant-level information on energy consumption, but these do not cover all plants or years. We could use the more aggregate state-level prices from EIA, but instead we use the Census plant-level data sets to create county-level prices. Specifically, the Annual Survey of Manufactures (ASM) collected fuel-specific expenditures and quantities between 1975 and 1981, and the Manufacturing Energy Consumption Survey (MECS) collected detailed fuel-specific information in 1985, 1988, 1991, 1994, 1998, 2002, 2006, and 2010. We aggregate the expenditure and quantity data for natural gas at both the county and state levels to calculate the average natural gas prices, and we construct the ratio of county to state prices in each of these years.[7] We then interpolate the county ratios between years to obtain data for each of the census years (using the 1975 value for 1972 and the 2010 value for 2012). We apply these county-year ratios to the state-level natural gas prices for industrial sector users in EIA's State Energy Data System (SEDS), generating county-specific natural gas prices for each census year.

We use the 1985 MECS data to define the cost shares of electricity and natural gas, since the earlier years of ASM fuel supplement data provide incomplete information on natural gas consumption. The plant-level expenditures on electricity and natural gas were aggregated for all plants within each NAICS4 industry and then divided by the total value of shipments. We use these fixed cost share values, rather than time-varying ones, to address potential concerns about the endogeneity of time-varying cost shares (i.e., that energy prices may affect the cost shares).

In addition to energy price changes, we control for changes in regulatory stringency as measured by county-level nonattainment with air quality criteria. We create nonattainment dummy variables for each of four pollutants (carbon monoxide, ozone, sulfur dioxide, and particulates) in each county and year. We then interact these nonattainment dummy variables with another dummy indicating whether the industry is an emitter of that pollutant, based on US Environmental Protection Agency data reported in Greenstone (2002). The original emitter dummies vary by NAICS6 industry. We aggregate the emitter dummies to the NAICS4 level, weighted by industry shipments, with the overall NAICS4 emitter dummy being turned on if NAICS6 industries account for more than 50 percent of NAICS4 industry employment.

We also include a number of control variables to allow for county-industry-level agglomeration factors, following Ellison and Glaeser (1999). These variables measure the change in county-level availability of inputs, interacted with the industry's use of those inputs. For example, we interact the county's per capita cattle with the industry's use of livestock inputs and the state's percentage

[7] Given some extreme outliers in these county-state ratios, we trim them to the 10th and 90th percentile values.

forested with the industry's use of lumber inputs. To control for labor requirements, we use the industry's shares of unskilled labor interacted with the fraction of the population in the county without a high school degree; skilled production workers interacted with the percentage unionized in the state; and executive and professional workers interacted with the fraction of the population in the county with a high school degree. We also interact the county's average manufacturing wage with three measures of the industry's sensitivity to labor costs: labor cost share, fraction of output exported, and import penetration rate. The construction of these control variables is described in detail in the data appendix.

Table 1 shows the summary statistics for the key variables used in our analysis, based on our full sample of nearly 1 million county-industry-year cells (to guard against disclosure concerns, sample sizes are rounded before being released by Census). Table 2 reports information for the key variables in our model for certain subsamples of the data, including disaggregation by region (the nine Census divisions) and by three groups of industries defined by natural gas intensity. The three industry groups have a natural gas cost share below 0.5 percent, between 0.5 percent and 1 percent, or over 1 percent, which correspond roughly to 50 percent, 25 percent, and 25 percent of the industries in our sample.[8] A list of these industry groups is provided in Appendix Table A3.

Table 3 presents the summary statistics of selected variables for the most recent observations in 2007–12, since those observations form the basis for the simulations in our later analysis. The average natural gas cost share was about 1 percent, and the natural gas price declined by about 50 percent between 2007 and 2012. If all industries had a Cobb-Douglas production function, the natural gas price decline would reduce employment by about 0.5 percent for the average industry. Appendix Table A4 shows summary statistics for all variables included in our regressions.

The average county-industry-year observation over the full sample has 133 employees and about $30 million of shipments. Average employment is somewhat larger among industries with the lowest natural gas cost share, although average employment growth is also somewhat larger for industries with higher natural gas cost shares. By definition, natural gas cost shares are highest for the third natural gas cost share group, and those industries are also considerably larger users of electricity than other industries. For the full sample, natural gas prices are highest in the Northeast and lowest in the South Central regions, although the growth rates are fairly similar. In the latest time period, the differences in natural gas prices are more pronounced, with much higher prices in the Northeast regions and much lower prices in the South Central regions, which also had the largest drop in natural gas prices between 2007 and 2012. In contrast, the average natural gas cost share is similar across regions. As discussed in the previous section, we expect the employment effect of a natural gas price shock to depend on the magnitude of the shock and the intensity of gas use. The data in Table 3 suggest that regional variation in the employment effects of natural gas prices is likely to arise from regional variation in the price shocks rather than in natural gas intensity.

[8] Of the 85 industries in our sample, 39 are in group 1 (low-NG), 20 in group 2 (medium-NG), and 26 in group 3 (high-NG).

5. Model Estimates

Table 4 presents our main estimation results for the impact of changes in energy prices on employment. Model 1 is our preferred specification, allowing a spline in the coefficient of natural gas prices interacted with the natural gas cost share while including a full set of controls for agglomeration effects at the county level. Model 2 shows the results without the spline to illustrate the effects of allowing for greater flexibility in the preferred model. To highlight the effects of the agglomeration variables, Models 3 and 4 display results without including those variables. Table 4 concentrates on the energy price variables, with the complete set of coefficients reported in the data appendix.

The negative sign on the electricity price interacted with cost share indicates that higher electricity prices tend to reduce employment in electricity-intensive industries. The effect is statistically significant, but the magnitude is small. Evaluated at the mean electricity cost share in our sample (1.7 percent), a doubling of electricity prices would reduce employment by only 0.7 percent (.017*.4001). The effect would be proportionately larger in industries with a higher electricity cost share.

Turning to natural gas prices, the first two spline terms are not statistically significant. The term is positive for the first group of industries (those with natural gas cost shares under 0.5 percent), and negative for the second group of industries (those with natural gas cost shares between 0.5 and 1 percent). The coefficient for the second group is larger in absolute magnitude, indicating that the impact of natural gas prices on employment turns negative midway through the second group. The coefficient for the third group of industries, those with natural gas cost shares above 1 percent, is negative and significant. Among natural gas–intensive industries, a higher natural gas cost share is associated with a greater elasticity of employment with respect to natural gas prices. Thus the spline suggests a small and statistically insignificant effect of natural gas prices for the lowest-consuming industries and a larger (negative) and statistically significant effect for higher-consuming industries.

Model 2 shows the effect of allowing less flexibility for the natural gas price impacts, using a single coefficient rather than a spline. The natural gas coefficient is negative and significant and similar in magnitude to the third spline coefficient in Model 1, picking up the rising impact of natural gas prices among industries that use more natural gas. The electricity coefficient is similar to that found in Model 1. Models 3 and 4 show the effect of omitting the agglomeration variables. The coefficients become slightly larger for the energy price terms that do not include a spline, but the natural gas spline in Model 3 is dramatically different, with a large and significant negative coefficient on the first spline term. Among the agglomeration variables, gas prices are more highly correlated with the labor market variables than with the other variables, suggesting that including the labor market variables would have a larger effect on the gas price coefficients than would the other agglomeration variables.

Figure 1 interprets the magnitudes of the natural gas price coefficients from all four models, showing the elasticity of employment with respect to natural gas prices evaluated at different values of natural gas cost shares between 0 and 6 percent. The figure shows that most of the models yield similar elasticity values, with the exception being Model 3 (natural gas spline estimated without agglomeration variables), which has elasticities nearly twice as large as the other models. Figure 2 shows the same information for the electricity elasticities, which are similar across all four models.

Appendix Table A5 shows the full set of coefficients from these models, including all the agglomeration variables. The labor-related agglomeration variables are generally statistically significant and have the expected signs. Rising manufacturing wages in a county are associated with lower employment in industries that are labor-intensive or import-exposed; growth in college graduates is associated with higher employment in industries that use more executive and professional workers; growth in high school dropouts is associated with higher employment in industries that use more unskilled workers. The changes in county nonattainment status for different pollutants are surprisingly positive, though never significant, and the other agglomeration variables are insignificant most of the time.

Implicit in the model is the assumption that the coefficients do not vary over time. This is an important assumption, given that we estimate the model using data from 1977 through 2012 and perform simulations based on gas price changes at the end of the sample. We assess the validity of this assumption by testing the preferred model's performance across alternative subsamples of the data. Specifically, we reestimate the model using subsamples that sequentially omit single years of data. For each of these estimations, we obtain predicted values for the corresponding year of data that was omitted. For example, in the first regression, we omit observations in the first year of the data and use the regression results to predict county by industry employment in the first year. We then compare the predicted values with observed values and compute the mean square prediction error. For each subsample, the out-of-sample prediction error is small relative to the variance of the dependent variable. The ability of the model to accurately predict employment changes out of sample supports our use of the model to simulate counterfactual natural gas price scenarios in the next section

Recall that we use the spline to allow the natural gas price–cost share interaction coefficient to vary across industries. We have tried alternative versions of the model that allow for other forms of heterogeneity, such as estimating separate price–cost share coefficients for each industry. In that case, we estimate positive energy price coefficients for some industries, and we find a weak correlation between the energy price coefficients and the energy cost shares. These results suggest that we do not have sufficient price variation to identify separate price coefficients for each industry.

When we tried running splines for both natural gas and electricity, the gas spline gave plausible results, but the electricity spline yielded a positive coefficient for the low electricity group (leaving many industries with a positive impact of electricity prices on employment). We have also tried defining a larger number of groups for the gas spline, which also yielded implausible results. As in the case where we estimate separate energy price coefficients for each industry, it seems that we lack sufficient energy price variation to allow more cross-industry heterogeneity than in the preferred model.

We also tried runs with different subsamples of the data set, such as including only the observations that had positive employment in both the starting and ending years of the periods or only those NAICS4-county combinations that had positive employment in all eight CMF years. Those runs tended to yield more industries showing negative gas price impacts (as compared with the full sample), but the coefficients were not always statistically significant. We do not report these results because disclosing results for both a full sample and a subsample is problematic for Census confidentiality rules.

6. Simulation Results

6.1. Employment Effects of 2007–2012 Natural Gas Price Decline

We use the estimated coefficients from the four models to simulate the employment impact of the observed 2007–12 natural gas price decline. To do this, we generate predicted values for all the 2012 county-industry observations, representing percentage changes in employment between 2007 and 2012, based on the actual values of the various explanatory variables (including the changes in natural gas prices in the county). We refer to these predicted employment values as the baseline employment.

We define the counterfactual scenario as a 2007–12 natural gas price change equal to zero. In the counterfactual, we allow for the fact that natural gas prices affect electricity prices. This approach is consistent with that of Linn and Muehlenbachs (2016), who use data from 2003 through 2012 and show that a drop in natural gas prices reduces electricity prices, and with that of Hausman and Kellogg (2015), who consider both the direct effects of natural gas prices and the indirect effects of natural gas prices acting through electricity prices.

Specifically, we account for the fact that natural gas prices and other factors, such as electricity demand, affect electricity prices. We estimate the electricity price change based on the average heat rate in a natural gas turbine, so that about 11 million British thermal units (mmBtu) of natural gas are required to produce 1 megawatt hour (MWh) of electricity. Thus a $1/mmBtu drop in natural gas prices would lower the cost of electricity generation by 1.1 cents per kilowatt hour ($11 per MWh). The actual adjustments to electricity prices are more nuanced, and this calculation represents an approximation of the long-run effect of natural gas prices on electricity prices. We calculate the electricity price reduction in percentage terms at the regional level, using the average natural gas price drop and the average electricity price in the region, and then apply that percentage reduction in electricity prices to all observations in the region. This approach is preferable to assuming that if natural gas prices had remained at 2007 levels, then electricity prices also would have remained at 2007 levels. That assumption would imply that all other factors affecting electricity prices, besides natural gas, had also remained constant between 2007 and 2012.

Besides natural gas and electricity prices, all other independent variables in the counterfactual scenario are the same as in the baseline. The difference between baseline and counterfactual employment is the effect of the 2007–12 natural gas price decline on employment.

We then multiply the percentage employment difference by the county-industry's 2012 employment value to obtain an employment change. We aggregate the county-industry employment change to the regional or industry group level and also to the national level.

Table 5 shows the simulation results based on the four different models from Table 4. For our preferred Model 1, overall employment in all industries is estimated to have increased by about 0.6 percent as a result of the natural gas price decline. The employment impact on group 3, the most natural gas–intensive industries, is three times as large, at 1.8 percent.

The simulated impacts are larger when we use the less flexible Model 2 (no spline in the natural gas interactions) and larger still when we exclude the agglomeration variables in Model 4. The largest impacts occur when we use the spline specification without the agglomeration variables, with overall employment increasing by 1.9 percent and by 3.3 percent in the natural gas–intensive industries. These results are consistent with the elasticities shown in Figure 1, recognizing that only Model 3 has nonnegligible elasticities for most industries that are assigned to group 1 or 2, those with a natural gas cost share less than 1 percent. In contrast, the preferred model yields approximately a zero effect of the natural gas price decline on employment for these industries, consistent with the fact that natural gas represents a negligible share of input costs for the majority of manufacturing industries. These differences across models illustrate the importance of allowing for as much flexibility as the data allow in the relationship between natural gas prices and employment, as well as the importance of including the agglomeration variables.

Figures 3 through 8 display the simulated impacts of the 2007–12 changes in natural gas prices on employment in each of the nine regions for Models 1 and 2, focusing on the employment impacts in all manufacturing industries (Figures 3 and 6), in the natural gas–intensive industries (i.e., the top quartile; Figures 4 and 7), and in the top decile (Figure 5 and 8). While Figures 4 and 5 show larger impacts than Figure 3, corresponding to the bigger effects on natural gas–intensive industries, the pattern of the employment impacts is similar across both figures, with the largest impact on employment occurring in the South Central states (regions 6 and 7), the geographic area experiencing the largest natural gas price decline (see Table 3). Though not shown here, the spatial patterns for Models 3 and 4 (excluding the agglomeration variables) are also similar: the differences across regions in their natural gas price changes drive the employment results, not differences in industry composition or other factors. Thus the regional effects of natural gas prices appear to be robust across our various models.

To put our results in context, we note that overall manufacturing employment declined by 17.8 percent between 2007 and 2012 because of the 2008–09 recession, but it grew 6.1 percent during the postrecession years (2010–12). Both of these employment swings dwarf our estimate of 0.6 percent for the impact of declining natural gas prices on overall manufacturing employment. Even the predicted 1.8 percent impact on employment in the top quartile of the gas-intensive industries is less than one-fifth of those industries' 2010–12 employment growth.

Natural gas prices do appear to explain a substantial share of the differences in employment growth across high- and low-intensity industries. We predict that employment would increase by 1.2 percent more for gas-intensive industries than for all manufacturing. Between 2007 and 2012, the employment decline in the gas-intensive industries was 1.9 percentage points less than employment decline across the entire manufacturing sector. Between 2010 and 2012, employment in gas-intensive industries grew 2 percentage points more than did employment across the entire manufacturing sector. Thus natural gas prices explain more than half (1.2/1.9 or 1.2/2.0) of the observed differences in employment growth rates between the gas-intensive industries and the entire sector.[9]

[9] Employment for gas-intensive industries declined by 15.9 percent for 2007–12, compared with a decline of 17.8 percent for all manufacturing, and grew by 8.1 percent for 2010–12, compared with a growth of 6.1 percent for all manufacturing.

Our predicted employment increases are much larger for the most intensive users of natural gas. For example, natural gas accounts for 10 percent of costs for the fertilizer industry (NAICS 325310). Using the coefficients from Model 1 (projecting beyond the right margin of Figure 1) yields an estimated elasticity of fertilizer industry employment with respect to the natural gas price of –0.45.[10] The observed 50 percent reduction in natural gas prices between 2007 and 2012 implies an employment increase of over 20 percent, slightly larger than the industry's actual employment increase of 17.6 percent during the period. The employment growth in this industry contrasts with an employment decline for the overall manufacturing sector of 17.8 percent, and our results suggest that natural gas prices explain the difference between the employment growth rate of the fertilizer industry and the average manufacturing growth rate.

We compare the results using the preferred model, in the first row of Table 5, with the estimates in the recent literature on natural gas prices and manufacturing. Our estimated employment change for gas-intensive industries is somewhat below the low-end estimate reported in Hausman and Kellogg (2015) and substantially below other estimates they report. Whereas Hausman and Kellogg (2015) define gas-intensive industries as the top decile of total electricity and gas use, we define gas-intensive industries as approximately the top quartile based on gas use. If we focus on the top decile of our industries and exclude agglomeration variables (Models 3 and 4), our estimated impacts are quite similar to their low-end estimate of 3.4 percent.

Our estimate of the average employment effect is also smaller than that reported in Melick (2014), Celasun et al. (2014), and Kirat (2016). There are numerous methodological and data differences between our analysis and theirs, but the fact that our employment effects are larger when we omit the agglomeration variables suggests that the agglomeration variables likely play an important role in explaining the differences between our results and theirs.

We have also performed simulations using other definitions of the counterfactual or other models. If we assume that the 2007–12 decrease in natural gas prices did not affect electricity prices, the estimated employment effects of natural gas prices are smaller than the results reported in Table 5. The geographic distribution of these effects differs slightly from the earlier results, because the percentage change in the electricity price for a region depends on the level of electricity prices in the region as well as the change in natural gas prices. For two regions with the same natural gas price change, the one with lower baseline electricity prices experiences a greater employment impact. In our simulations, region 6 still has the highest impact, while region 7 shows a smaller impact than some other regions.

We also ran the simulations for a variety of alternative models, including those discussed in our specification testing. When we estimate the model for individual industries, the overall impact on employment is somewhat larger, but the average impact for group 2 (intermediate natural gas intensity) is larger than for group 3 (high natural gas intensity). When we estimate the model allowing splines for both the natural gas and electricity interactions, the overall impact of

[10] The fertilizer industry's electricity cost share of under 2 percent contributes only negligibly to this elasticity.

the decline in natural gas prices is slightly larger than the estimates presented here, but the impact of electricity prices goes in the opposite direction. As noted earlier, it seems that we lack sufficient energy price variation to allow more cross-industry heterogeneity than in the preferred model.

6.2. Employment Effects of Expanding Natural Gas Exports

Since at least the 1960s, the United States has been a net importer of natural gas. Recently, however, lower natural gas prices have coincided with a decrease in imports and an increase in exports, causing net imports to be close to zero in 2016. Most exports are by pipeline to Canada or Mexico, but the recent disparity between US and international prices has spurred investments in liquefying and exporting gas by ship to other regions such as Europe.

By law, liquefied natural gas (LNG) exporters must receive permission from the Department of Energy to export. A number of export projects have received approval, and several more await approval. Exports of LNG are currently small, but as current investment projects come online, EIA expects annual LNG exports to grow to 3 tcf by 2020 and possibly as high as 4.5 tcf by the mid-2020s.

As noted earlier, the potentially adverse effects on gas consumers has been a focus of the policy debate about whether to slow or accelerate approvals for exports and possibly encourage exports via tax incentives. We can use our model estimates to simulate the employment effects of a hypothetical natural gas price increase. For comparability with the results reported in section 6.1, we perform these simulations by assuming that natural gas exports had been higher in 2012 than they actually were. EIA (2014) considers annual exports of about 4–7 tcf and estimates natural gas price increases ranging from 3 to 9 percent. We use our model to simulate the employment effects of increasing 2012 natural gas prices by these amounts.[11] We use the same process as in our earlier simulations, but instead of using the actual 2007–12 reduction in natural gas prices for a county, we increase the 2012 prices in the county by 3 percent (or 9 percent) and calculate a new predicted employment level in the county. The difference between this calculation and the prior counterfactual employment reflects the impact of expanding natural gas exports on employment. We expect these effects to be negative, because according to our estimates of equation (1), higher natural gas prices tend to reduce employment.

Since the simulated natural gas price increase is about one-tenth (6–18 percent) of the original 50 percent price decrease, the magnitude of this impact is substantially smaller than the impacts of the original price decrease. Table 6 reports the percentage national employment changes for each of the estimation models, considering 3 or 9 percent natural gas price increases. The preferred Model 1 suggests that natural gas exports would reduce national employment by 0.1 to 0.2 percent, depending on the magnitude of the export-induced natural gas price increase.

[11] EIA (2014) estimates price changes for 2015–40. Our counterfactual assumes an immediate price increase and should be considered as illustrative of the effects of higher natural gas prices caused by expanding exports. It also does not account for the possibility that natural gas prices in regions near the export terminals may be more affected by exports than prices in more distant regions.

The effects are larger for the high natural gas group, 0.2 to 0.5 percent, and still larger for the top-decile industries, 0.3 to 0.7 percent. Overall, expanding natural gas exports would have only a small effect on national manufacturing employment.

7. Conclusions

The overall finding of this research is that the 50 percent US natural gas price declines of the past decade have indeed had a favorable impact on domestic manufacturing employment, albeit not as favorable as previous studies have estimated. In contrast to the previous literature, we examine county-level rather than national-level employment, which allows us to control for a variety of location-specific factors that other analyses have ignored. Unsurprisingly, the local availability of skilled labor, proximity to key intermediate inputs, and other agglomeration factors can exert a strong influence on firms' decisions to change employment. Failure to account for these factors can distort the estimated role of natural gas price changes.

We estimate that the 2007–12 natural gas price decline raised overall manufacturing employment by about 0.6 percent. For the industries in the top quartile of the energy intensity distribution, we estimate employment gains of 1.8 percent. While the estimated average impact is small relative to the large swings in manufacturing employment actually observed over the period between 2007 and 2012, natural gas prices account for more than half of the faster employment growth that gas-intensive industries experienced over the period relative to overall manufacturing. For the most intensive users of natural gas, such as the fertilizer industry, we predict quite large employment increases, consistent with their experience over the period. Regionally, the predicted employment gains are greater in the South Central region. Our model predicts that variation across regions in natural gas price declines is a more important determinant of employment gains than variation across regions in industry gas intensity.

Regarding the continuing debate about the impact of potential expansion of US natural gas exports, recent EIA analysis concludes that for the scenarios considered, higher exports would increase natural gas prices by 3 to 9 percent, which is small compared with the 50 percent price decrease that occurred between 2007 and 2012. Given the relatively modest natural gas price impacts predicted by EIA, our analysis suggests relatively small employment effects for the entire manufacturing sector—with somewhat larger effects for the gas-intensive industries.

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TABLE 1. SUMMARY STATISTICS: KEY VARIABLES

	mean	std. dev.
Change in employment	0.033	1.2881
Total employment	133.135	913.615
Change in total value of shipments	0.2004	2.9537
Total value of shipments	29,900	351,000
Electricity cost share	0.0173	0.0158
Change in county-level natural gas price	0.2842	0.6117
County-level natural gas price	5.0979	3.4509
Natural gas cost share	0.0111	0.018

Note: The sample includes about 900,900 county-industry-year observations.

Table 2. Means of Key Variables for Subsamples of Data (All Years)

	Low natural gas intensity	Medium natural gas intensity	High natural gas intensity
Change in employment	0.0162	0.0499	0.0443
Total employment	160.5751	125.963	97.2868
Change in output	0.1622	0.2252	0.2374
Total output	30900	25400	32300
Elec cost share 1985	0.0099	0.014	0.0317
Change in NG price	0.2842	0.2838	0.2847
County NG price	5.0959	5.1096	5.0907
NG cost share 1985	0.003	0.0068	0.0272
	New England	Middle Atlantic	East North Central
Change in employment	–0.0148	–0.053	0.0196
Total employment	231.0552	226.6162	174.075
Change in output	0.1663	0.0977	0.1802
Total output	39200	40800	39800
Elec cost share 1985	0.0169	0.0171	0.0172
Change in NG price	0.2576	0.2863	0.2685
County NG price	6.8016	6.028	5.2826
NG cost share 1985	0.0111	0.0115	0.0112
	West North Central	South Atlantic	East South Central
Change in employment	0.0541	0.0342	0.0291
Total employment	70.0974	106.3658	93.8321
Change in output	0.2174	0.2036	0.1868
Total output	17400	21400	20800
Elec cost share 1985	0.0172	0.0176	0.0178
Change in NG price	0.2945	0.2773	0.2541
County NG price	4.9265	5.2895	4.7899
NG cost share 1985	0.0107	0.0112	0.0106
	West South Central	Mountain	Pacific
Change in employment	0.0487	0.0854	0.0755
Total employment	93.9062	66.0814	300.9489
Change in output	0.2107	0.2736	0.2846
Total output	34500	15200	62800
Elec cost share 1985	0.0174	0.0172	0.0169
Change in NG price	0.3123	0.3203	0.2948
County NG price	3.9661	5.0452	5.0623
NG cost share 1985	0.0112	0.0109	0.0113

Note: Census divisions: 1 = New England (CT, ME, MA, NH, RI, VT), 2 = Middle Atlantic (NJ, NY, PA), 3 = East North Central (IN, IL, MI, OH, WI), 4 = West North Central (IA, KS, MN, MO, NE, ND, SD), 5 = South Atlantic (DE, FL, GA, MD, NC, SC, VA, WV), 6 = East South Central (AL, KY, MS, TN), 7 = West South Central (AK, LA, OK, TX), 8 = Mountain (AZ, CO, ID, NM, MT, UT, NV, WY), 9 = Pacific (CA, OR, WA).

TABLE 3. MEANS OF KEY VARIABLES FOR SUBSAMPLES OF DATA (2007–2012 OBSERVATIONS)

	All	Low natural gas intensity	Medium natural gas intensity	High natural gas intensity
Change in employment	–0.1609	–0.1919	–0.1513	–0.1216
Total employment	98.5813	112.256	100.569	75.861
Change in output	–0.2052	–0.2694	–0.1938	–0.1166
Total output	52500	47800	45400	66100
Elec cost share 1985	0.0173	0.0099	0.014	0.0317
Change in NG price	–0.5066	–0.5067	–0.5058	–0.5072
County NG price	6.5858	6.5742	6.6013	6.5899
NG cost share 1985	0.0111	0.003	0.0068	0.0272

	New England	Middle Atlantic	East North Central	West North Central	South Atlantic
Change in employment	–0.178	–0.1943	–0.1373	–0.1016	–0.2109
Total employment	143.718	130.713	129.585	64.2264	72.5474
Change in output	–0.193	–0.2379	–0.148	–0.0833	–0.3182
Total output	80900	54600	65300	32000	33100
Elec cost share 1985	0.0169	0.0171	0.0172	0.0172	0.0176
Change in NG price	–0.3122	–0.164	–0.4464	–0.5674	–0.5433
County NG price	10.5977	10.1101	6.7222	6.2213	6.7783
NG cost share 1985	0.0111	0.0115	0.0112	0.0107	0.0112

	East South Central	West South Central	Mountain	Pacific
Change in employment	–0.2149	–0.1163	–0.1324	–0.183
Total employment	72.0359	82.8464	64.0951	227.536
Change in output	–0.3351	–0.1227	–0.182	–0.2246
Total output	37900	79300	28500	107000
Elec cost share 1985	0.0178	0.0174	0.0172	0.0169
Change in NG price	–0.7123	–0.6761	–0.4103	–0.3781
County NG price	4.8687	4.6247	6.5125	6.5888
NG cost share 1985	0.0106	0.0112	0.0109	0.0113

TABLE 4. REGRESSIONS: EMPLOYMENT MODELS

	Model 1	Model 2	Model 3	Model 4
(elec price change) *	–0.4001**	–0.3970**	–0.4383***	–0.4522***
(elec cost share)	(0.1303)	(0.1297)	(0.1300)	(0.1293)
(NG price change) *		–0.4770***		–0.5403***
(NG cost share)		(0.1247)		(0.1224)
Spline 1: (NG price change)	0.4635		–7.9525***	
* (NG cost share) <Low-NG>	(2.3774)		(2.3001)	
Spline 2: (NG price change)	–0.5290		1.2702	
* (NG cost share) <Medium-NG>	(1.4429)		(1.4323)	
Spline 3: (NG price change)	–0.4971***		–0.4771**	
* (NG cost share) <High-NG>	(0.1487)		(0.1465)	
Agglomeration variables	X	X		
Industry dummies	X	X	X	X
County-year dummies	X	X	X	X
R-squared-adj	0.0139	0.0139	0.0135	0.0135
No. obs (rounded)	909,600	909,600	909,600	909,600

TABLE 5. PERCENTAGE EMPLOYMENT CHANGES CAUSED BY 2007–12 NATURAL GAS PRICE DECLINE

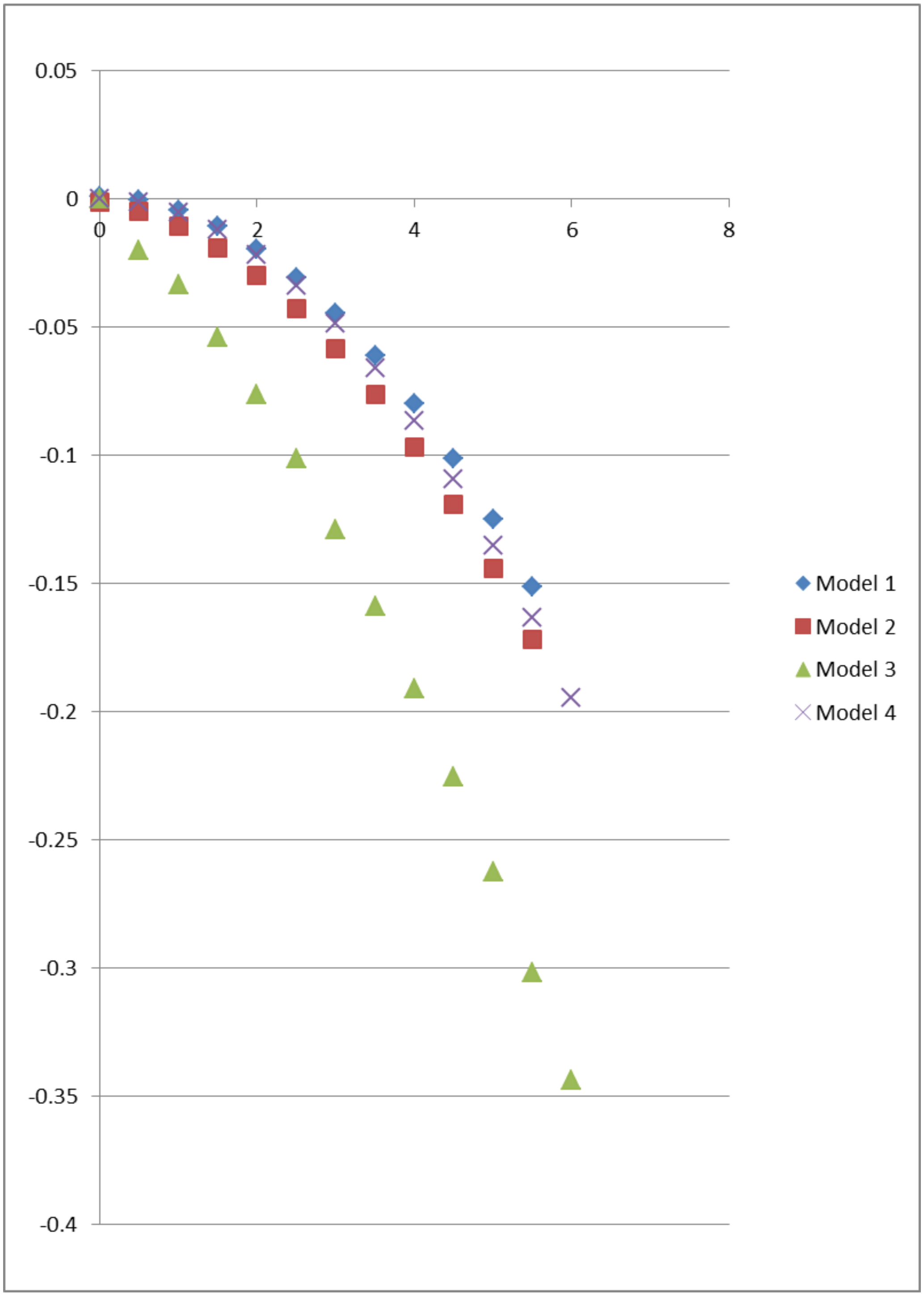
	All industries	High-NG	Top decile
Model 1 (NG spline, with agglom X)	0.605	1.778	2.626
Model 2 (no spline, with agglom X)	0.754	1.952	2.780
Model 3 (NG spline, no agglom X)	1.946	3.335	4.223
Model 4 (no spline, no agglom X)	0.857	2.220	3.160

TABLE 6. PERCENTAGE EMPLOYMENT CHANGES CAUSED BY NATURAL GAS EXPORTS–INDUCED PRICE INCREASES

Panel A. 3 Percent Natural Gas Price Increase			
	All industries	High-NG	Top decile
Model 1 (NG spline, with agglom X)	–0.087	–0.246	–0.336
Model 2 (no spline, with agglom X)	–0.097	–0.257	–0.345
Model 3 (NG spline, no agglom X)	–0.182	–0.363	–0.457
Model 4 (no spline, no agglom X)	–0.110	–0.292	–0.393

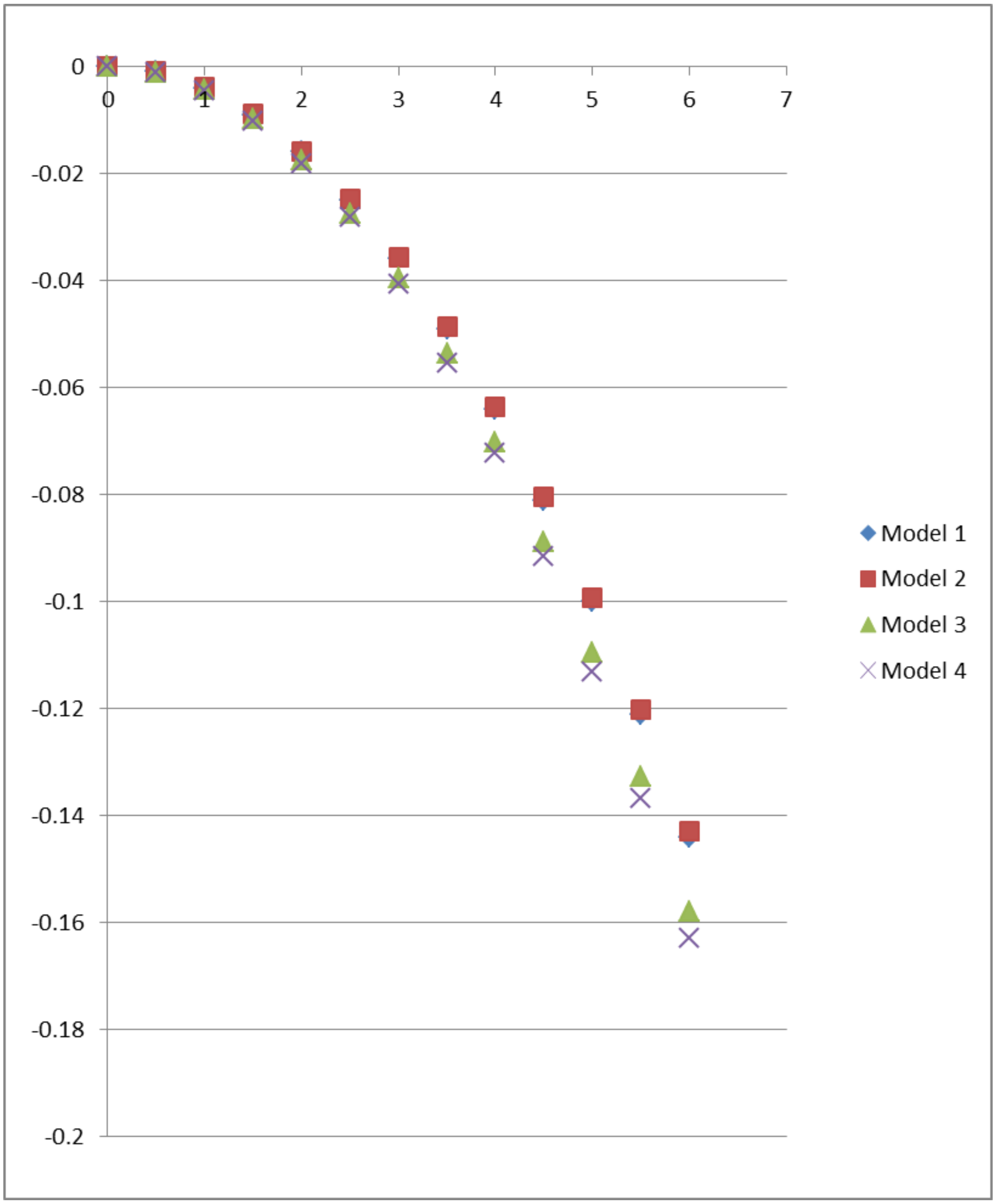
Panel B. 9 Percent Natural Gas Price Increase			
	All industries	High-NG	Top decile
Model 1 (NG spline, with agglom X)	–0.189	–0.531	–0.730
Model 2 (no spline, with agglom X)	–0.214	–0.560	–0.755
Model 3 (NG spline, no agglom X)	–0.433	–0.825	–1.032
Model 4 (no spline, no agglom X)	–0.244	–0.637	–0.859

FIGURE 1. ELASTICITY OF EMPLOYMENT WITH RESPECT TO NATURAL GAS PRICES EVALUATED AT DIFFERENT NATURAL GAS COST SHARES



Note: Natural gas cost shares from 0 to 6 percent; elasticities from +0.001 to –0.35.

FIGURE 2. ELASTICITY OF EMPLOYMENT WITH RESPECT TO ELECTRICITY PRICES EVALUATED AT DIFFERENT ELECTRICITY COST SHARES



Note: Electricity cost shares from 0 to 6 percent; elasticities from +0.00 to –0.16.

FIGURE 3. SIMULATED EMPLOYMENT IMPACTS OF NATURAL GAS PRICE DECLINE MODEL 1 (WITH NG SPLINE), ALL INDUSTRIES

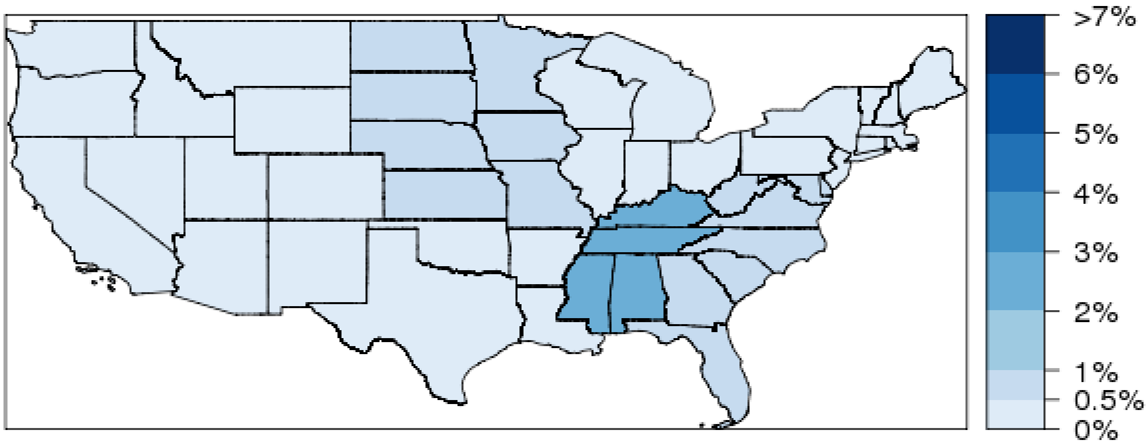


FIGURE 4. SIMULATED EMPLOYMENT IMPACTS OF NATURAL GAS PRICE DECLINE MODEL 1 (WITH NG SPLINE), INDUSTRIES IN TOP QUARTILE OF NATURAL GAS INTENSITY

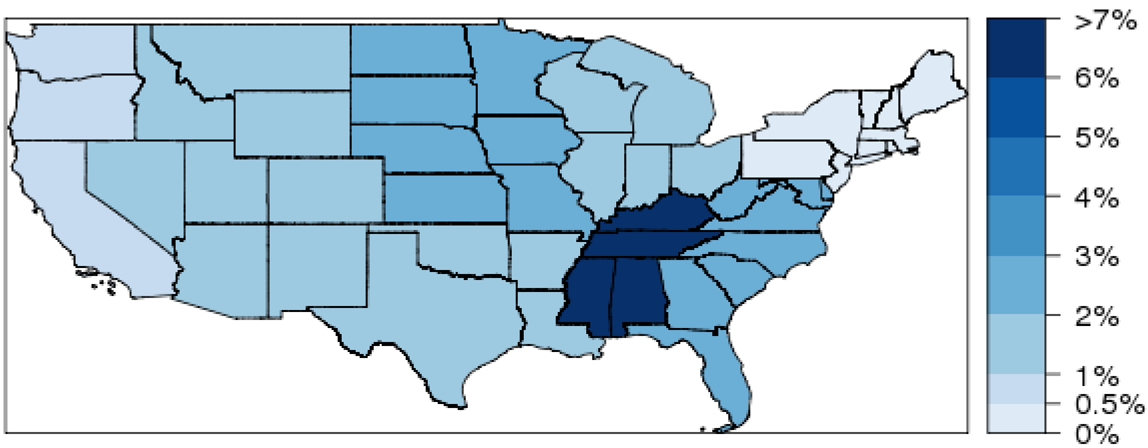


FIGURE 5. SIMULATED EMPLOYMENT IMPACTS OF NATURAL GAS PRICE DECLINE MODEL 1 (WITH NG SPLINE), INDUSTRIES IN TOP DECILE OF NATURAL GAS INTENSITY

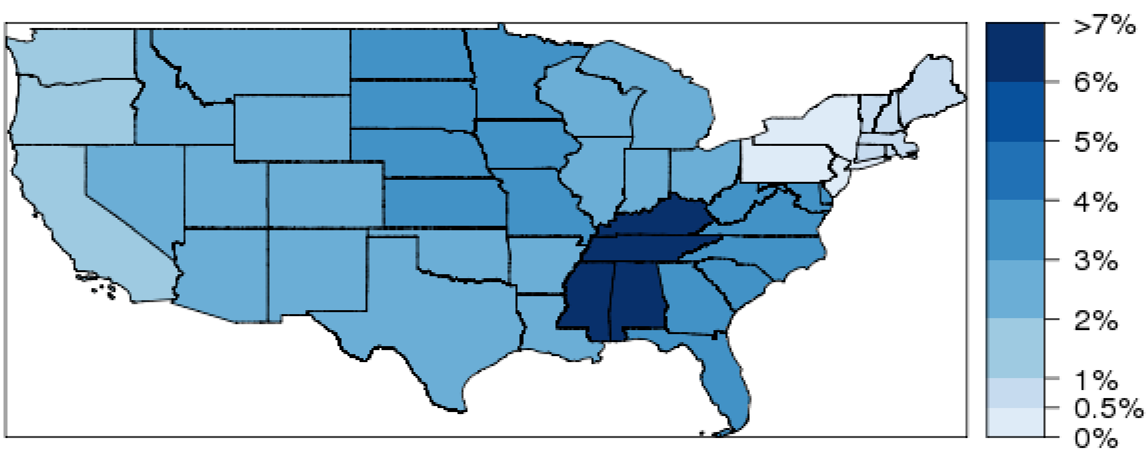


FIGURE 6. SIMULATED EMPLOYMENT IMPACTS OF NATURAL GAS PRICE DECLINE MODEL 2 (NO NG SPLINE), ALL INDUSTRIES

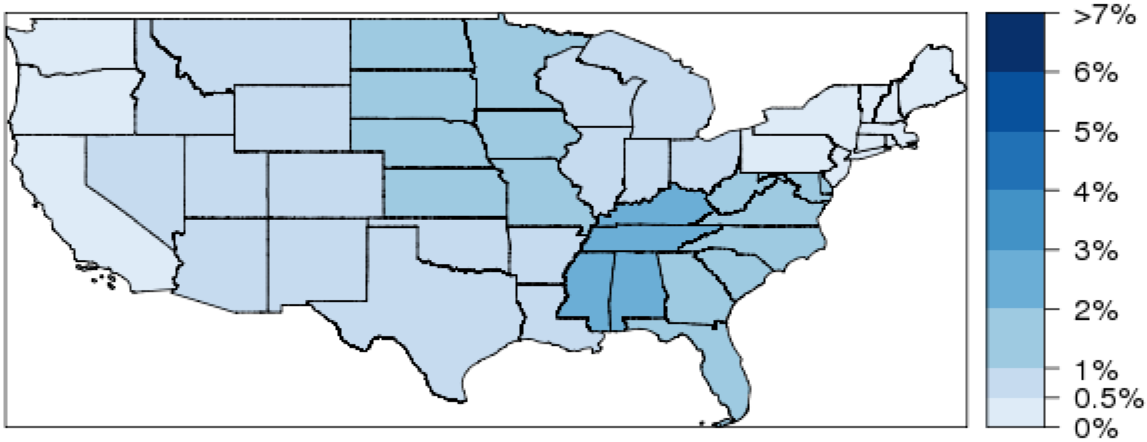


FIGURE 7. SIMULATED EMPLOYMENT IMPACTS OF NATURAL GAS PRICE DECLINE MODEL 2 (NO NG SPLINE), INDUSTRIES IN TOP QUARTILE OF NATURAL INTENSITY

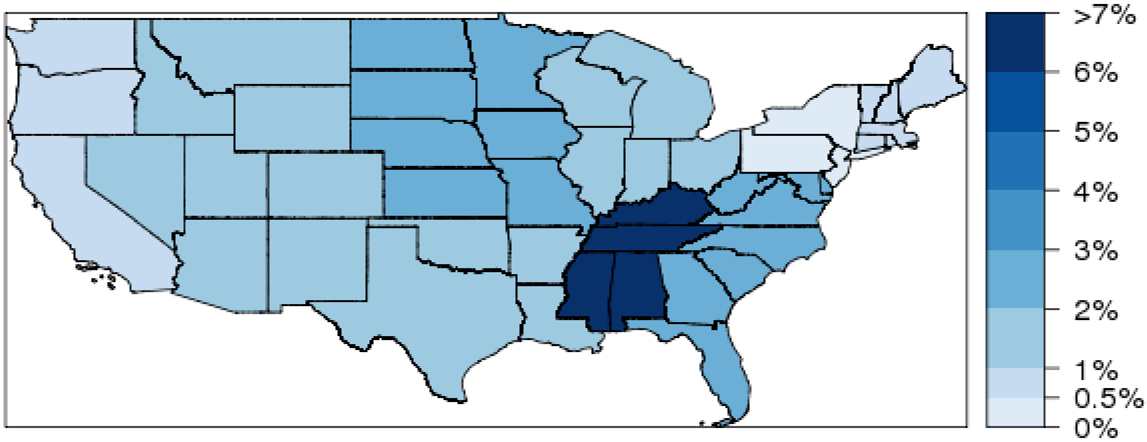
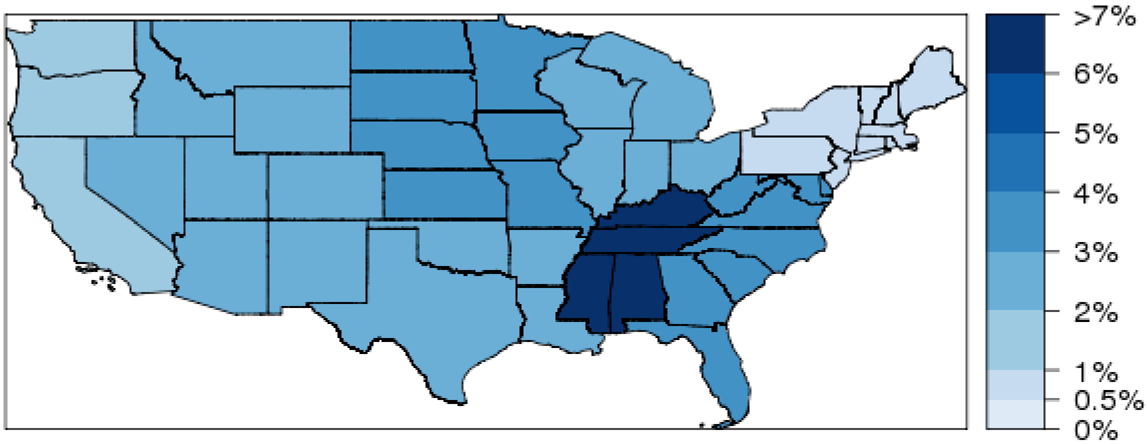


FIGURE 8. SIMULATED EMPLOYMENT IMPACTS OF NATURAL GAS PRICE DECLINE MODEL 2 (NO NG SPLINE), INDUSTRIES IN TOP DECILE OF NATURAL INTENSITY



Data Appendix: Agglomeration Variables

The variables designed to measure agglomeration effects are based on Ellison and Glaeser (1999). Our observations are calculated at the county-industry-year level, interacting factor availability measures for the county with measures of the industry's use of those factors. Since we estimate our model in change form, we multiply the changes in the county variable over the five-year period by the industry variable at the start of the five-year period. This requires the county measures to have variation over time and requires that both county and industry measures are available for the census years in our data set (1972, 1977, 1982, 1987, 1992, 1997, 2002, 2007, and 2012). Ellison and Glaeser did their analysis with state-level data, but most of the variables are also available at the county level; for those that are not (e.g., unionization rate), the state's number is applied to all its counties. Many of the county-level variables are available only periodically, and the intervening years are interpolated between the reported values.

TABLE A1. LIST OF STATE AND COUNTY VARIABLES

State and county variables	Source	Level	Period	Data set names
Percentage farmland	ICPSR	County	1959–2012	Farms, Acreage, and Value: Censuses of 1959, 1964, 1969, 1974, 1978, 1982, 1987, 1992, 1997, 2002, 2007, 2012
Per capita cattle	ICPSR	County	1959–2012	Cattle and Calves–Inventory and Sales: Censuses of 1959, 1964, 1969, 1974, 1978, 1982, 1987, 1992, 1997, 2002, 2007, 2012
Percentage timberland	USFS	State	1960–2014	Land Areas of the National Forest System (LAR)
Average mfg wage	BLS; BEA	County	1975–2014	Quarterly Census of Employment and Wages; Regional Economic Accounts, Table CA5, Local Area Personal Income by Major Component and Earnings by SIC Industry
Percentage without HS degree	USDA ERS	County	1970–2013	Educational Attainment for the U.S., States, and Counties, 1970–2015
Percentage with BA or more	USDA ERS	County	1970-2013	Educational Attainment for the U.S., States, and Counties, 1970–2015
Unionization percentage	UnionStats	State	1964–2015	Union Density Estimates by State, 1964–2015
Coast dummy	NOAA	County	2015	NOAA's List of Coastal Counties
Population density	NBER	County	1960–2014	Census US Intercensal County Population Data; ICPSR United States Agriculture Data, 1840–2012
Income share – mfg share	BEA	County	1969–2014	Regional Economic Accounts, Table CA1, Local Area Personal Income Summary
Per capita income	BEA	County	1969–2014	Regional Economic Accounts, Table CA1, Local Area Personal income Summary
State GDP	BEA	State	1964–2014	Regional Economic Accounts, Annual Gross Domestic Product (GDP) by State

Sources: BEA (Bureau of Economic Analysis): Regional Economic Accounts, Table CA1, Local Area Personal Income Summary, Table CA5, Local Area Personal Income by Major Component and Earnings by SIC Industry, https://www.bea.gov/regional/downloadzip.cfm; Annual Gross Domestic Product (GDP) by State, https://www.bea.gov/iTable/iTable.cfm?reqid=70&step=1&isuri=1&acrdn=2#reqid=70&step=1&isuri=1

BLS (Bureau of Labor Statistics): Quarterly Census of Employment and Wages, https://www.bls.gov/cew/datatoc.htm

ICPSR (Inter-university Consortium for Political and Social Research): United States Agriculture Data, 1840–2012, http://www.icpsr.umich.edu/icpsrweb/ICPSR/studies/35206?sortBy=&searchSource=revise&q=agriculture

NBER (National Bureau of Economic Research): Census U.S. Intercensal County Population Data, 1970–2014, http://www.nber.org/data/census-intercensal-county-population.html

NOAA (National Oceanic and Atmospheric Administration): NOAA's List of Coastal Counties, https://www.census.gov/geo/landview/lv6help/coastal_cty.pdf

UnionStats: Union Density Estimates by State, 1964–2016, http://unionstats.gsu.edu/MonthlyLaborReviewArticle.htm

USDA ERS (US Department of Agriculture, Economic Research Service,): Educational Attainment for the U.S., States, and Counties, 1970–2015, https://www.ers.usda.gov/data-products/county-level-data-sets/county-level-data-sets-download-data.aspx
USFS (US Forest Service): Land Areas of the National Forest System (LAR), https://www.fs.fed.us/land/staff/lar-index.shtml

TABLE A2. LIST OF INDUSTRY VARIABLES

Industry variables	Source	Level	Period	Data set names
Agricultural inputs	BEA	Industry	1958–2012	Input-Output Table, Total Requirements (1958, 1963, 1967, 1972, 1977, 1982, 1987, 1992, 1997, 2002, 2007, 2012)
Livestock inputs	BEA	Industry	1958–2012	Input-Output Table, Total Requirements (1958, 1963, 1967, 1972, 1977, 1982, 1987, 1992, 1997, 2002, 2007, 2012)
Lumber inputs	BEA	Industry	1958–2012	Input-Output Table, Total Requirements (1958, 1963, 1967, 1972, 1977, 1982, 1987, 1992, 1997, 2002, 2007, 2012)
Wages/value added	NBER	Industry	1958–2011	NBER-CES Manufacturing Industry Database
Exports/output	Schott	Industry	1972–2012	HS-Level U.S. Import and Export Data; SIC87- and NAICS-Level U.S. Import and Export Data, 1972–2005
Import competition	Schott	Industry	1972–2012	HS-Level U.S. Import and Export Data SIC87- and NAICS-Level U.S. Import and Export Data, 1972–2005
Percentage unskilled	IPUMS CPS /NBER	Industry	1970–2014	Current Population Survey
Percentage precision products	IPUMS CPS /NBER	Industry	1970–2014	Current Population Survey
Percentage executive/ professional	IPUMS CPS /NBER	Industry	1970–2014	Current Population Survey
Percentage to consumers	BEA	Industry	1958–2012	Input-Output Table, Use Table (1958, 1963, 1967, 1972, 1977, 1982, 1987, 1992, 1997, 2002, 2007, 2012)

Sources: BEA (Bureau of Economic Analysis): Benchmark Input-Output Accounts, https://www.bea.gov/industry/index.htm#benchmark_io

IPUMS CPS: Current Population Survey Data for Social, Economic and Health Research, https://cps.ipums.org/cps/ (provided data from 1970-1978)

NBER (National Bureau of Economic Research): Current Population Survey (CPS) Data at the NBER, http://www.nber.org/data/cps_index.html (provided data from 1979-2014); NBER-CES Manufacturing Industry Database, http://www.nber.org/data/nberces.html
Schott: Schott's International Economics Resource Page, http://faculty.som.yale.edu/peterschott/sub_international.htm

Table A3. List of NAICS 4-Digit Industries Grouped by Natural Gas Cost Share

Low-NG-intensity industries (0–0.5 percent)	
3111	Animal Food
3116	Animal Slaughtering and Processing
3117	Seafood Product Preparation and Packaging
3122	Tobacco
3131	Fiber, Yarn, and Thread Mills
3141	Textile Furnishings Mills
3151	Apparel Knitting Mills
3152	Cut and Sew Apparel
3159	Apparel Accessories and Other Apparel
3162	Footwear
3169	Other Leather and Allied Product
3211	Sawmills and Wood Preservation
3231	Printing and Related Support Activities
3254	Pharmaceutical and Medicine
3325	Hardware
3331	Agriculture, Construction, Mining Machinery
3332	Industrial Machinery
3333	Commercial and Service Industry Machinery
3334	Ventilation, Heating, Air-Conditioning, etc.
3336	Engine, Turbine, Power Transmission Equip
3339	Other General Purpose Machinery
3342	Communications Equipment
3343	Audio and Video Equipment
3344	Semiconductor, Other Electronic Component
3345	Navigational, Measuring, Electromedical,
3352	Household Appliance
3353	Electrical Equipment
3361	Motor Vehicle
3362	Motor Vehicle Body and Trailer
3363	Motor Vehicle Parts
3364	Aerospace Product and Parts
3365	Railroad Rolling Stock
3366	Ship and Boat Building
3369	Other Transportation Equipment
3371	Household, Institutional Furniture, Cabinets
3372	Office Furniture (including Fixtures)
3379	Other Furniture Related Product
3391	Medical Equipment and Supplies
3399	Other Miscellaneous

Medium-NG-intensity industries (0.5–1 percent)	
3115	Dairy Product
3118	Bakeries and Tortilla
3119	Other Food
3121	Beverage
3132	Fabric Mills
3149	Other Textile Product Mills
3161	Leather and Hide Tanning and Finishing
3212	Veneer, Plywood, Engineered Wood Product
3222	Converted Paper Product
3255	Paint, Coating, and Adhesive
3256	Soap, Cleaning Compound, Toilet Preparation
3261	Plastics Product
3262	Rubber Product
3322	Cutlery and Handtool
3323	Architectural and Structural Metals
3324	Boiler, Tank, and Shipping Container
3329	Other Fabricated Metal Product
3335	Metalworking Machinery
3351	Electric Lighting Equipment
3359	Other Electrical Equipment and Component

High-NG-intensity industries (over 1 percent)	
3112	Grain and Oilseed Milling
3113	Sugar and Confectionery Product
3114	Fruit and Vegetable Preserving, Specialty Food
3133	Textile and Fabric Finishing, Fabric Coating Mills
3219	Other Wood Product
3221	Pulp, Paper, and Paperboard Mills
3241	Petroleum and Coal Products
3251	Basic Chemical
3252	Resin, Synthetic Rubber, Artificial Fibers
3253	Pesticide, Fertilizer, Other Agricultural Chemical
3259	Other Chemical Product and Preparation
3271	Clay Product and Refractory
3272	Glass and Glass Product
3273	Cement and Concrete Product
3274	Lime and Gypsum Product
3279	Other Nonmetallic Mineral Product
3311	Iron and Steel Mills and Ferroalloy
3312	Steel Product from Purchased Steel

	High-NG-intensity industries (cont.)
3313	Alumina and Aluminum
3314	Nonferrous Metal (except Aluminum)
3315	Foundries
3321	Forging and Stamping
3326	Spring and Wire Product
3327	Machine Shops; Screw, Nut, and Bolt
3328	Coating, Engraving, Heat Treating, etc.
3346	Reproducing Magnetic and Optical Media

Table A4. Summary Statistics

	Mean	Std. dev.
Change in employment	0.033	1.2881
Total employment	133.135	913.615
Change in total value of shipments	0.2004	2.9537
Total value of shipments	29900	351000
Change in county-level electricity price	0.2166	0.5657
Change in electricity price * electricity cost share	0.0037	0.0155
County-level electricity price	10.15	1387.9884
Electricity cost share	0.0173	0.0158
Change in county-level natural gas price	0.2842	0.6117
Change in natural gas price * natural gas cost share	0.0032	0.014
Change in natural gas price spline	0.0012	0.0026
Change in natural gas price spline	0.0006	0.0019
Change in natural gas price spline	0.0014	0.0117
County-level natural gas price	5.0979	3.4509
Natural gas cost share	0.0111	0.018
Change in county OZ attainment status	0.0179	0.3131
Change in county SO_2 attainment status	0.0005	0.1137
Change in county CO attainment status	0	0.1779
Change in county PM attainment status	0.0024	0.2453
Change in county OZ attainment status * emitter	0.0048	0.1637
Change in county SO_2 attainment status * emitter	0.0001	0.0422
Change in county CO attainment status * emitter	0	0.0407
Change in county PM attainment status * emitter	0.0003	0.0941
Change in wage * wages/value added	1974.7051	1413.2114
Change in wage * exports/total shipments	731.8839	1140.7738
Change in wage * imports/total shipments	7713.7775	6.33E+04
Change in HS dropout % * % unskilled workers	–2.1217	1.2688
Change in unionization % * % production workers	–0.3133	0.3833
Change in pop. density * personal consumption/total shipments	5.9403	242.5541
Change In BA degree % * % exec. and professional workers	0.2505	0.2065
Change in (Income share – Share) * personal consumption/total shipments	0	0.0001

Change in % farmland * agricultural input requirement	–0.3383	16.9552
Change in per capita cattle * livestock input requirement	–0.0012	0.0925
Change in state % timberland * lumber input requirement	0	0.0002
Change in wage	5305.6447	3747.5157
Change in HS dropout %	–4.4739	2.1564
Change in unionization %	1.6814	1.047
Change in pop. density	–1.718	1.974
Change In BA degree %	14.4106	308.9027
Change in (Income share – Share)	0	0.0002
Change in % farmland	–0.0098	0.0553
Change in per capita cattle	–0.0506	0.6285
Change in state % timberland	0.0002	0.0192
Heavy product * import rate	179.9558	1416.4716
Wages/value added	0.3798	0.108
Exports/total shipments	0.1316	0.133
Imports for consumption/total shipments	1.4677	9.2394
% unskilled workers	0.4625	0.1199
% executive and professional workers	0.1493	0.0694
% precision production workers	0.1876	0.0671
Heavy product * export rate	0.0072	0.007
Agricultural input requirement	0.0359	0.082
Livestock input requirement	0.0261	0.1003

TABLE A5. REGRESSIONS: EMPLOYMENT MODELS

	Model 1	Model 2	Model 3	Model 4
(elec price change)*	–0.4001**	–0.3970**	–0.4383***	–0.4522***
(elec cost share)	(0.1303)	(0.1297)	(0.1300)	(0.1293)
(NG price change) *		–0.4770***		–0.5403***
(NG cost share)		(0.1247)		(0.1224)
(NG price change) *	0.4635		–7.9525***	
(NG cost share)	(2.3774)		(2.3001)	
(NG price change) *	–0.5290		1.2702	
(NG cost share)	(1.4429)		(1.4323)	
(NG price change) *	–0.4971***		–0.4771**	
(NG cost share)	(0.1487)		(0.1465)	
(ozone nonattainment change) *	0.01172	0.01190		
(ozone emitting industry)	(0.009820)	(0.009805)		
(sulfur dioxide nonattainment change) *	0.03046	0.03044		
(sulfur dioxide emitting industry)	(0.03494)	(0.03494)		
(carbon monoxide nonattainment change) *	0.005116	0.005270		
(carbon monoxide emitting industry)	(0.03451)	(0.03450)		
(particulates nonattainment change) *	0.0002130	0.0002688		
(particulate emitting industry)	(0.01589)	(0.01588)		
(manufacturing wage change) *	–0.00001695***	–0.00001696***		
(industry wages/value added)	(0.000003778)	(0.000003778)		
(manufacturing wage change) *	0.000003997	0.000003974		
(industry exports/shipments)	(0.000002559)	(0.000002559)		
(manufacturing wage change) *	–2.619e-07***	–2.622e-07***		
(industry imports/shipments)	(3.505e-08)	(3.504e-08)		
(change in share of high school dropouts) *	0.04401***	0.04376***		
(industry share unskilled workers)	(0.005989)	(0.005966)		
(change in unionization rate) *	–0.01257	–0.01237		
(industry share skilled production workers)	(0.01172)	(0.01171)		
(change in share of college graduates) *	0.05723**	0.05723**		
(industry share executive and professional)	(0.02036)	(0.02036)		
(change in population density) *	–0.000004490	–0.000004450		
(share of consumer purchases in total)	(0.000006554)	(0.000006553)		
(change in relative income) *	2.9135	2.9588		
(share of consumer purchases in total)	(14.421)	(14.420)		
(change in share of farmland) *	0.0001119	0.0001119		
(industry use of farm products)	(0.00008553)	(0.00008553)		
(change in cattle per capita) *	–0.0007572	–0.0007463		
(industry use of livestock)	(0.01629)	(0.01629)		
(change in share of timberland) *	–20.629*	–20.633*		

(industry use of lumber)	(9.4442)	(9.4441)		
industry electricity cost share in 1985	30.989***	30.887***		
	(6.3912)	(6.3875)		
industry natural gas cost share in 1985	–106.75***	–106.21***		
	(13.104)	(13.041)		
industry heavy product * import rate	–0.000003233	–0.000003258		
	(0.000002163)	(0.000002162)		
industry wages/value added	–0.006501	–0.007245		
	(0.04897)	(0.04895)		
industry exports/shipments	–0.01678	–0.01565		
	(0.02551)	(0.02540)		
industry imports/shipments	–0.002711***	–0.002673***		
	(0.0005545)	(0.0005483)		
industry share unskilled workers	0.1874**	0.1860**		
	(0.07096)	(0.07091)		
industry share executive and professional	–0.5275***	–0.5255***		
	(0.09915)	(0.09903)		
industry share skilled production workers	–0.1444*	–0.1445*		
	(0.06914)	(0.06913)		
industry heavy product * export rate	8.7379***	8.6890***		
	(2.4398)	(2.4374)		
industry use of farm products	–0.05968*	–0.05923*		
	(0.02911)	(0.02909)		
industry use of livestock	–0.04624	–0.04641		
	(0.02750)	(0.02746)		
constant	0.2362***	0.2364***	–0.02230*	–0.03217**
	(0.06891)	(0.06891)	(0.01104)	(0.01060)
industry dummies	X	X	X	X
county-year dummies	X	X	X	X
R-squared-adj	0.0139	0.0139	0.0135	0.0135
no. obs. (rounded)	909,600	909,600	909,600	909,600