United States Department of Agriculture

Economic
Research
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Economic
Research
Report
Number 159

November 2013

# Emerging Energy Industries and Rural Growth

Jason P. Brown
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Timothy R. Wojan

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Recommended citation format for this publication:

Brown, Jason P., Jeremy G. Weber, and Timothy R. Wojan. *Emerging Energy Industries and Rural Growth,* ERR-159. U.S. Department of Agriculture, Economic Research Service, November 2013.

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## Abstract

Expansion of emerging energy industries—unconventional natural gas extraction, wind power development, and corn-based ethanol production—in rural areas of the United States during the last decade has led, on average, to net gains in local employment. Unconventional natural gas (so-called because it uses unconventional extraction methods—hydraulic fracturing and horizontal drilling—to reach gas trapped in relatively impermeable shale and sandstone) had the biggest employment effect, largely reflecting the scale of the activity. Despite its relatively large employment effect, the effect of natural gas development is smaller than what prior simulation models projected. Estimates of employment impacts for wind turbines and ethanol plants, in contrast, are consistent with some earlier projections. This report synthesizes and builds on findings from recent studies led by U.S. Department of Agriculture, Economic Research Service researchers investigating the local economic effects of these energy industries.

**Keywords:** natural gas, wind power, ethanol, economic growth

## Acknowledgments

The authors thank Todd Kuethe and Jayson Beckman of U.S. Department of Agriculture, Economic Research Service, as well as Harry Baumes, USDA, Office of the Chief Economist; Anthony Crooks, USDA, Rural Development; Tim Kelsey, Pennsylvania State University; and David Swenson, Iowa State University, for their reviews. The authors also thank ERS editor Priscilla Smith and ERS designer Cynthia A. Ray.

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*A report summary from the Economic Research Service* November 2013

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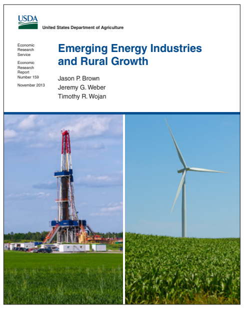

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## What Is the Issue?

The production of natural gas (primarily from unconventional sources), wind power, and corn-based ethanol in each case more than doubled from 2000 to 2010, with most of the growth occurring in rural areas with abundant land for drilling pads, wind turbines, and corn fields. (Unconventional natural gas is differentiated from regular natural gas by its unconventional extraction methods—hydraulic fracturing and horizontal drilling—that are used to reach gas trapped in relatively impermeable shale and sandstone). Previous studies have projected the new industries' contributions to local and regional economies. After industry expansion, it is useful to compare the projections with what actually happened.

## What Did the Study Find?

For two industries, the overall employment impacts were statistically significant. For counties in Colorado, Texas, and Wyoming that experienced a large increase in natural gas production, we find that natural gas development was associated with a 12-percent increase in total employment over 8 years. For a 12-State region stretching from Texas to North Dakota, counties with expansion in wind power experienced a 0.6-percent increase in average total employment over a similar period. For ethanol production, statistically significant employment growth can be confirmed only among closely linked industries such as trucking and natural gas distribution. The entrance of an ethanol plant in Midwestern counties led on average to a 0.9-percent increase in employment within industries that previous studies suggest are closely linked to ethanol production.

The contribution of each of these three energy industries to local employment growth varied. For both natural gas and wind counties, the average increase in county employment from all sources was about 3,000 jobs. The 1,780 new jobs associated with natural gas development therefore represented about half of the average increase in local employment. For wind, the 60 new jobs associated with wind power development represented roughly 2 percent of the average increase in county employment from all sources. For counties with an ethanol plant, the average increase in local employment from all sources was smaller, at 254 jobs. The effect of 1 ethanol plant on local employment in closely linked industries, at 82 jobs, therefore represented a large share of employment growth in the typical ethanol plant county.

The effect of natural gas development, despite its relatively large employment effect, is smaller than what prior studies projected. Estimates for wind turbines and ethanol plants, in contrast, are consistent with some earlier projections.

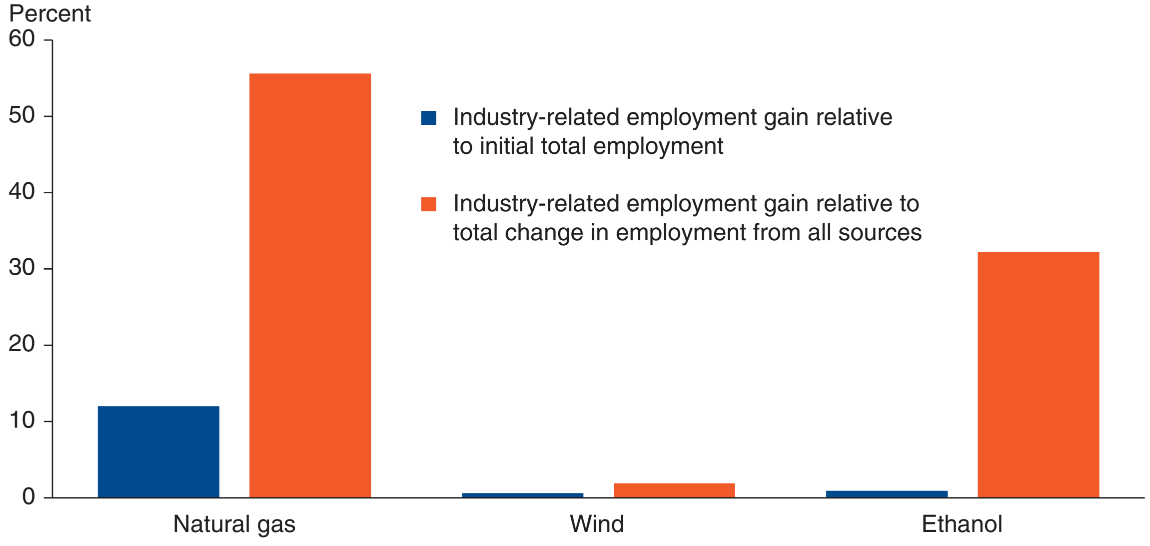
Overall, our findings suggest that expansion of unconventional gas drilling (and with similar technology, oil drilling) will contribute the most to short-term economic growth across rural areas, while the wind and ethanol industries will have more modest effects. Looking ahead, the growth potential of the three industries and their contribution to local economies may be quite different than what these short-term economic effects suggest. Gas reserves in specific locations will eventually decline, ethanol plants will have to compete with other end users for feedstocks, and variable winds pose increasing challenges for the electrical grid as their role as a power source increases. In addition, the environmental impacts associated with further development of each of these energy industries could lead to countervailing contractions in other local industries in the long run.

Our analysis provides a limited view of how the industries affect life in rural communities. The costs and benefits related to the industry can be unevenly distributed among local residents. Furthermore, the net economic benefits to an area may be quite different than gross private monetary gains measured by employment or personal income. A review of the literature suggests that the environmental impacts from wind power development are fewer compared with extracting natural gas and producing corn-based ethanol. However, each industry brings its own challenges for local communities: groundwater and road traffic concerns with natural gas; disruption of the landscape by wind turbines; and use of wastewater or water from ethanol plants.

## How Was the Study Conducted?

This report synthesizes and builds on recent studies by ERS economists that used empirical approaches to estimate causal effects based on a model of what would have happened in a county if expansion of the energy industry in question had never occurred. The industry-specific studies discussed in this report employed a combination of matching and regression analysis, including difference-in-difference and instrumental variable estimation. Despite differences in statistical details, the three studies share the same empirical thrust. They compare the growth in counties where the energy industry expanded with the growth in counties with less or no expansion, while controlling for other potential differences between counties. The studies draw primarily on data from the U.S. Department of Commerce's Bureau of Economic Analysis Local Area Personal Income and Employment estimates, the Bureau of Labor Statistics Quarterly Census of Employment and Wages, State agencies that monitor oil and gas development, Lawrence Berkeley National Laboratory, and National Renewable Energy Laboratory.

**Employment gains from the emergence of energy industries in selected regions**



Source: USDA, Economic Research Service.

# Emerging Energy Industries and Rural Growth

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## Introduction

Expansion of three emerging energy industries—unconventional natural gas extraction, wind power development, and corn-based ethanol production—in rural areas of the United States during the last decade has led, on average, to net gains in local employment. Unconventional natural gas (so-called because it uses unconventional extraction methods—hydraulic fracturing and horizontal drilling—to reach gas trapped in relatively impermeable shale and sandstone) had the biggest employment effect, largely reflecting the scale of the activity.

From 2000 to 2010, domestic production of unconventional natural gas grew by 116 percent, causing U.S. natural gas production to reach historic highs (U.S. DOE/EIA, 2012b). Over the same period, installed wind power capacity increased from 2.5 to 40 gigawatts (GW), and total ethanol production, most of which is derived from corn, saw a sevenfold increase (U.S. DOE/EIA, 2012b). Much of the growth occurred in rural areas with abundant land for wind turbines, corn fields, and drilling pads.

In addition to reducing energy imports and offering potential environmental benefits like reducing particulate emissions by replacing coal with natural gas in electricity generation, proponents of the three industries highlight the economic opportunities that they create. Studies using simulation models projected the economic contributions of these new industries to local and regional economies before much, if any, industry growth actually occurred. Most studies used an input-output model approach to simulating employment and income impacts. When used appropriately, input-output and other simulation models can provide realistic projections of the economic activity supported by expansion of an industry. Because of their timeliness, the projections are often the only source of quantitative information on economic impact and can influence policy debates.

After expansion has occurred, however, causal empirical studies can estimate the actual economic impact to local economies. ("Causal" implies that the estimated effect is the consequence of industry expansion and not a reflection of other changes in the economy). Studies of this kind have been rare due to the small sample size characteristics of emerging industries, limited data availability, and the sophisticated statistical techniques often required for definitive findings.

In this report, we synthesize recently published studies led by ERS economists that assess how natural gas production, wind power development, and new corn-based ethanol plants affected economic growth at the county level using statistical approaches (for more details on those approaches, see appendix section "Empirical Approaches To Estimating Causal Effects"). We use the findings to assess the importance of each energy industry to growth in select counties in the first decade of the 2000s.

# Three Emerging Energy Industries and Their Contributions to Rural Growth

This chapter describes the geography of energy industry growth and summarizes its economic contributions to specific regions. Unconventional natural gas extraction, wind power development, and corn-based ethanol production are most likely to occur in rural areas because of resource availability. The growth in gas production largely follows the location of unconventional gas formations, covering large rural areas in Colorado, Wyoming, Arkansas, Louisiana, Oklahoma, and Texas, as well parts of the Appalachian region such as areas in New York, Pennsylvania, Ohio, and West Virginia. The Great Plains of the central United States have the greatest onshore wind potential, and the Midwest and Great Plains grow most of the country's corn. Consequently, most installation of wind turbines and construction of ethanol refineries to date have occurred in the Midwest and the Great Plains. Within areas that have the resource potential for energy development, many other factors can affect location decisions, including the cost of land and access to infrastructure like gas pipelines, railways, and electrical grids (fig. 1).

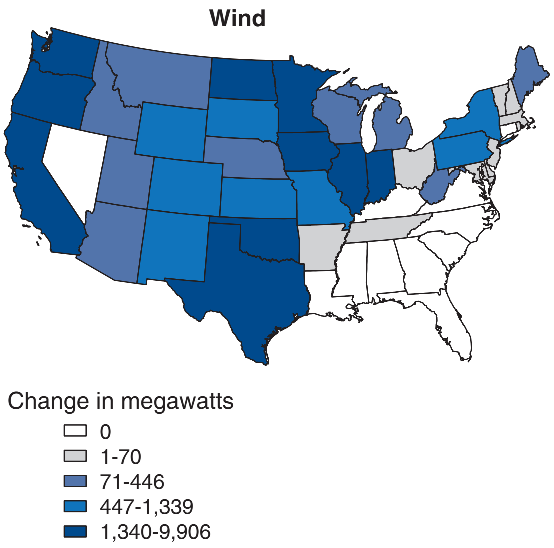
For the areas and periods considered, growth in natural gas production from the exploitation of unconventional sources made substantial contributions to employment growth, while the contributions from wind energy and ethanol plants were smaller (table 1). The empirical analysis of natural gas focused on counties in Colorado, Texas, and Wyoming and found that for counties that experienced considerable growth in production, the increase in employment from natural gas development caused a 12-percent increase in employment from 1999 to 2007. The wind empirical analysis focused on a 12-State region in the middle of the United States. In counties with some wind turbine installation, development caused a less-than-1-percent increase in employment from 2000 to 2008. For the same period, an estimate that draws on empirical methods suggests that the typical employment effect for a county with an ethanol plant was similar to that found for wind power development (with employment growth of 0.9 percent in closely linked industries).

For natural gas counties, the average change in employment from all sources from 1999 to 2007 was about 3,000 jobs. From 2000 to 2008, wind counties experienced a similar change in employment from all sources. The 1,780 new jobs associated with natural gas development therefore represented about half of the total change in local employment; for wind, the roughly 60 new jobs associated with wind power development represented roughly 2 percent of the total change in local employment. In contrast to wind and natural gas counties, the average total change in employment from 2000 to 2008 for counties with an ethanol plant was only 254 jobs. The employment effect of the typical ethanol plant within closely linked industries, at 82 jobs, therefore, represented a large share of employment growth (32 percent) in the typical ethanol plant county (fig. 2).

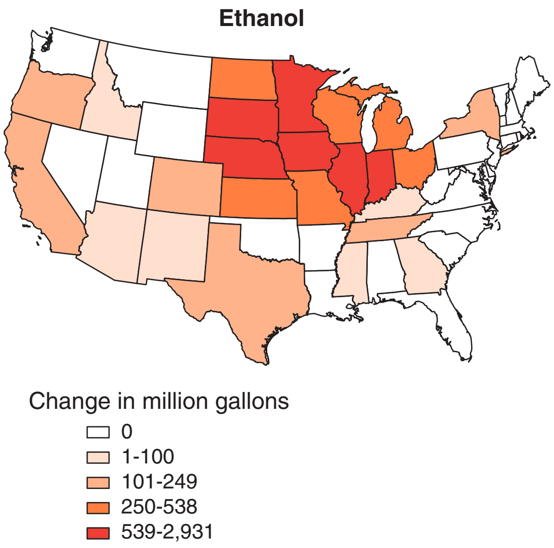
The net effect of each emerging energy industry on total employment at the county level in part reflects differences in the intensity of labor use, the strength of the linkages to the other sectors in the local economy, and the scale of activities. Over the study period, the average gas-boom county saw the annual value of gas production increase by $757 million, part of which reflected an increase in well-head natural gas prices from roughly $2 to $6 per 1,000 cubic feet. At $2.32 a gallon—the price in the 2006/2007 marketing year—a 60-million-gallon ethanol plant would, if used at full capacity, produce $139 million in ethanol. Similarly, the average county developing wind power had 123 megawatts of installed capacity by the end of 2008, which translates into $30 million in electricity a year (assuming production at 30 percent of capacity, a 2008 price of $97 per megawatt hour, and deflating to 2007 dollars) (U.S. DOE/EIA, 2012b). The ranking of the three industries by their total local employment effect, therefore, follows their ranking by growth in the value of production.

Figure 1

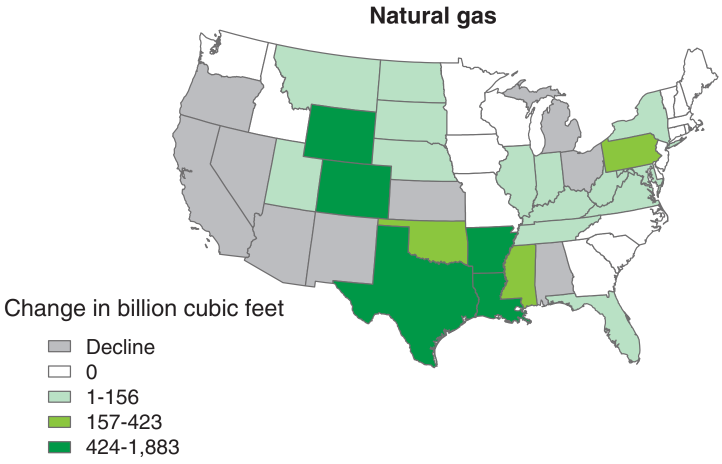
**Expansion in wind power, corn-based ethanol capacity, and natural gas production, 2000-10**



Source: U.S. Department of Energy, National Renewable Energy Laboratory.



Source: Renewable Fuels Association.



Source: U.S. Department of Energy, Energy Information Administration.

Table 1

**Average employment effects for study counties experiencing energy industry expansion**

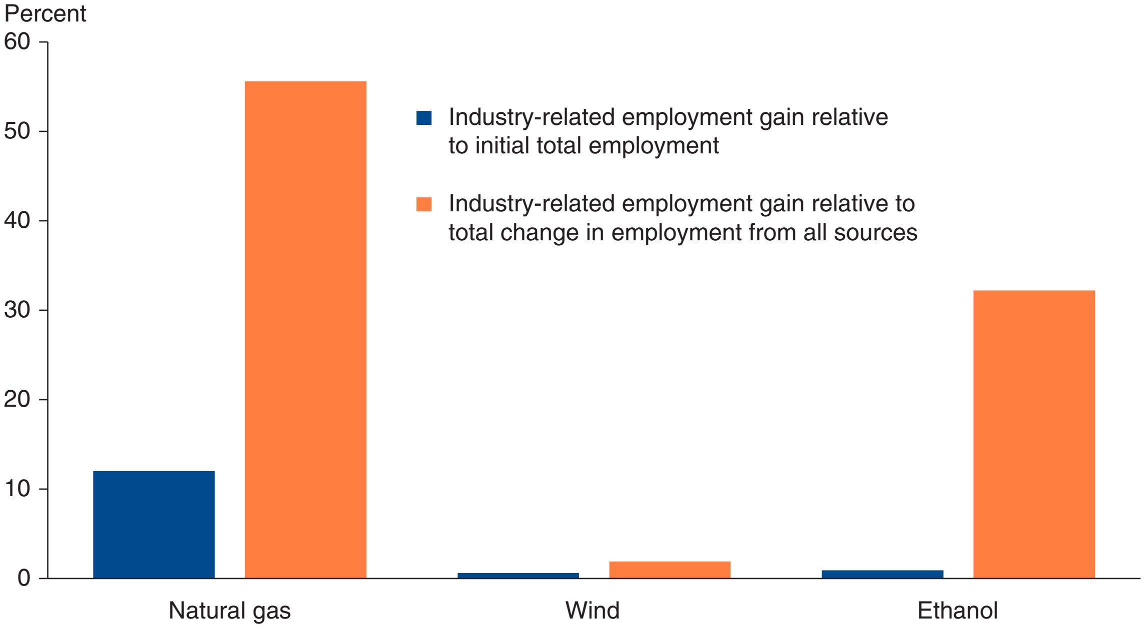
| Industry | Industry growth in the average county ($ million) | Average total jobs created | Percent of base year employment | Mean change in total employment from any source |
|---|---|---|---|---|
| Natural gas | 757 | 1,780 | 12 | 3,199 |
| Wind | 30 | 59 | 0.6 | 3,047 |
| Ethanol | 139 | 82 | 0.9 | 254 |

Notes: The estimated employment effect and the average total jobs created correspond to the same period used when measuring the change in production in the average energy county. For natural gas, the change is from 1999 to 2007. The average total jobs created in energy counties refers to the average jobs created in the 61counties that experienced substantial increases in gas production. For wind, the change is from 2000 to 2008. Wind energy counties are the 128 counties with installed wind power capacity. For ethanol, the change is from 2000 to 2008. The employment multiplier was estimated from a set of closely linked industries accounting for 75 percent of the indirect jobs created by an ethanol facility, as found by Low and Isserman (2007). Ethanol energy counties are 46 counties that received a single ethanol plant during the study period. Natural gas production was valued at State-level wellhead prices in the beginning and end year of the study period. The 123 megawatts of installed capacity for the average wind county translates into $30 million in electricity a year, assuming production at 30 percent of the available capacity, a price of $97 per megawatt hour in 2008, and deflating to 2007 dollars. The change in ethanol production is for a plant producing 60 million gallons of ethanol a year at $2.32 per gallon.

Source: Weber (2012); Brown et al. (2012).

Figure 2

**Employment gains from the emergence of energy industries in selected regions**



Source: USDA, Economic Research Service.

# Technological Innovations Spurred Growth in Unconventional Natural Gas Extraction

From 2000 to 2010, production of conventional gas declined by more than 4 trillion cubic feet. Production of unconventional gas, by contrast, increased by almost 7 trillion cubic feet (U.S. DOE/EIA, 2012b). The growth reflects improvements in technology that made it easier to extract unconventional gas together with higher well-head gas prices. Natural gas prices averaged $5.87 per 1,000 cubic feet over the early 2000s in real terms, well above the average price for the 1990s of just $2.78 (U.S. DOE/EIA, 2012d). Even after a large drop in 2009, real prices have generally exceeded those of the 1990s.

The two primary innovations in drilling technology are hydraulic fracturing and horizontal drilling. Hydraulic fracturing involves injecting a mix of chemicals and water deep into the ground to open fissures in rocks and has been used in some form for decades. Innovation in drilling horizontally has occurred more recently, partly because of the Federal Government's investment in research on extracting gas from hard rock formations, which lowered the cost of drilling horizontal wells (King, 2010; U.S. DOE/NETL, 2011). Though generally more expensive than vertical wells, horizontal wells can draw gas from larger areas, thereby reducing the pipelines and wells needed to extract and transport gas from an area.

Reservoirs of unconventional gas are distributed throughout much of the United States, but most large-scale development first occurred in three of the leading producing States of onshore natural gas: Colorado, Texas, and Wyoming. From 1995 to 2000, production changed little in Wyoming and Texas and increased in Colorado. In subsequent years, production in all three States grew rapidly, with gross withdrawals of natural gas increasing by more than 80 percent in Colorado and Wyoming from 2000 to 2008. Though smaller in percent terms, the largest absolute increase in production occurred in Texas (Weber, 2012).

More recently, several other States have experienced dramatic increases in production. Arkansas experienced a tripling of production from 2007 to 2010 from development of the Fayetteville Shale. Despite lower prices after 2008, production in Pennsylvania (Marcellus Shale) and Louisiana (Haynesville Shale) both spiked from 2009 to 2010, with production in Pennsylvania more than doubling. Other States showing trends towards greater production include Oklahoma and Utah (U.S. DOE/EIA, 2012c). Table 2 shows the top 10 producing States for onshore natural gas production as of 2010.

## Boom Counties Experience Increased Employment, Income

Total natural gas production increased in the early 2000s in Colorado, Texas, and Wyoming, but the location of reservoirs meant that some counties participated in the production boom while others did not. The counties that did not participate in the boom provided a business-as-usual scenario: what would have happened in boom counties had development not occurred.

Ranking all counties in the three States by their change in gas production from 1998/1999 to 2007/2008 reveals that only about 20 percent of counties saw a substantial increase in production, with most counties experiencing little or no change. Figure 3 shows that the 20 percent of counties with a substantial increase, referred to as boom counties, saw steady growth in production, with production increasing by 125 percent. Other counties, referred to as nonboom counties, had almost no change.

Table 2

**Top 10 States for onshore production of natural gas**

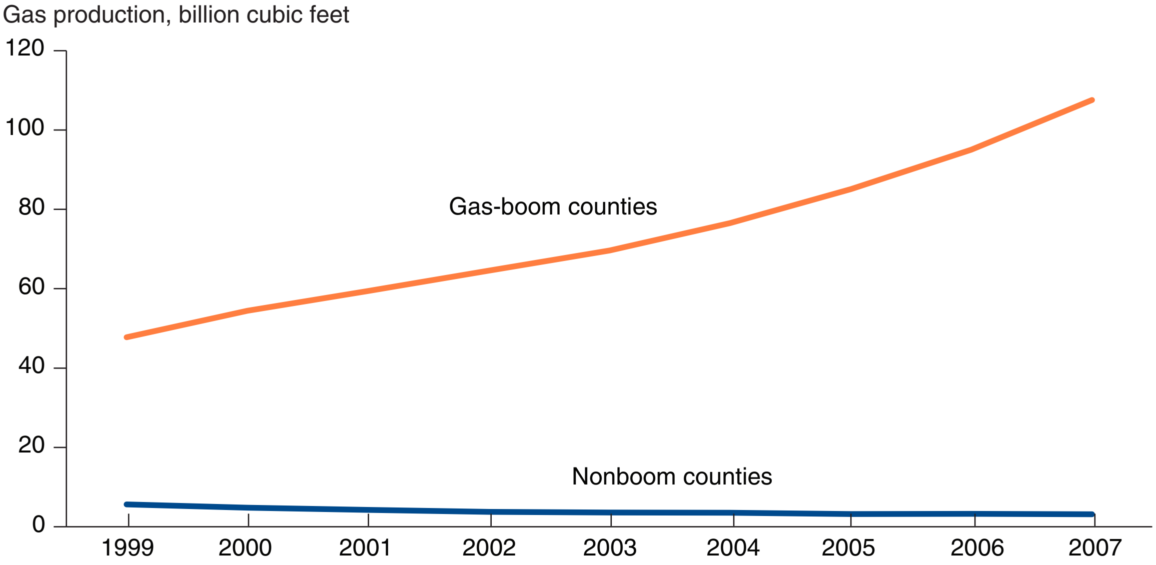
| State | Bcf 2000 | Bcf 2010 | Change (2010-2000) |
|---|---|---|---|
| Texas* | 5,682 | 7,565 | 1,883 |
| Louisiana | 1,343 | 2,969 | 1,626 |
| Alaska | 3,265 | 2,827 | –438 |
| Wyoming* | 1,326 | 2,515 | 1,189 |
| Oklahoma | 1,613 | 1,827 | 214 |
| Colorado* | 760 | 1,590 | 829 |
| New Mexico | 1,714 | 1,341 | –372 |
| Arkansas | 172 | 927 | 756 |
| Pennsylvania | 150 | 573 | 423 |
| Utah | 281 | 437 | 156 |

*States used in the natural gas analysis.
Bcf = billions of cubic feet.

Source: U.S. Department of Energy, Energy Information Administration, http://www.eia.gov/dnav/ng/ng_prod_sum_dcu_NUS_m.htm

Figure 3

**Gas production more than doubled in gas-boom counties, 1999-2007**



Source: USDA, Economic Research Service tabulations of data from the Colorado Oil and Gas Conservation Commission, the Texas Railroad Commission, and the Wyoming Oil and Gas Conservation Commission.

In high-population counties, normal churning of the economy, like plant closures and openings, can overshadow the effect of gas activity on the economy. Furthermore, the boom happened primarily in counties without large cities. We therefore exclude the 10 percent of counties that were the most populous (more than 130,000 people) as well as counties adjacent to gas-boom counties that did not experience a boom in production themselves. Adjacent counties may not represent a business-as-usual scenario since their proximity to boom counties could have led to greater economic activity due to commuters or sourcing of inputs used in production not found in the boom counties.

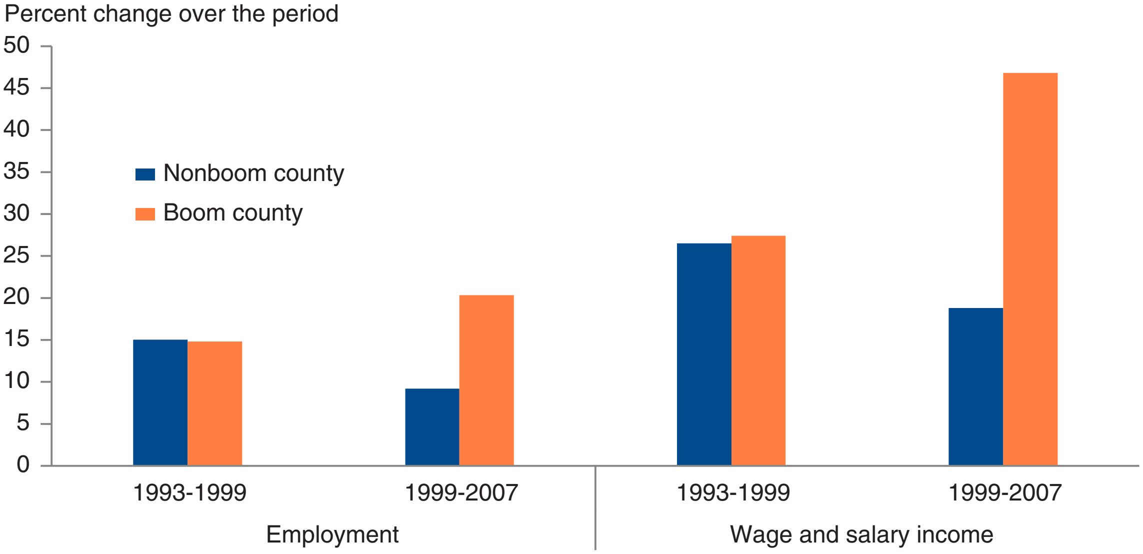
A straightforward comparison of the percent increase in employment from 1993 to 1999 and from 1999 to 2007 for boom and nonboom counties shows that employment gains accompanied natural gas development (fig. 4). From 1993 to 1999, both groups of counties experienced similar growth in employment and wage and salary income, but from 1999 to 2007, employment in boom counties grew faster by 1.4 percentage points annually, and wage and salary income grew 3.4 percentage points faster relative to growth in the prior period.[1] The larger increase in wage and salary income is likely because natural-gas-sector jobs pay higher-than-average wages (IHS Global Insight, 2011). A doubling of jobs in the natural gas sector would then imply a more-than-doubling of wages and salaries.

A similar comparison yields an employment estimate of 962 jobs and $59 million in wage and salary income, on average. Differences between gas-boom counties and nonboom counties unrelated to natural gas production, however, may have caused the two groups to have different changes in employment and income from 1999-2007 relative to the period 1993-1999 (table 3). Boom counties, for example, may have been less dependent on sectors that grew more slowly during the early 2000s. Consequently, we control for differences in the 1992 values of several variables, like the share of earnings accounted for by manufacturing and each county's per capita income and population density and those of adjacent counties.

Because unobserved factors could still affect the results, we use an instrumental variable approach that uses only the boom counties statistically linked to the percent of the county covering an unconventional gas reservoir (see appendix section "Empirical Approaches To Estimating Causal Effects"). When the instrumented and noninstrumented approaches give results that are statistically different from each other, the more robust instrumented estimate is preferred. When the results are statistically indistinguishable, the noninstrumented estimate is preferred because it gives more

Figure 4

**Boom counties experienced higher growth in employment and wage and salary income during the boom period but not in the prior period**



Source: USDA, Economic Research Service tabulations of data from the Colorado Oil and Gas Conservation Commission, the Texas Railroad Commission, and the Wyoming Oil and Gas Conservation Commission.

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[1] The 1.4-percentage-point greater employment growth is calculated as: ("percent change 1999-2007, boom counties" – "percent change 1993-1999, boom counties") – ("percent change 1999-2007, nonboom counties" – "percent change 1993-1999, nonboom counties"). The wage and salary growth is calculated in the same manner.

Table 3

**Changes in employment and wage and salary income for natural-gas boom and nonboom counties**

| | Employment (jobs) | Wage and salary income ($ million) |
|---|---|---|
| | Boom counties | |
| Change 1999-1993 | 2,342 | 68 |
| Change 2007-1999 | 3,199 | 132 |
| Difference (1) | 857 | 63 |
| | Nonboom counties | |
| Change 1999-1993 | 1,572 | 46 |
| Change 2007-1999 | 1,467 | 50 |
| Difference (2) | –106 | 4 |
| Triple difference: (1) minus (2) | 962 | 59 |
| | (314) | (17) |
| | Regression results | |
| Conditional triple difference, noninstrumented approach | 510 | 23 |
| | (364) | (15) |
| Conditional triple difference, instrumented approach | 1,780 | 69 |
| | (820) | (31) |
| Best estimate | 1,780 | 69 |
| Annualized increase relative to 1998 level | 1.5% | 2.6% |

Source: The first two sets of numbers are calculated using data from the U.S. Department of Commerce, U.S. Census Bureau and the U.S. Department of Labor, Bureau of Economic Analysis. Boom and nonboom county designations are based on growth in natural gas production from 1999 to 2007 and are the same counties used in Weber (2012). The regression results are from Weber (2012).

precise estimates. The row labeled “Best estimate” in table 2 applies this decision rule to the two sets of estimates.

The best estimates suggest that natural gas extraction added 1,780 jobs and $69 million in wage and salary income to the average boom county economy. The estimates imply that natural gas development increased employment by 12.0 percent from 1999 to 2007 for the average boom county; for wage and salary income the increase is even larger, at 20.9 percent. Because a few counties have dramatically higher production than other counties, the employment and income effects for the mean boom county are greater than for the median county (table 4). (The median gas-boom county is the county at which half of the boom counties had a larger increase in production and half had a smaller increase). Details of the analysis are available in the appendix and in Weber (2012).

## Rapid and Unequal Growth, Environmental and Public Infrastructure Costs, and Boom-Bust Cycles

Development of unconventional natural gas has implications for the quality of life of rural residents that extend beyond local aggregate employment and income effects. Issues associated with rapid development of unconventional gas include: the social consequences of rapid and unequal growth; environmental costs; public infrastructure costs; and boom-bust cycles of extractive industries.

Table 4

**Empirical estimates of natural gas development, 1999-2007**

| | Employment (jobs) | | | |
|---|---|---|---|---|
| | Change in gas production ($ million) | Estimated effect per $1 million in production | Total effect (jobs) | Percent of 1998 mean value of employment |
| | | | | *Percent* |
| 25th percentile | 124 | 2.35 jobs | 292 | 2.0 |
| 50th percentile | 382 | | 898 | 6.1 |
| 75th percentile | 946 | | 2,224 | 15.0 |
| Mean | 757 | | 1,780 | 12.0 |
| | Wage and salary income | | | |
| | | | Total effect ($ million) | |
| 25th percentile | 124 | 0.09 dollars in wage and salary income | 11 | 3.4 |
| 50th percentile | 382 | | 35 | 10.6 |
| 75th percentile | 946 | | 86 | 26.1 |
| Mean | 757 | | 69 | 20.9 |

Source: The estimated effects are from Weber (2012). The change in gas production uses county-level production data from State agencies and wellhead natural gas prices from the U.S. Department of Energy, Energy Information Administration. Employment in 1998 is from the U.S. Department of Labor, Bureau of Economic Analysis.

### *Social Consequences*

Rapid increases in gas drilling can change life quickly in rural communities. The influx of gas company workers and contractors increased the demand for housing in Pennsylvania, leading to higher rental rates, especially in low population counties (Williamson and Kolb, 2011). In Sublette County, WY, the expansion of drilling came with a 12-percent increase in population, and police arrests more than doubled (Jacquet, 2005). Aside from potential tension between long-term residents and gas industry newcomers, the distribution of costs and benefits also can undermine social cohesion. A landowner without mineral rights may receive almost nothing from drilling pads on his property while neighbors receive large royalty payments. Likewise, rising food and housing costs may strain the budget of low-income residents without the skills to compete for higher paying jobs in the new local industry.

### *Environmental Consequences*

The environmental consequences of unconventional natural gas drilling have drawn attention mostly to hydraulic fracturing, the method commonly used to extract unconventional gas. Among other potential risks, the U.S. Environmental Protection Agency is investigating the potential for fluids (including gas) to migrate through the subsurface (U.S. EPA, 2012). Methane venting or flaring, volatile organic compounds from wastewater, and diesel exhaust from heavy truck traffic can lower air quality (Kargbo, Wilhelm, and Campbell, 2010). Pumping stations, drilling pads, and pipelines can give the landscape an industrial look. (For an overview of potential environmental consequences, see Resources for the Future, *Risk Matrix for Shale Gas Development*, 2012). Likely related to environmental or aesthetic issues, Boxall et al. (2005) found that in Alberta, Canada, properties located closer to natural gas facilities had lower values than properties located further away. Similarly, Muehlenbachs et al. (2012) found that the value of properties dependent on wellwater in one county in Pennsylvania declined with the properties' proximity to unconventional gas wells.

### *Public infrastructure costs*

One unconventional gas well can require thousands of truckloads of materials, which cause roads to deteriorate faster, and up to 10 million gallons of water, much of which will return to the surface and require proper management in impoundments or wastewater treatment plants (U.S. Dept of Interior, National Park Service, 2009; Kargbo, Wilhelm, and Campbell, 2010). In the absence of State and local revenue policies tailored to the costs and revenues of the industry, a deterioration of public finances and infrastructure may mean that private monetary gains overstate the net economic gain to a community. If absentee landownership is common, much of the monetary gain may accrue to residents outside the community who are insulated from how industry development is affecting the quality of life in producing areas.

### *Boom-bust cycles*

When natural gas drilling causes an economic boom in an area, the severity of the economic bust that may follow is unknown. Volatility in natural resource prices and its destabilizing effect on the broader economy is cited as a reason why local or national economies more dependent on natural resources often grow more slowly in the long run (van der Ploeg, 2011). Because of export restrictions and infrastructure constraints, most domestic production of natural gas is sold on the domestic market. Consequently, greater production of natural gas through unconventional means has caused a decline in domestic prices, slowing development in some areas. Permits issued in the Barnett Shale in Texas, for example, declined by more than 50 percent from 2008 to 2009.

Even though exporting natural gas may help to limit how much prices decline on the domestic market, global energy markets have shown much volatility in the last 40 years. Integration with broader energy markets may therefore do little to stabilize domestic prices. Another dynamic consideration is that development of a natural gas formation may occur in defined stages, with large year-over-year increases in production for several years followed by a plateau and then a long, steady decline. The production curve for specific formations cannot be known until the drilling process has begun, creating another source of uncertainty for State and local public revenues in addition to the volatility in natural gas prices.

Declines in natural gas prices reduce drilling activity in producing areas and decrease royalty payments and tax revenues from the industry as well as lower the cost of energy consumption by households and businesses throughout the economy. The decline in prices from roughly $8 per 1,000 cubic feet in 2008 to around $4 per 1,000 cubic feet in the ensuing 3 years meant lower heating bills for households and higher profits for industries using natural gas.

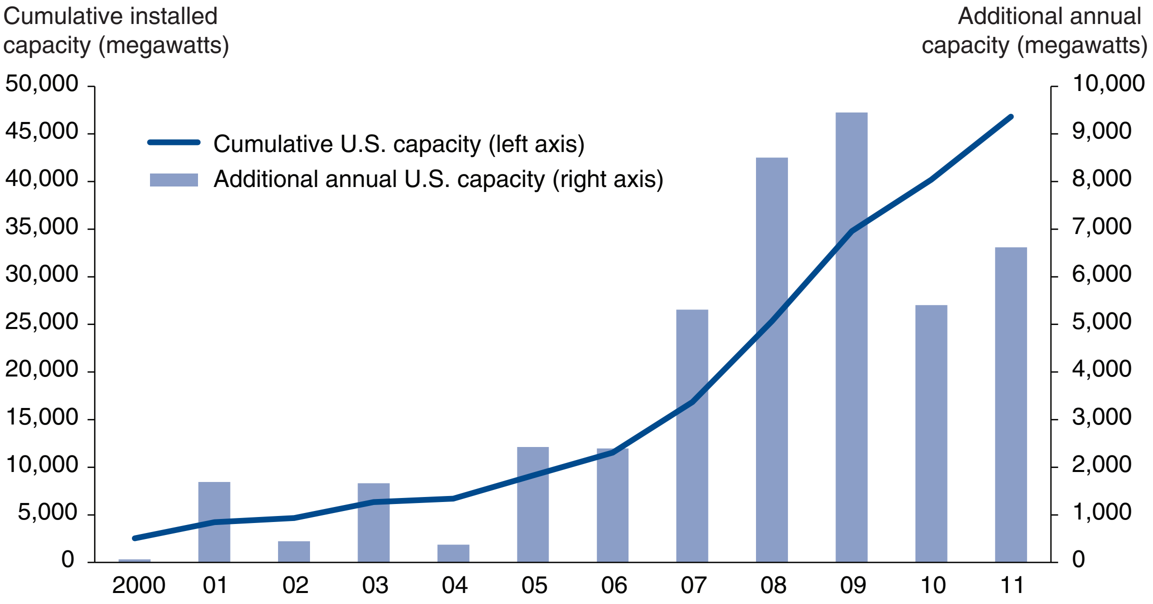
# Higher Electricity Prices, Supportive Policies Encouraged Wind Power Expansion

Wind power capacity has expanded dramatically in the United States. From 2000 to 2011, the cumulative installed capacity increased from 2,500 to 46,800 megawatts (fig. 5). Wind contributed 36 percent of all new electric generation capacity added to the U.S. power system from 2007 to 2010 (Wiser and Bolinger, 2011), and it is technically feasible for a fifth of the U.S. electric supply to come from wind power by 2030 (U.S. DOE, 2008). Despite recent growth in the wind power industry, wind accounts for less than 3 percent of the electricity generated in the United States (fig. 6).

Higher electricity prices and supportive Federal and State Government policies have encouraged growth in wind development in the past decade (Bolinger and Wiser, 2009; Wiser et al., 2011). The national average electricity price in 2010 was 9.83 cents per kilowatt-hour, representing a 16-percent increase since 2000 in real terms (U.S. DOE/EIA, 2011a; and U.S. DOE/EIA, 2011b). At the Federal level, production-based tax credits have reduced the cost of wind energy to purchasers (Lu et al., 2011), and the more recent ability to convert the credits to an upfront cash grant has helped the wind industry weather the 2008-10 financial crisis (Bolinger et al., 2010).[2] Established by the Energy Policy Act of 1992, the credit reduces taxable income for qualified wind developers by 2.2 cents per kilowatt-hour of electricity produced for the first 10 years of operation.[3] Wiser (2007) estimates that the credit offsets the cost of developing wind power by approximately one-third. States have also supported the industry through a combination of policies (Bird et al., 2005). Recently, State-specific renewable portfolio standards requiring electricity suppliers to use a certain amount of renewable energy in their supply mix have been a primary method of support for the emerging wind power industry (Wiser and Barbose, 2008).

Figure 5

**Wind power capacity in the continental United States, 2000-11**



Source: U.S. Department of Energy, Energy Information Agency.

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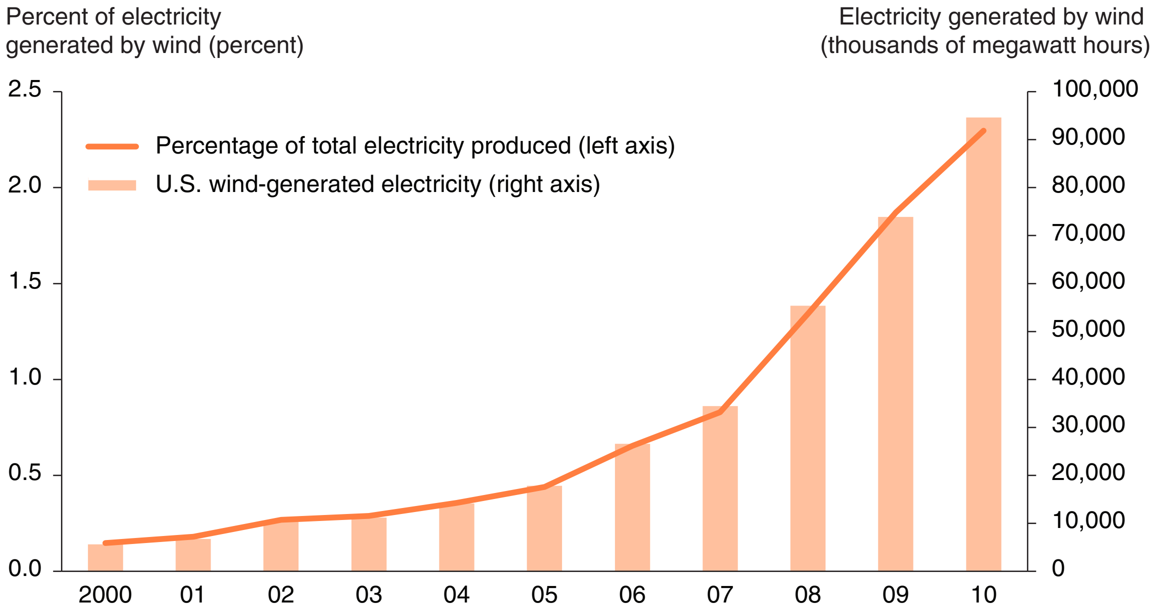
[2] Tax-exempt entities such as municipalities, publicly owned utilities, rural electrical cooperatives, nonprofit educational institutions, or other governmental entities are not eligible for the production tax credit or cash grant.

[3] The credit has been adjusted upward over time to account for inflation.

Figure 6

**Wind-generated electricity in the United States, 2000-10**



Source: U.S. Department of Energy, Energy Information Administration (2011a).

## Great Plains and Midwest Are Sites for Most Wind Power Development

Most installations of wind power have occurred in the Great Plains and parts of the Midwest where wind resources abound and there is ample land for wind turbines (U.S. DOE, 2012). Of the top 10 States in wind power capacity growth between 2000 and 2010, Texas led the way, followed by Iowa (table 5). By 2010, installed wind power capacity was capable of providing more than 5 percent of the electricity supply in 13 States, with 4 States—Iowa, Minnesota, North Dakota, and South Dakota—obtaining more than 10 percent of their electrical supply from wind power.

Figure 7 illustrates that wind resources vary substantially in the 12-State study region. And among areas with large wind resources, the profitability of developing wind varies across the region. Long distances to population centers and making capacity available on transmission lines increase the cost of transmission, thereby affecting which wind-rich areas experience development. State policies vary, which affects development incentives. By 2011, 29 States had renewable portfolio standards, including States with significant wind development such as Iowa, Minnesota, and Texas (U.S. EPA, 2011).

Wind power development also has varied over time. Figure 5 shows that less development occurred in the years when the production-based tax credit was set to expire (2000, 2002, and 2004). Consistent with the pattern in the figure, Barradale (2010) argues that the renewal and expiration of the credits has created boom and bust cycles of development. Although the data are not yet available, development in 2012 is expected to be greater than in 2010 or 2011 because of the expectation that the credits would expire at the end of the year. However, in January 2013, Congress passed legislation that extended the credits through 2013. The bill also changed the provision for projects to be eligible for the credit as long as construction began before the end of 2013 rather than needing to be completed.

Table 5

### Top 10 States with new installed wind power capacity

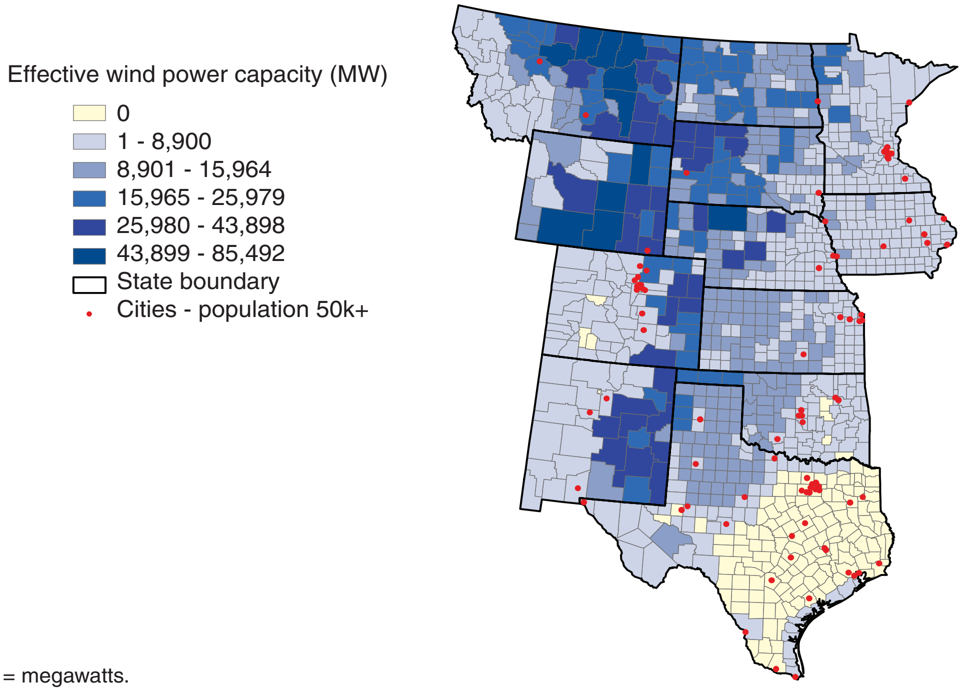
| State | MW in 2000 | MW in 2010 | Change (2010-2000) |
|---|---|---|---|
| Texas* | 184 | 10,089 | 9,906 |
| Iowa* | 242 | 3,675 | 3,433 |
| Washington | - | 2,104 | 2,104 |
| Oregon | 25 | 2,104 | 2,079 |
| Illinois | - | 2,045 | 2,045 |
| Minnesota* | 291 | 2,205 | 1,914 |
| California | 1,616 | 3,253 | 1,637 |
| Oklahoma* | - | 1,482 | 1,482 |
| North Dakota* | 0.4 | 1,424 | 1,423 |
| Indiana | - | 1,339 | 1,339 |

*States used in the wind power development analysis.
MW = megawatts.

Source: U.S. Department of Energy, http://www.windpoweringamerica.gov/wind_installed_capacity.asp

Figure 7

### Technical wind resource potential for wind capacity



MW = megawatts.
Source: U.S. Department of Energy, National Renewable Energy Laboratory.

## Estimates of Employment and Income Effects of Wind Power Development

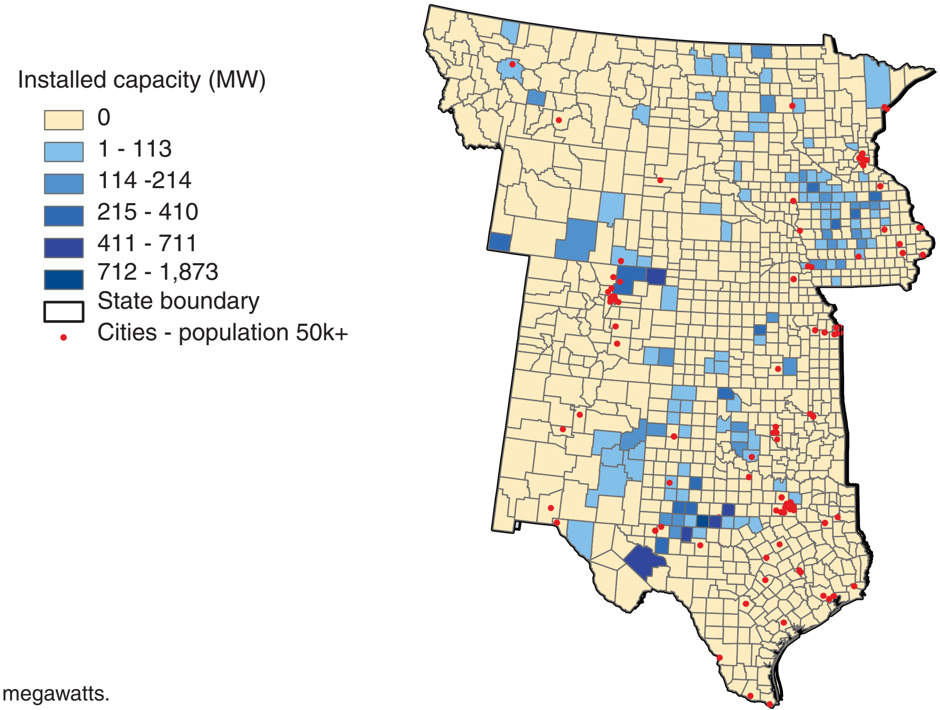
Similar to unconventional natural gas development, the large expansion in wind power development in the Great Plains and parts of the Midwest provided an opportunity to study the consequences of wind power development on local economies. Although total installed capacity increased in several States, the location of wind turbines within each State meant that some counties experienced development while others did not. Similar to the natural gas analysis, the wind empirical analysis uses variation in wind development across space and time to estimate the effect of installed capacity on employment and income. To isolate the effect of greater installed capacity from confounding factors, the wind analysis also takes an instrumental variable approach, using measures of a county's wind resource potential as instruments for changes in installed capacity (see appendix section, "Empirical Approaches To Estimating Causal Effects").

Brown et al. (2012) estimated the effects of wind power installation on personal income and total employment at the county level for a 12-State region. Figure 8 shows the main variable of interest, the total installed wind power capacity from 2000 to 2008. The counties in the study region with the highest installed wind power capacity from 2000 to 2008 are in north-central/west Texas, southern Minnesota, and northern Iowa. Controlling for a county's initial socioeconomic and demographic characteristics, each megawatt of installed capacity from 2000 to 2008 increased personal income by $11,150 and added 0.48 jobs over the same period (see table 6 for a summary of the findings and appendix A2 for more details).

To gauge the economic significance of the estimates, a total effect for each county can be calculated by multiplying the marginal effect ($11,150 for personal income or 0.48 for employment) by the installed wind power capacity of each county. Doing so for all counties in the 12-State region reveals that wind development added $1,371,450 in personal income and 59 jobs to the mean county from 2000-08.

Figure 8

**Total installed wind power capacity (megawatts) 2000-08**



MW = megawatts.
Source: U.S. Department of Energy, Lawrence Berkeley National Laboratory.

Table 6

**Empirical estimates of wind power development**

| | Change in wind power capacity (MW) | Estimated effect per MW of installed capacity | Total effect (jobs) | Percent of 2000 mean value of employment |
|---|---|---|---|---|
| | | **Employment (jobs)** | | |
| | | | | *Percent* |
| 25th percentile | 15 | 0.48 jobs | 7 | 0.1 |
| 50th percentile | 70 | | 34 | 0.3 |
| 75th percentile | 154 | | 74 | 0.7 |
| Mean | 123 | | 59 | 0.6 |
| | | **County personal income** | | |
| | | | Total effect ($) | |
| 25th percentile | 15 | $11,150 per MW of installed capacity | 167,250 | 0.02 |
| 50th percentile | 70 | | 780,500 | 0.08 |
| 75th percentile | 154 | | 1,717,100 | 0.18 |
| Mean | 123 | | 1,371,450 | 0.14 |

MW = megawatts.

Source: Brown et al. (2012) estimated the impacts from cumulative installations of wind power from 2000 to 2008 at the county level for a 12-State region of Iowa, Kansas, Minnesota, Nebraska, North Dakota, South Dakota, New Mexico, Oklahoma, Texas, Colorado, Montana, and Wyoming.

The increases represent 0.14 and 0.6 percent of initial mean income and employment for counties with wind development. Similar to the case of unconventional natural gas, much installed wind capacity is concentrated among relatively few counties. The mean employment and income effects are therefore higher than the effects for the median wind county (in terms of installed capacity).

## Beyond Employment and Income: Environmental Benefits and Local Nuisances

Prior research has suggested that wind could be used to achieve large reductions in carbon dioxide emissions and fossil fuel use (DeCarolis and Keith, 2006). Wind turbines produce no particulate emissions like coal-fired electric power, which increases the incidence of mercury or other heavy metals in streams and lakes.

Wind power also uses much less water than corn-based ethanol production or unconventional natural gas extraction. Still, wind turbines can impose costs on nearby residents.

Wind turbines can interrupt rural landscapes, harm birds, and create noise (National Wind Coordinating Collaborative, 2010). A review of epidemiological studies conducted near turbines in the United States and Europe by the Massachusetts Department of Environmental Protection (MDEP) reported that a typical modern utility-scale wind turbine creates about 103 decibels in noise (40 decibels is associated with annoyance), but can vary with the design and power of the turbine. In most cases the noise decreases rapidly with distance, dropping below the level associated with annoyance at 400 meters (MDEP, 2012). The turning of turbine blades can also cause a flickering of light when the blades come between the observer and the sun. During winter, ice can form on the blades and be thrown a good distance. The MDEP report concluded that light flickering does not pose a risk for causing seizures but that falling ice could be physically harmful and recommended measures be taken to mitigate the risk.

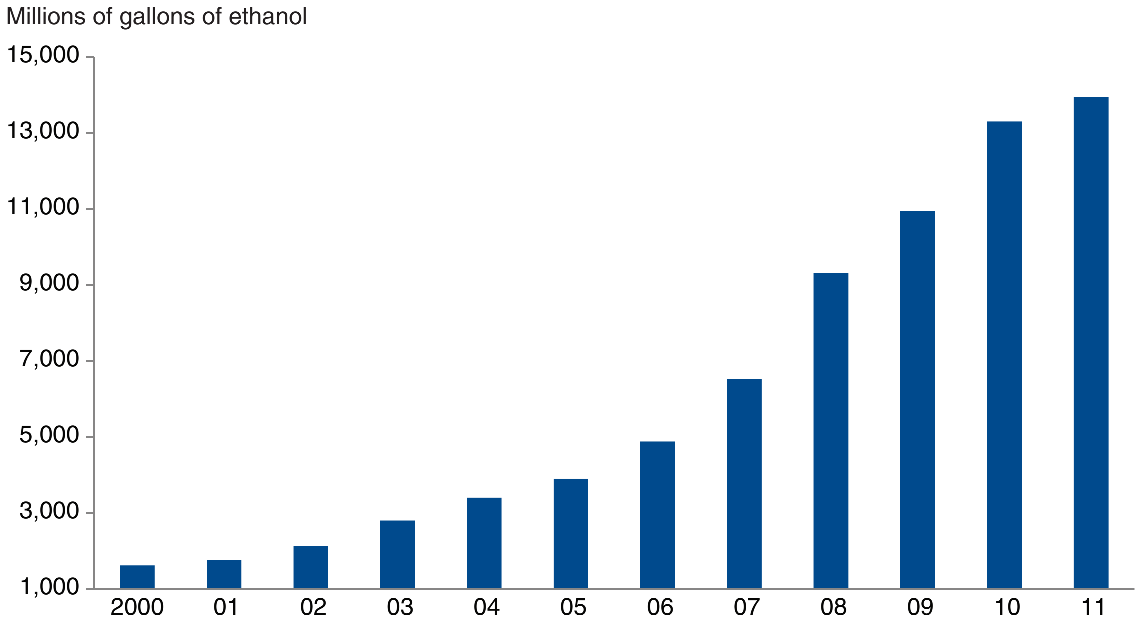
## Gains in Economies of Scale, High Energy Prices Propelled Ethanol Production

Since 2000, ethanol has become an important source of fuel in the United States, with production increasing from 1.6 billion gallons to 13.9 billion gallons in 2011 (fig. 9). Most of that production was derived from more than 5 billion bushels of corn (USDA, 2013). By the end of 2011, there were 209 ethanol biorefineries in 29 States (RFA, 2012). Growth of the ethanol industry stems from high energy prices, State and Federal policies, and gains in economies of scale as the ethanol market has expanded (Tyner, 2008; Low and Isserman, 2009).

Substituting ethanol for methyl tertiary butyl ether (MTBE) as a fuel additive in gasoline increased demand for ethanol. In 2005, the Energy Policy Act created the Renewable Fuel Standard (RFS) program. A 2007 expansion and 2010 revision to that act now mandate that 15 billion gallons of biofuels be used in gasoline annually by 2015, representing a 100-percent increase from the original quantity required by 2012 (US EPA, 2010). Other Federal policies that supported the industry include the Reformulated Gasoline Program,[4] the Winter Oxygenated Fuels Program, the Small Ethanol Producer Tax Credit of 10 cents per gallon for plants producing less than or equal to 60 million gallons of ethanol per year, the 45-cents-per-gallon ethanol blender's credit (RFA, 2010), and a 54-cents-per-gallon tariff applying to imported ethanol (Zhang, 2007). Blending requirements remain, but the blender's credit and the tariff expired in January 2012.

Figure 9

**U.S. ethanol fuel production, 2000-11**



Source: U.S. Department of Energy, Energy Information Administration (2011a).

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[4] Reformulated gasoline (RFG) conforms to pollution reduction requirements established by the EPA in the 1990 Clean Air Act. RFG may include some level of ethanol that is an "oxygenate" used to supply additional oxygen to increase octane levels, enhance combustion, and reduce emissions.

State policies also have supported the ethanol industry through: producer incentives (grants or preferential tax treatment); retailer/infrastructure incentives for ethanol blends; State use mandates; retail pump-label requirements; and State fleet fuel-use requirements.

Increases in plant scale have helped to increase innovation and lower production costs (Shapiro and Gallagher, 2005; Gallagher et al., 2007; Tyner, 2008). Figure 10 shows the number of ethyl alcohol manufacturing establishments by employment size between 2000 and 2010. The temporary bust that the sector experienced in 2008 occurred mostly in the smallest size class of 5 to 19 employees. In contrast, the number of plants in the largest category (100 to 249 employees) has remained fairly constant, with 7 establishments as of 2010, and the number of midsized plants has grown steadily.

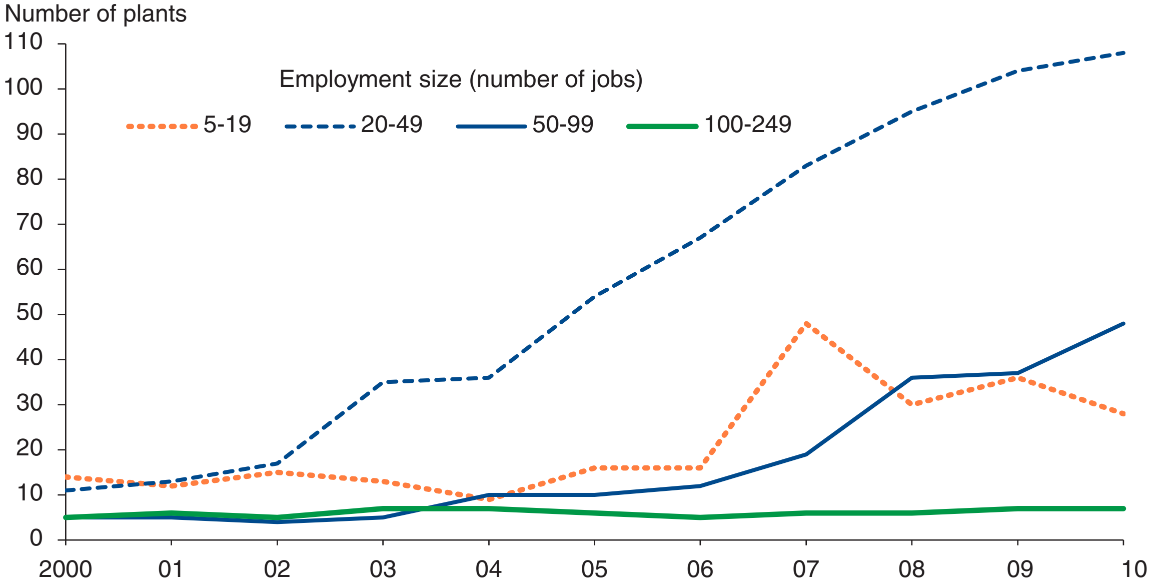
## Ethanol Is Produced Primarily in the Midwest and Great Plains

Most of the increase in ethanol production capacity has occurred in rural areas where supplies of corn and other feedstock are readily available, and users of byproducts (e.g., dried distillers grain) like livestock producers are located nearby (Lambert et al., 2008). One 2006 study suggested that it is not economical to transport corn to an ethanol facility more than 50 miles away given the price of corn, ethanol, and fuel at the time (Swenson and Eathington, 2006). Table 7 reports the top 10 States with the most ethanol production capacity added between 2000 and 2010. All of the States listed are in the Midwest or the Great Plains (see fig. 1). By 2010, Iowa alone had approximately 3.2 billion gallons per year in production capacity.

Ethanol plants are not evenly distributed across corn-growing areas. Railroad, highway, and water access also affect where plants are built (Low and Isserman, 2009). Lambert et al. (2008) found that the supply of corn and railroad access influence plant location, while Haddad et al. (2010) found that within major corn-producing areas, population density and proximity to blending terminals also matter.

Figure 10

**Number of ethanol plants by number of jobs**



Note: The data are for Ethyl Alcohol Manufacturing (NAICS 325193), a manufacturing sector that predominantly manufactures nonpotable ethyl alcohol, including ethanol, for fuel as well as other uses.
Source: USDA, Economic Research Service calculations using County Business Patterns (U.S. Census Bureau, 2012).

Table 7

**Top 10 States with new installed corn-based ethanol production capacity**

| State | MGY in 2000 | MGY in 2010 | Change | Number of plants in 2010 |
|---|---|---|---|---|
| Iowa | 362 | 3,293 | 2,931 | 39 |
| Nebraska | 304 | 1,507 | 1,203 | 25 |
| South Dakota | 27 | 1,005 | 978 | 14 |
| Minnesota | 198 | 1,118 | 921 | 21 |
| Indiana | 85 | 908 | 823 | 11 |
| Illinois | 631 | 1,383 | 752 | 12 |
| Ohio | 0 | 538 | 538 | 7 |
| Wisconsin | 0 | 498 | 498 | 9 |
| Kansas | 41 | 444 | 403 | 11 |
| North Dakota | 28 | 353 | 325 | 6 |

MGY = million gallons per year.

Source: USDA, Economic Research Service calculations derived from published tables from the Renewable Fuels Association (2010). All of the top 10 States were used in the ethanol plant analysis.

## The Employment Effects of Ethanol Capacity

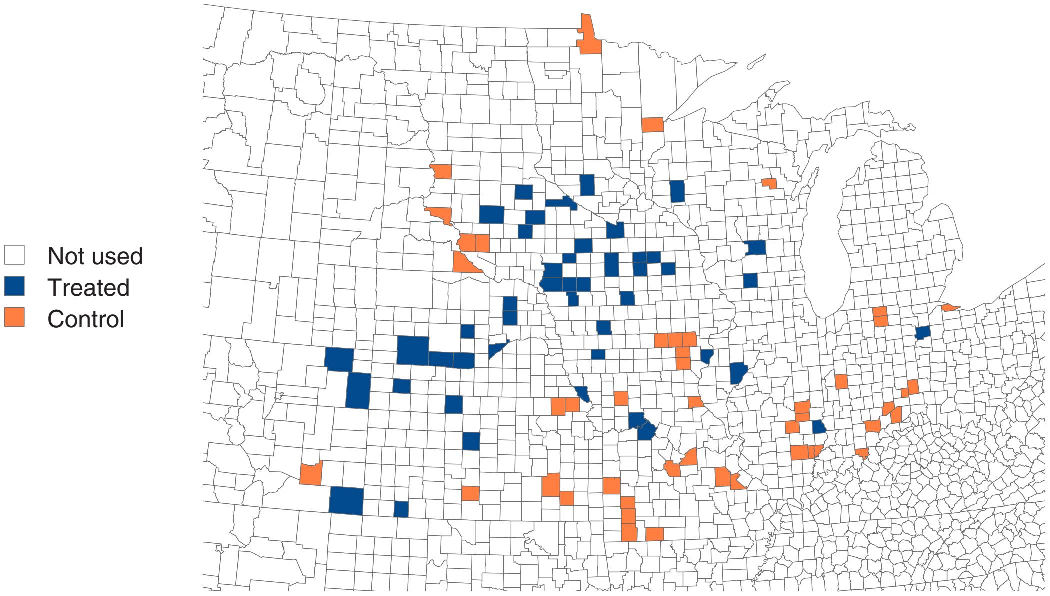
Blanco and Isenhouer (2010) studied the link between ethanol production capacity at the county level and employment and wages, finding a very small but statistically significant relationship in the major corn-producing States. Their study did not estimate how opening a new ethanol plant would affect employment in the local economy.

We looked at changes in employment in a county 1 year before and 2 years after construction of an ethanol plant to estimate the effect of a plant in operation. We then used a matching algorithm to select control counties (those without an ethanol facility) that closely resembled counties with an ethanol facility, so that comparisons could be refined further (fig. 11). This approach estimates the net number of jobs generated in the local economy as a result of the ethanol plant operating. We considered a 12-State region and plant operations beginning between 2000 and 2006 and find an imprecise (i.e., not statistically different from 0) estimate for total employment. This is unsurprising because the large variation in annual employment can statistically mask a relatively small employment effect, especially in small samples.

The analysis therefore focused on a subset of industries that accounted for approximately three-quarters of the indirect and induced jobs that the IMPLAN analysis by Low and Isserman (2007; 2009) projected would be created from a new ethanol facility. Considering only employment in these particularly “sensitive” industries gave a more statistically precise effect: each job in an ethanol plant created 2.6 jobs in the subset of industries (table 8). The estimate is likely a lower bound of the true employment effect since it only covers three-quarters of the total number of jobs that Low and Isserman projected would be created. Accounting for the additional 25 percent of the indirect and induced jobs that they projected would be created in industries believed to be less sensitive to the effects of ethanol production implies a total employment multiplier of 3.2 jobs (2.55 × 1.25 = 3.2) created for every ethanol job. This estimated multiplier, which combines empirical and model-based results, assumes that creation of an ethanol production facility does not cause a decline in employment in the industries excluded from the empirical analysis, either through displacement of lower valued activities or increases in wages or land prices (Steininger and Wojan, 2011). While possible, the total employment of a typical ethanol plant makes it unlikely that its creation would cause local wages to increase and other industries to become less competitive and shrink. Details of the analysis may be found in the appendix.

Figure 11

**Treatment and selected control counties in the ethanol analysis**



Note: Treatment counties are counties where an ethanol plant began operation between 2000 and 2006. Control counties are counties with characteristics similar to treatment counties but where an ethanol plant was not established.
Source: USDA, Economic Research Service tabulation using U.S. Department of Labor, Bureau of Labor Statistics, Quarterly Census of Employment and Wages.

Table 8

**Empirical estimates of corn-based ethanol impacts**

| | Employment (jobs) | | | |
|---|---|---|---|---|
| | Change in ethanol employment | Estimated effect of ethanol employment | Total effect (jobs) | Percent of mean employment prior to plant entry |
| | | | | *Percent* |
| 25th percentile | 21 | 2.6 jobs per ethanol job | 55 | 0.6 |
| 50th percentile | 33 | | 86 | 0.9 |
| 75th percentile | 39 | | 101 | 1.1 |
| Mean | 31 | | 82 | 0.9 |
| | | | Total effect ($) | |
| 25th percentile | 21 | 3.2 jobs per ethanol job | 68 | 0.7 |
| 50th percentile | 33 | | 106 | 1.1 |
| 75th percentile | 39 | | 124 | 1.3 |
| Mean | 31 | | 101 | 1.1 |

Notes: The employment multiplier 2.6 was estimated from a set of industries comprising 75 percent of the indirect jobs created by an ethanol facility as found by Low and Isserman (2007). If another 25 percent of the jobs created are in other industries, it would imply an upper bound of the total employment multiplier of 3.2 (2.55 × 1.25 = 3.2). The higher estimated effect could not be empirically confirmed.

Source: USDA, Economic Research Service analysis.

The estimated multiplier can be used to calculate estimates for the total jobs created for counties in the sample with an ethanol facility (see table 8). Using the empirically estimated multiplier of 2.6, which only considers industries thought to be linked to the ethanol industry, implies the creation of 82 jobs. Using the multiplier that combines the empirical estimate with an estimate based on IMPLAN gives a total local employment effect of 101 jobs. These estimates represent 0.9 and 1.1 percent of the initial mean employment in ethanol plant counties, respectively. Ethanol plant employment, which is used to determine the total employment effects, is more evenly distributed across counties compared to natural gas production or installed capacity for wind. The mean and median employment effects for ethanol are therefore very similar.

All of the ethanol plants in the analysis were built after 2000 and before 2008. Because the jobs created by the plant were expected to remain at similar levels at least through 2008, the estimated effect approximates the change in employment from 2000 to 2008 attributable to the entry of an ethanol plant.

## Beyond Employment: Water Use and Air Quality

Water usage and discharge are common environmental concerns for ethanol plants. Depending on the plant type, water use ranges from 1.5 to 4 gallons for each gallon of ethanol produced, with an industry average between 3.0 and 3.5 gallons (Ethanol Across America, 2009). Plants discharge wastewater with brine from purifying water or from cleaning salts that accumulate in cooling towers and boilers, but the EPA does not consider corn ethanol plants to cause major effluent quality issues (U.S. EPA, 2010). Many local governments require ethanol plants to purchase water rights from other users so that the plants have no net effect on water demand. The cost of acquiring clean water and disposing of wastewater has encouraged innovation in plant water management, such as using municipal wastewater, supplying discharge water to farmers for crop irrigation, and developing zero-discharge technology.

Emissions from ethanol production may vary slightly depending on the feedstock and emission controls used. Dust control equipment monitors particulate matter that is less than 10 microns in diameter created during corn delivery, handling, milling, and drying. Fermentation, distillation, and drying create volatile organic compounds, which arise regardless of the biofuel technology used. Combustion from a plant's boilers generates carbon monoxide, nitrogen oxides, and sulfur oxides. Although the total amounts emitted are small compared to a power plant, local residents may still notice the emissions (U.S. EPA, 2010).

# Simulation Approach To Modeling Impacts

Academic and nonacademic authors and institutions have used simulation models, principally input-output models such as IMPLAN, to project the economic effects of expansion of the unconventional natural gas, wind, and ethanol industries. The input-output approach consists of creating a mathematical representation of an economy by specifying linkages between sectors, for example, assuming that each dollar in output from the automobile industry uses 20 cents of output from the steel manufacturing industry as an input. When combined with location-specific industry information, the relationships between sectors permit projections of how expansion of one industry would affect output in the entire economy. The total effect is the combination of direct, indirect, and induced effects. Direct effects come from the value of production and employment in the industry under study. Indirect effects are from the industry purchasing goods and services from local firms and from any additional local purchases by those firms. Induced effects come from consumption expenditures by industry employees, or those of its suppliers and their suppliers, in the local economy. Examples of input-output analysis applied to energy industries include:

| Industry | Study |
|---|---|
| Unconventional natural gas | CBER (2006); L.C. Scott and Associates (2010) |
| Wind power | Lantz and Tegen (2009); Slattery et al. (2011) |
| Ethanol | Swenson (2006); Low and Isserman (2009) |

Ex-ante simulation approaches have several advantages and limitations. Empirical approaches often require smaller geographic units to have sufficient observations for statistical analysis, whereas simulation approaches can model effects over a large economic region. Most importantly, they can provide projections before much industry growth has happened.

At the same time, ex-ante simulation approaches often use employment and expenditure projections reported by companies engaged directly in the industry. If companies benefit by being perceived as making large contributions to local economies, they may have an incentive to overstate the scale of their operations or projected activities. Assuming that companies report reliable information, the approach often involves untested assumptions about fixed relationships between inputs and outputs. Input-output approaches, in particular, often assume that greater demand for an input will not cause the price of the input to increase, such as greater demand for labor causing wages to increase (Kilkenny and Partridge, 2009). Most simulation approaches also use information derived from national accounts data rather than information about the unique organization of the local economy (Rickman and Schwer, 1995). If the assumptions poorly approximate the economy under study, the models likely will make inaccurate projections. Evidence from two empirical studies suggests that input-output models, in particular, tend to overestimate the contribution of new industrial development to local economic growth (e.g., Edmiston, 2004; Fox and Murray, 2004), but our results indicate that input-output based projections can approximate actual impacts when the models are properly designed.

## Natural Gas

Multiple studies have used input-output models to project the number of jobs that would be created from developing natural gas resources. These projections have been cited often by newspapers, policymakers, and industry groups. Their broad use underscores the need to verify if the studies have overstated or understated the economic contributions of natural gas development. The estimated employment effects from natural gas extraction in Colorado, Texas, and Wyoming combined with the change in the value of gas production from 1999 to 2007 imply that each $1 million in gas production created 2.35 jobs. We survey nine economic impact studies involving the natural gas industry. Some look only at natural gas and some combine oil and gas. From each study, we use the projected level or change in jobs and the corresponding level or change in the value of production to calculate the number of jobs for each $1 million in production (table 9).

All of the simulation studies differ in some way from our empirical study, but some are similar in many aspects. One study looks at the county-level effects from shale gas development in Arkansas; two studies look at a multicounty region within Texas; and two other studies look at State-level effects for Colorado and Wyoming. We also consider four more State-level studies for Arkansas, Oklahoma, Louisiana, and Pennsylvania. Combined, the nine simulation studies provide a sense of how model estimates vary.

Estimates of the jobs created for each $1 million in production vary from about 3.5 jobs to more than 20 jobs. Some of the differences across the studies may reflect the level of analysis (State versus region), the scope (natural gas only or all oil and gas); the specifics of the area studied such as whether most wells are on public or private land; or the years considered, since natural gas prices were substantially lower in 2009 and later. But a close look at the nine studies reveals that such differences appear to explain little of the variation in estimates. None of the three studies that look below the State level provide the smallest estimate. Studies covering oil and gas do not always give larger or smaller results. Wyoming has more drilling on Federal lands than any other State, which reduces the royalty payments paid directly to local residents, yet its employment estimate is larger than that of Arkansas. Three of the four highest employment impacts correspond to 2009 and later. Because of the decline in prices, a dollar in production in 2007 involved much less gas than a dollar of gas in 2010. If a given quantity of gas requires a certain amount of labor, we would expect higher employment effects per dollar in times of low prices. This explanation, however, is also not fully consistent with results: two of the three studies with the smallest employment effect correspond to periods of lower prices.

It is not surprising that obvious differences across input-output studies (State versus county, natural gas or oil and gas) seem to explain little of the variation in their results. Details of the modeling approach used in each study, which we do not explore, may provide a better explanation. For example, a change to an industry can be modeled as a change in capacity or as an expansion in sales, with each approach using different data and assumptions.

The University of Arkansas Center for Business and Economic Research study of the Fayetteville Shale in Arkansas is the most comparable to our empirical estimate because it estimates the number of jobs created in producing counties (CBER, 2006). Taking the difference between the employment supported by shale gas development in 2005 and 2008 in Fayetteville Shale counties and dividing it by the change in the value of gas production implies that 3.57 jobs are created for each $1 million in production. Another study comparable in several aspects is from the University of Texas Center for Community and Business Research (CCBR, 2011), which looks at the multicounty region covering the Eagle-Ford Shale in southeastern Texas. It suggests that each $1 million in shale oil and gas production creates 4.17 jobs. Despite looking at Statewide effects, the 2012 CBER study of the Fayetteville Shale gives an estimate similar to the county-level analysis in the 2006 CBER study. The remaining input-output studies all estimate larger employment effects. Four of them imply that $1 million in production creates more than 10 jobs.

Table 9

**Input-output estimates of the employment sustained by oil and gas development**

| Study | Period | Location | Geographic level | Model | Jobs per $1 million of production | Jobs/Bcf | Scope |
|---|---|---|---|---|---|---|---|
| CBER (2006) | 2005-2008 | Fayetteville Shale Counties, AR | County | IMPLAN | 3.57 | 23 | Natural gas only |
| CBER (2012) | 2008-2011 | Arkansas | State | IMPLAN | 3.47 | 9 | Natural gas only |
| CCBR (2011) | 2010 | Eagle-Ford Shale Counties, TX | Multicounty region | IMPLAN | 4.19 | NA | Oil and gas |
| Perryman Group (2008) | 2006-2007 | Barnett Shale, TX | Multicounty region | Proprietary I-O Model | 17.97 | 134 | Natural gas only |
| LSB (2011) | 2011 | Colorado | State | IMPLAN | 12.69 | NA | Oil and gas |
| Booz Allen Hamilton (2008) | 2007 | Wyoming | State | IMPLAN | 5.60 | NA | Oil and gas |
| S.C.A. ERPI (2012) | 2011 | Oklahoma | State | IMPLAN | 6.38 | NA | Oil and gas |
| L.C. Scott & Associates (2010) | 2009-2010 | Louisiana | State | RIMS II | 11.51 | 57 | Natural gas only |
| Kelsey et. al (2011) | 2009 | Pennsylvania | State | IMPLAN | 20.35 | 86 | Natural gas only |
| | | | | I-O Min | 3.47 | 9 | |
| | | | | I-O Max | 20.35 | 134 | |
| | | | | I-O Median | 6.38 | 57 | |
| Weber (2012) | 1999-2007 | Counties in TX, WY, CO | County | Empirical | 2.35 | 27 | |

Bcf = billions of cubic feet; CBER = Center for Business and Economic Research; CCBR = Center for Community and Business Research; LSB = Leeds School of Business; S.C.A. ERPI = Steven C. Agee Economic Research Policy Institute; NA = not applicable.

Notes: The value of production is in real terms, using 2007 as the base year as in Weber (2012). Natural gas production for the two CBER studies is taken directly from the studies. Oil, gas, and gas condensate production for Eagle-Ford Shale counties is from the Texas Railroad Commission. Gas production for Barnett Shale counties is also from the Texas Railroad Commission. The total value of oil and gas production for the Colorado and Wyoming studies comes directly from the studies. Total oil and gas production for Oklahoma is from the U.S. Department of Energy, Energy Information Administration as is production for Louisiana and Pennsylvania. Prices used to value production are also from DOE/EIA. For the studies that span more than 1 year, the employment effect was calculated by differencing the first-year and last-year employment and production levels.

Source: USDA, Economic Service analysis.

An alternative way to express employment effects is per billion cubic feet of gas. An increase in natural gas prices explains part of the increase in the value of production in the empirical study. In contrast, the changes in the value of production used to understand the simulated projections come primarily from changes in quantities. Higher gas prices should increase the economic effect of a given scale of production since they will affect lease and royalty payments. Ignoring prices would then cause the empirical study employment effect expressed in the quantity of gas to be larger because, in reality, an increase in prices accompanied the increase in production.

Our empirical study implies that each billion cubic feet of gas is associated with 27 jobs. We calculate a similar effect for the five input-output studies that only considered natural gas. The empirical employment effect is slightly larger than the effect from the two CBER studies and less than that of the other three studies. Thus, even when expressing the effect in a way that may exaggerate our empirical employment effect, our estimate is still on the lower end of impacts projected earlier by simulation models (see table 9). The disparity between our employment effects and theirs suggests that the projected local economic benefits of gas development may have been overstated. More empirical studies, however, would permit firmer conclusions.

## Wind Power

Most studies of the economic effects of wind power development have relied on project-level case studies of the direct effects of individual wind power plants. Their employment, cost, and revenue data come from project developers or operators, or simulation model estimates of the potential impacts of one wind power plant or an aggregate amount of assumed wind development (e.g., Pedden, 2006; Lantz and Tegen, 2009). Table 10 summarizes several studies of the local economic effects of wind power development. The estimated effects on employment in a county or group of counties range from 0.1 to 0.6 jobs per megawatt during the operations period.[5]

The same simulation studies found that during the long-term operations period, each megawatt creates between \$5,000 and \$18,000 in wage and salary income (in 2010 dollars). Some of the studies also examined the effects on total economic output and found that for plants in the operating phase, each megawatt supports between \$13,000 and \$55,000 in output (GAO, 2004) (see table 10).

The empirical estimates from Brown et al. (2012) are not strictly comparable to these earlier simulation studies because the estimates correspond to personal income rather than the narrower category of labor income (or the even broader category of total economic output). Furthermore, Brown et al. were unable to separate construction period impacts from operating impacts for installations occurring in 2008, while all of the input-output studies in table 10 consider only operating effects. Both differences imply that the empirical approach would yield higher impacts than the input-output approach applied to labor income and employment. But, in contrast to the input-output approach, the empirical approach allows wind development to discourage or displace other economic activities, which would lower empirical estimates compared to input-output estimates. Differences aside, the estimated impact on personal income and employment of approximately \$11,000 and 0.5 jobs per megawatt are bounded by the minimum and maximum estimates from input-output models, which range from \$5,000 to \$18,000 in labor income per megawatt and from 0.1 to 0.6 jobs per megawatt for plants in operation. The estimated effects based on actual employment and income levels are also close to the median projections from earlier studies (see table 10).

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[5] Power is measured as a unit of energy over time—a megawatt-hour can power about 1,000 homes for 1 hour.

Table 10

**Input-output estimates of wind power development**

| Study | Year | Location | Geographic level | MW | Methodology | Jobs/MW | Income/MW (2010 dollars) | Output/MW (2010 dollars) |
|---|---|---|---|---|---|---|---|---|
| DanMar & Associates | 1996 | Southwest, MN | Six counties (Phase 1) | 100 | Proprietary I-O model | 0.19 | 5,849 | 12,650 |
| DanMar & Associates | 1996 | Southwest, MN | Six counties (Phase 2) | 100 | Proprietary I-O model | 0.54 | 7,209 | 12,723 |
| NEA | 2003 | Lincoln, MN | County | 107 | IMPLAN | 0.29 | 11,019 | NR |
| NEA | 2003 | Morrow & Umatilla, OR | County | 25 | IMPLAN | 0.24 | 5,396 | NR |
| NEA | 2003 | Culberson, TX | County | 30 | IMPLAN | 0.37 | 14,959 | NR |
| EcoNorthwest | 2002 | Kittitas, WA | County | 390 | IMPLAN | 0.14 | 13,385 | NR |
| Torgerson et al. | 2006 | Umatilla, OR | County | 5 | JEDI | 0.24 | 10,734 | 26,084 |
| Kildegaard & Myers | 2006 | Stone, MN | County | 10.5 | IMPLAN | 0.41 | NR | NR |
| Slattery et al.* | 2011 | West Texas | Four counties | 1,398 | JEDI | 0.16 | 6,867 | 22,246 |
| GAO | 2004 | Multiple locations | County | 40 | JEDI | 0.30 – 0.62 | 8,704 – 16,933 | 18,591 – 51,360 |
| | | | | | I-O min | 0.14 | $5,396 | $12,650 |
| | | | | | I-O max | 0.62 | $17,759 | $55,488 |
| | | | | | I-O median | 0.38 | $11,019 | $31,586 |
| Brown et al. (2012)* | 2000-2008 | Counties in IA, KS, MN, NE, ND, SD, NM, OK, TX, CO, MT, and WY | County | | Empirical | 0.48 | $11,150 | |

MW = megawatts; NEA = Northwest Economic Associates; I-O model = input-output model; IMPLAN = Impact Analysis for Planning; JEDI = Jobs and Economic Development Impact; GAO = Government Accountability Office; NR = not reported. * Indicates publication in a peer-reviewed journal.

For more information on the JEDI model, see http://www.nrel.gov/analysis/jedi/about_jedi.html

Source: USDA, Economic Service analysis.

## Ethanol

Similar to wind power development and natural gas production, most studies of the economic effects of ethanol facilities have used input-output models. The studies typically report direct, indirect, and induced employment from developing the capacity to produce a given amount of ethanol. Projections are typically reported as employment multipliers: the number of jobs created for each job at an ethanol plant. Table 11 summarizes several studies and shows that the reported employment multiplier ranges from 1.8 to 17.9 jobs for each ethanol job, with the median multiplier of 4.3. The multiplier of 17.9 comes from an early study by Urbanchuk and Kappell (2002). Perhaps due to more or better information, over time the estimated impacts have become more conservative, with the more conservative estimates often found in peer-reviewed journal articles. The study by Low and Isserman (2009) is of particular interest because they studied two different-sized plants (producing 60 versus 100 million gallons per year) in two mainly rural counties and two counties with sizeable rural and urban areas. The largest impacts occurred in the counties with sizeable rural and urban areas, with an employment multiplier of 5.6 versus 3.9 in the rural counties. The point estimate of the multiplier for local employment in closely linked industries, based on our empirical analysis is somewhat below the median of the multipliers reported in table 11, but certainly within a 95-percent confidence interval. This suggests that similar to the case of wind, carefully constructed input-output studies of ethanol can generate impacts in line with empirical estimates. It should be noted that the empirical estimate of the employment multiplier on closely linked industries, however, is also noticeably higher than the smallest input-output multiplier.

## The Role of Simulation and Empirical Approaches

A key finding is that for wind and ethanol, employment projections from carefully constructed simulation models are consistent with empirical estimates based on actual changes in local employment over time. One limitation of empirical methods is that they often require multiple years of data on many counties to yield precise and credible estimates. Simulation models like input-output models, on the other hand, can estimate the effects of a proposed activity well before an empirical study would be possible. Based on their different strengths and weaknesses, the two methods complement rather than substitute for each other, with empirical methods playing an important role in verifying earlier input-output results.

In the case of natural gas, the input-output employment effects are generally larger than the empirical estimate. Subsequent empirical studies, potentially looking at different regions or periods, may show larger employment effects; nonetheless, there are at least three potential reasons for input-output studies to provide larger employment effects than the empirical study of county-level effects in Texas, Wyoming, and Colorado. First, most input-output models are static and do not allow for the expansion of one industry to crowd out other industries: for example, greater natural gas extraction increases wages and, consequently, labor costs for other industries. The assumption is most appropriate when employed in the study of small changes to an economy, which better describes placement of a wind turbine or construction of an ethanol plant than a boom in natural gas extraction. Evidence from the Eagle Ford Shale in Texas, for example, suggests that drilling activity has caused weekly wages to increase by as much as a third (Gilmer et al., 2012).

A second possible explanation for the difference is that input-output models reflect outdated technology while empirical estimates implicitly reflect the technology in use during the study period. Empirical estimates, for example, may capture labor-saving innovations in drilling not yet captured in input-output models. Finally, some of the industry expenditures incorporated into input-output models may go to businesses outside of the study region, such as equipment manufacturers in other States.

Table 11

### Input-output estimates of ethanol plant development

| Study | Year | Location | Geographic level | MGY | Methodology | Direct jobs | Indirect jobs | Induced jobs | Multiplier |
|---|---|---|---|---|---|---|---|---|---|
| Gallagher, Otto, and Dikeman*,† | 2000 | Midwest | Multiple States | 376 | IMPLAN | 900-1,200 | 5,499 | | 4.4-5.9 |
| Urbanchuk and Kappell | 2002 | n/a | Not specified | 40 | IMPLAN | 41 | 694 | | 17.9 |
| Petersan | 2003 | NE | State | 24 | IMPLAN | 31 | 73 | | 3.4 |
| Swenson | 2005 | IA | State | 41 | IMPLAN | 32 | 135 | | 5.2 |
| Swenson | 2006 | IA | State | 50 | “ | 35 | 75 | 23 | 3.8 |
| Parcell and Westoff* | 2006 | n/a | Not specified | 60 | IMPLAN | 54 | 156 | | 3.9 |
| Flanders et al. | 2007 | GA | State | 100 | IMPLAN | 46 | 362 | | 8.9 |
| Low and Isserman* | 2009 | Kankakee County, IL | County | 100 | IMPLAN | 39 | 152 | 29 | 5.6 |
| “ | “ | Hamilton County, IL | County | 100 | “ | 39 | 97 | 17 | 3.9 |
| “ | “ | Coles County, IL | County | 60 | “ | 35 | 83 | 34 | 4.3 |
| “ | “ | Harlan County, NE | County | 60 | “ | 35 | 50 | 15 | 2.9 |
| Guerro et al.* | 2011 | Hockley County, TX | County | 40 | IMPLAN | 35 | 18 | 9 | 1.8 |
| “ | “ | Southern High Plains TX | County | 40 | “ | 35 | 86 | 48 | 4.8 |
| | | | | | | | | I-O min | 1.8 |
| | | | | | | | | I-O max | 17.9 |
| | | | | | | | | I-O median | 4.3 |
| ERS analysis | 2000 - 2008 | Counties in IA, NE, KS, MN, ND, SD, IL, IN, WI, MO, CO, and OH | County | | Combination of Empirical and IMPLAN | | | | 2.6 – 3.2 |

n/a = data not available; MGY = million gallons per year; IMPLAN = Impact Analysis for Planning.

IMPLAN was the most commonly used model to determine the impacts. * Indicates publication in peer-reviewed journal. † The study analyzed a hypothetical expansion of 376 MGY across multiple facilities. Their assumptions were that a wet mill generating 90 to 120 MGY employs 300 workers and that a dry mill producing 100 MGY employs about 300 workers. We have calculated the range of implicit multipliers from these assumptions.

Source: USDA, Economic Service analysis.

# Possible Future Job Growth Constraints

This study provides empirical estimates of the local economic effects of three emerging energy industries. The contribution of each emerging industry to local economies varies because of the nature of the regional economy where the new industry occurs, differences in the scale of the industry, the intensity of labor use, and the linkages to other sectors in the local economy. Our analysis provides a limited view of how the industries affect life in rural communities. Each industry brings its own challenges for local communities: groundwater concerns with natural gas; disruption of the landscape by wind turbines; and use of wastewater or water from ethanol plants. The net economic benefits to an area may be quite different than gross private monetary gains. For example, a landowner's gas royalty payments may overstate the net economic gain to the local economy if wellwater must be replaced by purchased water. The interaction between the emerging industries and other local activities remains largely understudied.

The distribution of costs and benefits of a new energy industry varies among local residents. Some residents may experience increases in costs and enjoy few or none of the benefits brought by the industry. Someone who owns a home near several wind turbines but otherwise has no connection to them may perceive a decrease in quality of life by having the view disrupted. Negative perceptions of wind turbines or natural gas wells could lower the property values of nearby residents. In contrast, owners of mineral rights can benefit substantially from natural gas lease and royalty payments. More broadly, greater traffic congestion from natural gas development or transporting corn could lower the quality of life for many rural residents, which may or may not be offset by greater tax collections and subsequent declines in tax rates or increases in public services.

Many rural residents enjoy natural amenities and aspects of rural communities, such as uncongested roads. For some residents not directly benefiting from the industry, such as retirees, truck traffic associated with natural gas drilling can create congestion on rural roads, encouraging people to retire elsewhere. More jobs and public revenues may or may not fully counteract such forces.

Our report focuses on short-term economic effects, which are likely to change over time. The effects of the drilling phase of natural gas extraction, for example, are likely larger than the effects of the production phase. Perhaps more importantly, the three industries all face distinct constraints over the medium- and long-term, with natural gas, being a nonrenewable energy source, facing the most severe constraint. Gas production is expected to expand through 2035, but reserves in specific areas will no doubt decline. After strong growth in the mid-2000s, production from the Barnett Shale in Texas leveled off from 2008 to 2012 (Texas Railroad Commission, 2013). As reserves decline in specific areas, the industry will develop new formations until those new drilling areas' productivity is too low to warrant extraction. The industry's long-term effect on a local economy, therefore, will depend on how people and governments in gas-producing areas manage any negative effects caused by the drilling and how they use revenues generated from extraction.

Ethanol may have greater capacity than the natural gas industry to maintain or expand production in the long term, but the supply of arable land used to produce ethanol feedstocks is largely fixed (Hertel, 2010). Although investments in agricultural research may increase land productivity, a growing global population and rising incomes will likely keep agricultural commodity prices high (Westcott and Trostle, 2012). An increase in the price of feedstocks larger than the price of oil will reduce ethanol producer profit margins (Hurt et al., 2006). Of course, technological improvements that allow plants to produce more ethanol with the same amount of feedstock or that increase the feasibility of using lower cost feedstocks, such as corn stover or switchgrass, will improve the industry's competitiveness.

Wind development also faces constraints, although they may be less rigid than those faced by the natural gas and ethanol industries. Electricity production depends on when winds blow rather than when consumers need power, which encourages utilities to use wind as a supplementary source of electricity instead of the primary source. The variability of wind means that integrating wind power into the electricity grid becomes more costly as wind accounts for a greater share of an area's electricity supply (Wiser and Bolinger, 2007). Many areas typically need costly new transmission lines to send wind-generated electricity from windswept rural areas where it is produced to areas of peak electricity demand in suburbs and cities (Logan and Kaplan, 2008).

Growth of the ethanol industry will depend heavily on feedstock and oil prices, innovation, and public policies. Global energy markets and policies such as the production tax credits will affect expansion of wind power. In addition, greater availability of natural gas is expected to substantially decrease electricity prices over the next 20 years, making natural gas a direct competitor with wind (Palmer et al., 2012). Despite public pressure to limit hydraulic fracturing in several States, the abundance of natural gas and the profitability of extraction under normal market conditions suggest that natural gas development will continue to expand across the United States. Our findings suggest that expansion of unconventional gas drilling (and with similar technology, oil drilling) will contribute the most to economic growth across rural areas in the short term, while the wind and ethanol industries will have more modest effects.

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# Appendix

## Empirical Approaches To Estimating Causal Effects

Most empirical approaches to estimating causal effects, like the effect of natural gas extraction on income, seek to mimic a randomized experiment in which membership in the treatment group (experiencing a natural gas extraction boom) and control group (not having a boom) is randomly assigned. In practice, social scientists rarely can assign treatment randomly and must use other approaches to estimating causal effects. We briefly describe three general approaches: difference-in-difference estimation, instrumental variables, and matching.

***Difference-in-Difference***: To continue with the natural gas boom example, the difference-in-difference requires a group of counties that experiences a boom and a group that does not. The approach involves taking: (1) the difference in income from the beginning and end of the boom period for each group of counties; and (2) the average difference for boom counties minus the average difference for nonboom counties. In the absence of other trends that affect income and that affect the two groups differently, the difference-in-difference approach provides an unbiased estimate of the mean effect of a gas boom on income.

Because income in boom counties may have been growing more (or less) than in nonboom counties in the period prior to the boom, taking differences in growth instead of levels provides a robust version of the basic difference-in-difference approach. In the income example, it involves taking the difference in income from before and after, subtracting from it the difference in the period prior to the boom, and then comparing boom and nonboom counties. Consider three points in time, where the boom happens between the second and third point. A difference-in-difference estimate of the effect of a gas boom on income (y) would then be

$$\left[\left(y_{p3}^{b}-y_{p2}^{b}\right)-\left(y_{p2}^{b}-y_{p1}^{b}\right)\right]-\left[\left(y_{p3}^{nb}-y_{p2}^{nb}\right)-\left(y_{p2}^{nb}-y_{p1}^{nb}\right)\right]$$

where *b* and *nb* indicate boom and nonboom counties.

***Instrumental Variables***: Gas companies choose where to drill, and their decisions may reflect factors such as the willingness of landowners to lease their land, which may be related to local income levels. Growth in drilling and production also may be related to a characteristic of the county that is unlikely to be related to income, like the presence of unconventional gas formations deep under a county's surface. Without drilling, the presence of unconventional gas formations should not affect income growth in a county. The instrumental variable approach involves using one or more variables that affect where extraction occurs but that are otherwise unrelated to income growth. Applied to the gas example, an instrumental variables approach estimates the effect of greater gas extraction for counties where their growth in gas production was related to having unconventional gas formations.

***Matching****:* Matching involves pairing a treatment county with one or more control counties. Continuing with the example of the natural gas boom, matching would involve matching a boom county with a nonboom county that had similar characteristics such as demographics and economic composition. The key assumption is that after appropriately matching counties, any difference between them in employment growth, for example, reflects the natural gas boom and not because the boom and nonboom counties are different in ways that have not been accounted for.

Many modifications of the basic difference-in-difference, instrumental variable, or matching approaches exist, and the methods can be combined with one another or with other techniques. The tie that binds them is the focus on providing the best estimate of causal effects by creating a credible estimate of what would have happened in a gas-boom county had drilling never occurred.

## Selection of Empirical Approaches

The natural gas analysis combines the difference-in-difference approach with an instrumental variable. Three points in time are used in the differencing to allow for the possibility that boom counties had a prior employment trend different from that of nonboom counties. We may expect a different prior trend because, prior to the boom, the conventional natural gas industry had a greater presence in boom counties as evidenced by greater natural gas production and greater dependence on mining employment than nonboom counties. The percent of the county covering an unconventional gas formation is used as an instrument for a county's status as a boom county. Most growth in drilling occurred in unconventional gas formations, so the instrument is related to a county's status as a boom county. At the same time, it is unlikely that the location of unconventional gas formations is correlated with economic activity outside of the correlation caused by greater gas extraction.

The relationship between wind resource potential and wind development enabled use of an instrumental variable approach in the wind analysis as well. Measures of a county's wind resources are used as an instrument for changes in installed wind power capacity over the study period. It is unlikely that counties with more wind systematically have better or worse economic performance than other counties, yet wind turbines are often placed in areas with greatest wind potential. Only two points in time were used in differencing because, unlike the natural gas case, counties where most wind power capacity was installed tended to have characteristics similar to other counties. Moreover, counties with wind turbines were not previously dependent upon the industry, as it was largely nonexistent prior to the study period. A look at prior trends confirms that growth in wind power capacity in the early 2000s was not correlated with income or employment growth in the 1990s.

Like the wind analysis, the ethanol analysis looks at changes before and after development. In the ethanol analysis, however, we used a matching approach because of a lack of a convincing instrument for whether a county received an ethanol plant. And whereas natural gas and wind power development grew over time, building an ethanol plant is a discrete event. Instead of looking at changes over a fixed period such as 2000 to 2008, we calculated changes in employment from 1 year prior to the beginning of plant construction and 2 years after completing construction. Doing so helps to distinguish changes in employment caused by construction of the plant from other economic events or trends.

## Sources of Data

We use multiple sources of county-level data. Total employment, population, and income come from the U.S. Department of Commerce, Bureau of Economic Analysis. Gas production data by county by year for Texas, Wyoming, and Colorado come from the State agencies that monitor oil and gas development (Colorado Oil and Gas Conservation Commission, Texas Railroad Commission, and Wyoming Oil and Gas Conservation Commission). Information on installed annual county-level wind capacity is from the U.S. Department of Energy's Lawrence Berkeley National Laboratory, while wind resource potential data were provided by the U.S. Department of Energy's National Renewable Energy Laboratory (NREL). Both sources cover a 12-State region with abundant onshore wind resources. State-level information on installed wind capacity for the entire country is from the U.S. Department of Energy (2012). Direct employment for the ethanol industry is from county files of the Quarterly Census of Employment and Wages compiled by the U.S. Department of Labor, Bureau of Labor Statistics. This information was compared to plant listings from the Renewable Fuels Association to identify corn-based ethanol facilities. State-level production of fuel ethanol came from the U.S. Department of Energy's Energy Information Administration (2012a).

## Natural Gas Empirical Details

Differencing growth over the boom period with growth in the preboom period, a triple difference approach calculates how boom counties grew over the boom period relative to their trend in the preboom period and compares it with the same outcome for nonboom counties. The approach can be implemented by defining the dependent variable $y_i$ as

$$\text{(1A)} \quad y_i = (y_{i2007} - y_{i1999}) - (y_{i1999} - y_{i1993})$$

Another triple-difference approach would be to use the year-to-year change in employment, for example, as the outcome variable and regress it on a boom-county variable, a boom-period variable, and the interaction between the boom-county and boom-period variables. This panel approach is not taken because the instrumental variable used for identification is time invariant. Letting $y_i = (y_{i2007} - y_{i1999}) - (y_{i1999} - y_{i1993})$ converts the model into a cross-sectional form while retaining the advantage of the triple difference approach, namely allowing for different growth trends for boom and nonboom counties. An even more robust specification would be to include control variables that allow counties with different characteristics to have different outcomes in $y_i$. This is the empirical approach taken, with the full specification being

$$\text{(2A)} \quad y_i = \alpha + \beta\left(Boom\ County\right) + \delta_1 X_{i92} + \delta_2 C_{n(i)92} + \theta_{s(i)} + \varepsilon_i$$

A county's initial conditions are captured in $X_{i92}$, as are the characteristics of neighboring counties ($C_{n(i)92}$) in the initial period, and a State fixed effect ($\theta_{s(i)}$). Included as control variables are the county's initial population density, per capita wage and salary income, and the percent of total earnings accounted for by the agricultural, mining, manufacturing, and construction sectors. To avoid confounding geographic characteristics with the effects of being a boom county, we also control for the average population density and per capita income in adjacent counties in the initial period. The following table shows the ordinary least squares (OLS) and instrumental variable (IV) estimation results (appendix table 1).

## Wind Power Development Empirical Details

Brown et al. (2012) assume that changes in annual per capita personal income and employment ($y$) at the county level are affected by the counties' own socio-economic and demographic characteristics ($X$), the county's own wind power development ($D$) (measured in megawatts of capacity per capita), and State-level fixed effects ($S$), as shown by:

$$\text{(1)} \quad y = Z\left(X, D\right)\beta + \alpha S + \mu$$

where $Z$ is vector containing $X$ and $D$, and $\mu$ is a vector of residuals.

Appendix table 1

**Employment and wage and salary income effects from a natural gas boom**

| | Employment | | Wage and salary income | |
|---|---|---|---|---|
| Variables | OLS | IV | OLS | IV |
| Boom county | 509.751 | 1,780.152** | 22.693 | 69.027** |
| | (364.102) | (819.705) | (15.295) | (30.570) |
| Per capita income, 1993 | -30.738 | -38.115 | 1.293 | 1.024 |
| | (40.264) | (37.979) | (1.059) | (1.083) |
| Population density, 1993 | 454.755 | 359.314 | -10.526 | -14.007 |
| | (920.816) | (973.018) | (42.537) | (42.685) |
| Agriculture share of earnings, 1993 | 2,949.848 | 4,447.750* | 53.342 | 107.974 |
| | (2,070.898) | (2,444.322) | (61.824) | (74.136) |
| Mining share of earnings, 1993 | 2,536.754*** | 1,529.984 | 149.463*** | 112.744** |
| | (879.979) | (995.343) | (56.696) | (56.611) |
| Manufacturing share of earnings, 1993 | 2,267.435 | 2,255.311 | 81.995 | 81.553 |
| | (1,919.027) | (1,888.647) | (71.882) | (72.155) |
| Construction share of earnings, 1993 | 625.841 | 499.340 | 23.178 | 18.564 |
| | (967.506) | (1,008.886) | (36.088) | (39.672) |
| Population density of contiguous counties, 1993 | -4,033.341** | -3,868.310** | -114.304 | -108.285 |
| | (1,816.576) | (1,829.850) | (78.017) | (75.901) |
| Per capita income of contiguous counties, 1993 | 108.524 | -128.958 | 18.650 | 9.989 |
| | (557.495) | (600.859) | (21.096) | (21.085) |
| Texas | 852.856** | 791.229** | 21.456 | 19.208 |
| | (418.396) | (403.097) | (19.210) | (17.602) |
| Wyoming | 3,522.734*** | 2,931.236*** | 186.801*** | 165.228** |
| | (938.787) | (958.270) | (68.163) | (67.477) |
| Intercept | 2,016.595 | 2,026.847 | 45.870 | 46.244 |
| | (1,813.452) | (1,771.150) | (75.232) | (72.752) |
| Observations | 188 | 188 | 188 | 188 |
| Adjusted R-squared | 0.126 | 0.047 | 0.268 | 0.218 |

OLS = ordinary least squares, IV = instrumental variables.

Source: Weber (2012).

The location of wind power development ($D$) may be endogenous to the outcome variables of interest. This could be because increases in per capita income or employment encourage wind development (e.g., if increased income enables local investors to invest in wind development), or because unobserved factors affecting income and employment are also correlated with wind development (e.g., if wind development is more likely to take place in communities that have fewer alternative economic opportunities or less ability to invest in such opportunities because of the quality of local resources or local leadership or entrepreneurial capacity).

A common approach for dealing with endogenous regressors is instrumental variables (IV) estimation. Availability of a high-quality wind resource (i.e., high-speed wind) is likely a primary factor affecting the location and amount of wind power development and is unlikely to be directly related to the outcome measures in question (change in income per capita and employment from 2000 to 2008). Consequently, to instrument actual wind power development, we ultimately use two instrumental variables related to wind resource conditions: (1) the presence of wind resource potential across power classes 3-7 in a county (where 3 is toward the low end of feasible power classes for economic wind energy development and 7 represents areas with the highest wind speeds), and (2) the cumulative technical potential for wind power development in a county, measured in megawatts, based on the amount of class 3-7 winds available. The following tables show the descriptive statistics for variables used in the analysis as well as the OLS and IV estimation for wind power development effects on changes in per capita income and employment. (See appendix table 2, appendix table 3, and appendix table 4.)

## Ethanol empirical details

We estimated an employment growth equation at the county level by using a difference-in-difference approach combined with matching treated counties that received an ethanol plant with similar control counties. The study was restricted to areas with a high probability of attracting an ethanol plant based on Stewart and Lambert's (2011) probabilistic model of ethanol facility location. The entire States of Iowa, Nebraska, Kansas, Minnesota, North Dakota, South Dakota, Illinois, Indiana, Wisconsin, and Missouri were included in the study along with western Ohio counties and the non-mountainous counties of Colorado. Data for Wyoming and Michigan were not available. Forty-six plants with five or more employees started operations between 2000 and 2006 in the study area. Each plant has a unique study period that begins 1 year prior to the plant's full operation and extends for 2 years of full operation.[6] While the 3-year study period may not capture all import substitution possibilities that are eventually exploited, extending the study period would introduce additional variation decreasing the probability of detecting a significant effect. The empirical findings should be interpreted as the short- or intermediate-term impacts of a new ethanol plant on local employment.

The selection of matching variables was based on meeting one of two criteria: (1) salience to ensuring that control counties are similar and comparable to their paired treatment county and (2) strong theoretical justification for inclusion in an employment-growth model. To satisfy the first criterion, county population in 2000 and a county's urban influence code were selected to ensure that treatment and control counties are roughly the same size and have comparable interaction with urban agglomerations. A third variable captures information on the relative attractiveness of the county based on whether the county lost or gained population between 1970 and 1980—a period of widespread rural growth. Eight variables were selected to satisfy the theoretical justification criterion. These include 5 industrial structure variables (share of employment in farming, mining, manufacturing, and services related to recreation), a measure of the endowment of natural amenities (Partridge et al., 2008), and a human-capital variable (share of the population aged 24-44 with at least a college degree). Finally, employment-growth equations typically include the initial level of employment to account for convergence phenomena. A stronger rationale in the present case is the need to control for regression to the mean since we are examining a small subset of the economy.

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[6] The ideal base period would start right before construction of the new ethanol facility to ensure that construction employment is not counted in the baseline, but this information is not generally available. Construction of an ethanol plant may extend for more than 1 year in particular cases, so our 3-year interval will underestimate the true impact of a new plant if construction employment is included in the treatment county baseline. Tests were done with a 4-year interval model, beginning 2 years prior to full operation and including the first 2 years of operation. Unfortunately, the 4-year study interval was unsatisfactory as variance in employment growth increases substantially. Estimates using the 4-year interval were not significant, and the test had significantly lower power.

Appendix table 2

## Variables used in the growth models

| Variable | Label |
|---|---|
| Change in per capita income 2000–2008[1] ($/capita) | dpci |
| Change in per capita employment 2000–2008[1] (jobs/capita) | demp |
| Change in installed wind capacity 2000–2008 (MW/capita) | mwcap |
| Technical wind resource potential (power class 3-7, MW) | twrp |
| Per capita income ($)[1] | pci |
| Population (thousands)[1] | pop |
| Poverty rate (percent)[2] | poverty |
| Natural amenity scale[3] | nascale |
| Agriculture, forestry, fishing, and hunting share of employment[1] | agffh |
| Construction share of employment[1] | const |
| Manufacturing share of employment[1] | manuf |
| Retail & trade share of employment[1] | retrade |
| Adult population (25 yrs >) with associates degree (percent)[2] | pedas |
| Adult population (25 yrs >) with bachelors degree (percent)[2] | pedbs |
| Adult population (25 yrs >) with masters degree (percent)[2] | pedms |
| Population density (persons per square mile)[2] | popdens |
| Amount of Interstate highway (miles)[4] | interst |
| Distance to nearest urban population of 25,000(miles)[5] | d25k |
| Distance to nearest urban population of 100,000 (miles)[5] | d100k |
| Distance to nearest urban population of 250,000 (miles)[5] | d250k |
| Distance to nearest urban population of 500,000 (miles)[5] | d500k |
| Distance to nearest urban population of 1,000,000 (miles)[5] | d1000k |
| Unemployment rate (percent)[6] | uer |
| Farmland share of total acres[7] | farmland |
| Population weighted distance to highway on-ramp (km)[5] | hwyaccess |
| Rural population share[2] | rurpopsh |
| Farmer population share[2] | frmpopsh |
| African American population share[2] | afrpopsh |
| Child population share[2] | chdpopsh |
| Elderly population share[2] | eldpopsh |
| Share of adult men working full time[2] | wfullmsh |
| Share of adult women working full time[2] | wfullwsh |
| Metro county (yes/no)[8] | metro |

Notes: N = 1,009; Source: [1] U.S. Department of Labor, Bureau of Economic Analysis, REIS; [2] U.S. Census Bureau, 2000 Census; [3] USDA, Economic Research Service; [4] U.S. Department of Transportation; [5] ERS Geographic Information Systems team calculations; [6] U.S. Department of Labor, Bureau of Labor Statistics; [7] U.S. Census Bureau, U.S. Counties; [8] U.S. Office of Management of Budget.

Source: Brown et al. (2012).

Appendix table 3

### Change in per capita income 2000-08

| | OLS | | IV Estimation | |
|---|---|---|---|---|
| Variable | Coefficient | Robust S.E. | Coefficient | Robust S.E. |
| mwcap | 9,326.30** | 4,858.10 | 11,150.05** | 5,410.78 |
| pci | 457.74*** | 159.19 | 458.89*** | 162.51 |
| pop | -2.05 | 1.27 | -2.05 | 1.30 |
| poverty | 3.65 | 105.96 | 6.69 | 108.20 |
| nascale | 150.71 | 131.31 | 151.06 | 134.11 |
| agffh | -17,346.00*** | 6,018.60 | -17,383.61*** | 6,149.17 |
| const | -12,938.00 | 9,232.60 | -12,648.34 | 9,432.33 |
| manuf | -24,799.00*** | 2,881.70 | -24,740.39*** | 2,944.06 |
| retrade | -7,169.80 | 9,242.90 | -7,069.71 | 9,440.70 |
| pedas | 215.86** | 95.44 | 215.64** | 97.52 |
| pedbs | -47.69 | 91.53 | -48.18 | 93.47 |
| pedms | -400.69*** | 153.90 | -399.62** | 157.24 |
| popdens | -0.09 | 0.92 | -0.09 | 0.94 |
| metro | -1,467.80*** | 366.43 | -1,458.50*** | 374.42 |
| uer | 261.29 | 170.40 | 259.04 | 174.95 |
| interst | 10.22 | 8.54 | 10.20 | 8.73 |
| farmland | 1,245.50 | 915.45 | 1,254.78 | 935.34 |
| hwyaccess | 10.25* | 5.49 | 10.28* | 5.61 |
| d25k | -3.74 | 4.51 | -3.78 | 4.61 |
| d100k | 3.14 | 3.20 | 3.15 | 3.27 |
| d250k | -1.89 | 2.57 | -1.90 | 2.63 |
| d500k | 3.21*** | 1.13 | 3.24*** | 1.16 |
| d1,000k | -0.35 | 0.71 | -0.36 | 0.73 |
| rurpopsh | 2,206.10*** | 828.51 | 2,194.24*** | 846.41 |
| frmpopsh | 1,0340.00 | 6,336.60 | 1,0331.45 | 6,469.94 |
| afrpopsh | 2,427.70 | 3,134.50 | 2,519.21 | 3,200.89 |
| chdpopsh | -19,243.00** | 8,823.80 | -19,247.39** | 9,013.07 |
| eldpopsh | -3,740.70 | 8,182.10 | -3,592.00 | 8,353.54 |
| wfullmsh | 20,288.00*** | 5,134.90 | 20,409.65*** | 5,246.88 |
| wfullwsh | -17,788.00*** | 4,961.00 | -17,810.95*** | 5,068.54 |
| constant | 6,011.40 | 6,330.20 | 5,832.22 | 6,464.29 |
| | | | | |
| Adj. $R^2$ | 0.38 | | 0.41 | |
| F-test (IVs) | – | | 9.26*** | |
| Hansen J | – | | 7.30 | |

Note: “Variable” column terms are defined in appendix table 2.

Source: Brown et al. (2012).

Appendix table 4

## Change in per capita employment 2000-08

| | OLS | | IV Estimation | |
|---|---|---|---|---|
| Variable | Coefficient | Robust S.E. | Coefficient | Robust S.E. |
| mwcap | -0.0655 | 0.1000 | 0.4817* | 0.2812 |
| pci | 0.0028* | 0.0016 | 0.0031* | 0.0016 |
| pop | -0.00002 | 0.00001 | -0.00002 | 0.00001 |
| poverty | -0.0001 | 0.0012 | 0.0008 | 0.0013 |
| nascale | 0.0009 | 0.0015 | 0.0010 | 0.0016 |
| agffh | -0.0989 | 0.0784 | -0.1101 | 0.0819 |
| const | -0.2971*** | 0.1128 | -0.2102* | 0.1183 |
| manuf | -0.2200*** | 0.0387 | -0.2023*** | 0.0403 |
| retrade | -0.2195* | 0.1207 | -0.1895 | 0.1237 |
| pedas | -0.0006 | 0.0014 | -0.0007 | 0.0015 |
| pedbs | -0.0019 | 0.0014 | -0.0021 | 0.0014 |
| pedms | -0.0012 | 0.0033 | -0.0009 | 0.0034 |
| popdens | -0.00002 | 0.00001 | -0.00002 | 0.00001 |
| metro | -0.0181*** | 0.0053 | -0.0153*** | 0.0054 |
| uer | 0.0019 | 0.0023 | 0.0013 | 0.0026 |
| interst | 0.00002 | 0.0001 | 0.00001 | 0.0001 |
| farmland | -0.0363*** | 0.0114 | -0.0335*** | 0.0119 |
| hwyaccess | 0.00001 | 0.00006 | 0.00002 | 0.0001 |
| d25k | -0.00006 | 0.00005 | -0.0001 | 0.0001 |
| d100k | 0.00002 | 0.00004 | 0.00002 | 0.00004 |
| d250k | -0.00002 | 0.00003 | -0.00002 | 0.00003 |
| d500k | 0.00001 | 0.00001 | 0.00002 | 0.00001 |
| d1,000k | 0.000001 | 0.00001 | -0.000003 | 0.00001 |
| rurpopsh | 0.0047 | 0.0102 | 0.0011 | 0.0107 |
| frmpopsh | 0.0333 | 0.0675 | 0.0308 | 0.0778 |
| afrpopsh | -0.0561 | 0.0467 | -0.0287 | 0.0475 |
| chdpopsh | -0.2001* | 0.1183 | -0.2015* | 0.1216 |
| eldpopsh | 0.0413 | 0.0868 | 0.0859 | 0.0902 |
| wfullmsh | 0.2839*** | 0.0778 | 0.3205*** | 0.0849 |
| wfullwsh | -0.1262* | 0.0678 | -0.1330* | 0.0712 |
| constant | 0.0037 | 0.0808 | -0.0500 | 0.0829 |
| | | | | |
| Adj. $R^2$ | 0.21 | | 0.21 | |
| F-test (IVs) | – | | 9.26*** | |
| Hansen J | – | | 1.08 | |

Note: “Variable” column terms are defined in appendix table 2; OLS = ordinary least squares; IV = instrumental variables.

Source: Brown et al. (2012).

The final specification from which the matching variables were selected is provided in appendix table 5.

Matching protocols are sensitive to possible contamination of candidate control counties by treatment counties. To minimize this possibility, we remove all counties that are adjacent to counties with ethanol plants as possible controls. Adjacent counties with no ethanol plant may still see employment growth related to a new plant if they supply a large share of feedstock or a large share of employees. Our dataset utilizes a place of employment geography that assigns direct employment effects to treatment counties correctly, but induced effects may occur in neighboring counties where workers reside or spend income. Removing these adjacent counties as potential controls ensures that employment growth differences are not diluted by uncontrolled spillover effects.

Our matching algorithm minimizes the Mahalanobis distance between treatment and selected control observations (Rubin, 1979). In contrast to the conventional algorithm that optimizes matches across all observations, we utilize a "greedy" match algorithm that better suits the highly variable nature of the "treatment" or direct employment across counties (Mayo Clinic, 2003). Sorting plants by descending employment size (from 80 to 5 employees), the algorithm assigns the best matches to treatment counties with the highest probability of generating detectable indirect and induced employment impacts. The match is greedy because the counties with the largest plants retain their best match even if their paired control counties would provide closer matches with counties with smaller plants. After the match is complete, differences between the variables (dependent and independent) are calculated for each matched pair. The employment growth (y) is estimated by ordinary least squares (OLS) using the differenced values as shown by:

$$y = \left[ \left( y^{t}_{i,p2} - y^{t}_{i,p1} \right) - \left( y^{c}_{i,p2} - y^{c}_{i,p1} \right) \right] = \left( X^{t}_{i} - X^{c}_{i} \right) \beta + \varepsilon,$$

where superscripts $t$ and $c$ represent treated and control counties, $i$ is the $i$th matched pair, $p_1$ and $p_2$ are the time periods 1 year before and 2 years after the ethanol plant became operational, $X$ is a vector of explanatory variables measured in 2000 levels, $\beta$ is a vector of coefficients, and $\varepsilon$ is an error term.

Appendix table 5

**County matching variables**

| Share of college graduates 25-44[1] |
|---|
| Natural amenity scale[2] |
| Employment share of farming[3] |
| Employment share of manufacturing[3] |
| Employment share of mining[3] |
| Employment share of recreation[3] |
| Indicator of population loss county from 1970 to 1980[1] |
| Urban influence code[2] |
| Level of population in 2000[3] |
| Selected industry employment in 2000[4] |

Source: [1]U.S. Census Bureau, Decennial Census; [2]USDA, Economic Research Service; [3]County Business Patterns; [4]U.S. Department of Labor, Bureau of Labor Statistics, QCEW.

This approach helps ensure that any remaining differences in employment growth between the treated (counties that received an ethanol plant) and the control (counties without an ethanol plant) are due to the ethanol plant. The following table shows the descriptive statistics of the variables used in the differenced employment growth equation as well as the estimation results (see appendix table 6 and appendix table 7).

## Counties With Multiple Emerging Industries

The employment estimates for each energy industry did not consider the possibility that multiple industries may be emerging in the county. This could affect the empirical estimates if, for example, natural-gas boom counties were systematically more or less likely than other counties to have wind power. Here we briefly assess the potential for industry overlap to affect our estimates.

Of the three States considered in the natural gas study, Wyoming had no ethanol plants and Colorado and Texas had 3 and 4, indicating little overlap. In considering wind-natural gas overlap, figure 1a shows that Texas was a leader in wind power development in the early 2000s. Texas counties in the top quartile for the change in gas production (the definition of a boom county) were less likely to experience wind development. Of Texas boom counties, 4 percent were also wind counties, while 13 percent of nonboom counties were wind counties. The positive effect of wind development on employment combined with the greater prevalence of wind in nonboom counties would tend to lower the employment estimates associated with a natural gas boom.

Appendix table 6

**Descriptive statistics of variables used in growth equation**

| | Mean | StdDev |
|---|---|---|
| Growth rate treatment | 0.0461 | 0.1561 |
| Growth rate control | -0.0276 | 0.1566 |
| Diff employment growth | 35.761 | 105.698 |
| Ethanol employment | 31.41 | 14.82 |
| Diff initial selected employment | 209.869 | 470.22 |
| Diff college graduates | 2.49 | 7.51 |

Source: USDA, Economic Research Service tabulations.

Appendix table 7

**Differences in employment growth for selected industries**

| | Coefficient | S.E. | t - value | Pr(>\|t\|) | 95% Conf. Interval |
|---|---|---|---|---|---|
| Intercept | -46.37 | 35.35 | -1.31 | 0.197 | |
| Ethanol employment | 2.559 | 1.006 | 2.54 | 0.015 | 0.529 - 4.589 |
| Diff initial selected employment | -0.030 | 0.0351 | -0.87 | 0.391 | |
| Diff college graduates | 3.258 | 2.195 | 1.48 | 0.145 | |
| | | | | | |
| F-stat | 2.82 | Adj. $R^2$ | 0.1083 | | |
| F p-value | 0.050 | N = 46 | | | |

Source: USDA, Economic Research Service tabulations.

Wind development and ethanol production may also overlap. However, of the 1,009 counties in the wind study region, only 18 had an ethanol plant, one of which was in a wind county. The few ethanol plants in the wind study region make it unlikely that any overlap would affect estimates of the wind employment effect.