Are U.S. Coal-Fired Power Plants Quantity-Quality Efficient?

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Objectives

(1) This study investigates the inclusion of quantity-quality variables including environmentally sensitive variables like ash, sulfur and heat content of coal on technical efficiency of coal-fired power plants generating electricity in the U.S.

(2) Is there (technical efficiency) difference in coal-fired power plants across states?

(3) A subsidiary objective is to look at the changes in the technical efficiency patterns across plants within North Dakota generating electricity using coal for the same time period.

Motive and Background

- **Coal plays a vital role in electricity generation worldwide.**

- **Coal-fired power plants currently fuel 41 percent of global electricity.**

- **According to the 2012 International Energy Agency report, South Africa fuels 93 percent, followed by Poland at 87 percent and China at 79 percent, while U.S. fuels 45 percent and Germany fuels 41 percent.**

- **For the first time in two decades, U.S. coal production fell below one billion short tons to 984.8 million short tons in 2013 from 1,016.5 million short tons in 2012.**

Motive and Background

- **Production in the Western Region, which represented about 53.8 percent of total U.S. coal production in 2013, totaled 530.2 million short tons. (U.S. Energy Information Administration, 2015)**

- **While U.S. coal exports decreased, domestic coal consumption increased 4.0 percent to 924.4 million short tons, an increase of 35.3 million short tons.**
- **The electric power sector consumed about 92.8 percent of the total U.S. coal consumption in 2013.**
- **The reason for this increase in demand and lower supply could also be linked to average sales price of coal from U.S. mines which decreased from $39.95 per short ton in 2012 to $37.24 per short ton in 2013 (6.8 percent lower than 2012).**
- **However, given this increase in domestic coal consumption, the issue of efficiency in coal use for electric power production remains relevant.**

Motive and Background

- **The competitiveness of electricity generation by coal-fired plants is affected by the fuel supplied, operating heat rate or heat content of the coal along with ash and sulfur emissions, rate of innovations/adoption and to a large extent the quantity-quality production efficiency of power plants.**

- **Operating heat rate, the amount of electricity produced per btu of fuel has been decreasing for coal, in part due to the loss of efficiency caused by the installation of scrubbers which have been installed to meet environmental regulatory requirements.**

Motive and Background

- **The use of emissions-reducing technology has been increasing since the passage of the Clean Air Act in 1970.**
- **The environmental benefits of these emissions-reducing technologies comes with a cost. There is a loss of efficiency as they require electricity to operate.**
- **The resulting parasitic load, electricity used internally by the power plant, is no longer available to customers. The parasitic load of scrubbers is typically two percent of output (Bellas and Lange 2008).**
- **Although coal is a relatively low-cost fuel, new regulations including mercury, sulfur, NO_2, have increased the cost of coal-fired electricity.**

Why North Dakota?

- **North Dakota is one of the least populated states but having one of the largest per capita gross domestic product in the United States. This is, in part, due to the oil boom in Williston Basin that includes the Bakken shale formation.**

- **North Dakota has other fossil energy resources, including the single largest known deposit of lignite in the world. Plus, biofuels-ethanol.**

- **Even with the push for clean energy production in the U.S. and North Dakota alike, these alternative energy source are not necessarily mutually exclusive. For example, an ethanol plant in western North Dakota teams with an electrical generation plant to use waste water heat to form a highly efficient plant.**

- **Of course, the three authors live in ND ☺**

Methods

- **Unlike the traditional primal production function that used quantity of inputs, this research differentiates the inputs into quantity variables x and quality variables z.**
- **The quantity variables includes the main ingredient, coal fuel used electricity by the boiler plants. Production theory suggests, the higher use of the traditional quantity inputs should lead to higher output.**
- **In contrast the quality variables include heat content, sulfur and ash content.**
- **To address the environmental aspects of sulfur and ash, the inverse of the two variables were used in the analysis. As positive sign of these variables indicates sulfur and ash negatively impact electricity generation by coal-fired plants.**

Methods

- Following Greene (2005), the true random effect (tre) panel stochastic frontier analysis (SFA) is used and primal production function is estimated:

$$y_{it} = f\,((\alpha + w_i),\ \mathbf{x};\ \beta,\ \mathbf{z};\ \gamma) + v_{it}\ -\ u_{it}$$

- y represents an endogenous dependent variable in logs;
- x is a vector of k = 1,…., n exogenous traditional inputs in logs;
- z is a vector of k = 1,…, m exogenous quantity and quality inputs in logs and technology represented by time trend used in the production function;
- beta and gamma are coefficients associated with inputs;
- pure random error *v* and negatively skewed one-sided inefficiency *u* that may be represented by alternative distributions including half normal, exponential, or truncated normal;
- *i* is counties, *t* is time and w_i is a time invariant and firm specific random term.

Data

- **Data for the analysis comes from the U.S. Energy Information Administration's survey EIA-923. This survey collects detailed monthly and annual electric power data on electricity generation, fuel consumption, sulfur and ash content at the power plant and prime mover level.**
- **Electricity power generated by plant measured in megawatts (MW).**
- **Coal used as fuel is reported in short tons on an as-received dry basis.**
- **The heat content of the coal reported as the actual average Btu for coal purchased in million (MMBtu) per ton is used as the second input variable.**
- **The sulfur and ash content of the fuel is in terms of percentage (to the nearest 0.01 percent) by weight.**
- **Considered the number of boiler plants in each state from 2008 to 2013 as reported by EIA in its EIA-923 database.**

Empirical Estimation: The translog production function

$$Electricity\ Generation_{it} =$$

$$(\alpha + w_i) + \beta^1\ fuel_{it} + \beta^2\ heat_{it} + \beta^3\ sulfur_{it} + \beta^4\ ash_{it} + \text{Trend} +$$

$$\gamma^{11}\ \tfrac{1}{2}\ (fuel)^2_{it} + \gamma^{12}\ (fuel_{it} * heat_{it}) + \gamma^{13}\ (fuel_{it} * sulfur_{it}) + \gamma^{14}\ (fuel_{it} * ash_{it}) +$$

$$\gamma^{22}\ \tfrac{1}{2}\ (heat)^2_{it} + \gamma^{23}\ (heat_{it} * sulfur_{it}) + \gamma^{24}\ (heat_{it} * ash_{it}) +$$

$$\gamma^{33}\ \tfrac{1}{2}\ (sulfur)^2_{it} + \gamma^{34}\ (sulfur_{it} * ash_{it}) +$$

$$\gamma^{44}\ \tfrac{1}{2}\ (ash)^2_{it} + (\text{Trend})^2 + v_{it} - u_{it}$$

Notation

Note:

- i and t represent the number of coal fired individual plants and years,

respectively;

- an exponential distribution of u (inefficiency part of the error term) is assumed in the analysis;
- all the variables, inputs and output are in logarithms, so the parameter coefficients are elasticities.
- It is to be noted, the quality variables - sulfur and ash are measured as the logarithm of inverses of their percent by weight in the model. The magnitude of the parameter coefficient of sulfur and ash is the same, but the sign is the opposite.

Results

- **Note: Table too cumbersome (large) to present on a PP slide; paper available per request. Only main results reported here.**

- **There is a positive and statistically significant relationship between fuel and the amount of coal-fired plants generating electricity. A one percent increase in fuel used by the power plant will increase electricity generation by 0.869 percent.**

- **The square of fuel is positive and statistically significant suggesting the use of fuel is increasing at an increasing rate of 0.021 percent to produce electricity.**

Results: Impact of the Input Quality Variables

- **The quality of the fuel in the terms of the heat content has also positive and significant impact: A one percent increase in the heat content will increase electricity generation by 3.309 percent.**

- **In contrast, the square of heat content is negative and significant suggesting increasing at a decreasing rate by 0.569 percent.**

Results: Impact of the Input Quality Variables

- **Positive relationships between the sulfur and ash coefficients are as expected as these are introduced as inverses: A one percent increase in sulfur and ash will decrease electricity generation by 0.322 percent and 2.735 percent, respectively.**

- **This suggests, compared to sulfur, ash has higher negative effect on electricity generation. So a slightly lower content of ash will lead to higher production of electricity.**

- **The square term of sulfur and ash is positive and statistically significant suggesting decreasing at a decreasing rate of 0.079 and 0.117 percent, respectively.**

Results: Impact of the Technology

- **The technology of coal-fired plants represented by the trend coefficient has a negative sign meaning that on average plants are becoming less efficient. This is not surprising given the industry's declining average operating heat rate which is occurring in part because of the use of scrubbers.**

- **In addition, the square term of trend is negative and significant suggesting the technology is decreasing at a decreasing rate. This is happening in spite of lower investment in developing technologies in coal industry due to negative stereotype or pessimism about the long-term viability of coal power in the face of increasing regulation. This need to be conveyed to the policy maker and more so the coal industry.**

Results: Interaction Terms

- **With respect to the interaction terms of the translog production function, all the variables are negative and also statistically significant with the exception of fuel-sulfur and heat-trend interaction.**

- **Interpretation: This suggests the interaction terms are increasing (decreasing) at a decreasing rate if the individual variables are positive (negative).**

Technical Efficiency Measures by State

- **Plant efficiency varies greatly across the country.**

- **This is best seen by looking at the maximum and minimum efficiency for each state. Kentucky and Michigan had among the least efficient plants while Minnesota, New York, and Wisconsin have among the most efficient.**

Technical Efficiency Measures by Plant by Year in ND

- **North Dakota's coal-fired power plants are in the middle range of efficiency (relative to other states in the Union) and are consistent.**

- **The efficiency of each plant in North Dakota is near the national industry average.**

- **There are only small fluctuations in efficiency across the period, with no sign of a trend.**

Conclusion

- **In this study the relative efficiency of U.S. coal power plants was estimated using data from EIA survey 923 for years 2008-2013.**
- **Stochastic frontier analysis proved a suitable method to estimate the relative efficiency of individual coal-fired plants generating electricity.**
- **This study used quantity-quality inputs to estimate a translog production function.**
- **The parameter coefficient of primary, square and interaction terms of the translog production function of coal-fired plants provided signs and estimates consistent with theory and expectations.**

Conclusion

- **The technology defined by time trend also provided consistent estimates for the coal-industry. Estimation of a negative time trend coefficient may be explained by the use of scrubbers which allow plants to meet emissions standards, but decrease efficiency.**

- **The analysis finds that North Dakota coal-fired power plants have efficiency near the national average and are relatively consistent performers over time. This result is of importance to policy makers and more importantly to coal industry in the region.**

Caveats and Potential for Future Research

- **There is a need to evaluate the role of ownership, state and federal regulations on inefficiency, i.e., enlarge the model and make it more complex and robust.**

- **With respect to modeling of stochastic frontier analysis, there is a need to evaluate the robustness of the alternative distributions of the inefficiency term, *u*. Recall: exponential distribution used here, but alternatives such as half-normal or truncated normal are plausible.**

- **Finally, the importance on technical (quantity) and economic (price) efficiency needs to be evaluated using the dual cost and profit functions, unlike estimated primal production function here.**