***SUBSTITUTING WIND FOR COAL: THE EFFECTS OFAN INCREASING SHARE OF WIND IN THE UNITED STATES***

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## Overview

Electricity generation in the United States has traditionally been dominated by coal; however, there has been a large degree of inter-fuel substitution in the past several years due to falling natural gas prices and advancements made in renewable energy technologies. For example, in South Dakota the share of wind generation increased from below 1 percent in 2000 to over 22 percent in 2011. As the share of renewable generation increases, it follows that other fuels must be displaced. Several recent studies have attempted to determine which fuels are most likely to be displaced (such as Kaffine et al. [2013]). The goal of this paper is to evaluate the effects of increasing electricity generation from wind on the electricity generation share of coal. Specifically, it asks whether or not increasing wind generation causes coal displacement, and if so, whether the effect varies by region. The estimation methodology uses interaction variables for the coal to gas price ratio and wind generation as well as interaction terms for the 8 regions of the North American Electric Reliability Council (NERC) to test if there are specific regional effects from increasing the share of wind generation. Two models, a log model and a model using generation shares, are estimated using data for a panel of 46 states over a 15 year period (from 1997-2011).

## Methods

To answer the basic question of the effect of wind on coal generation, the following model is proposed:

$$C\_{it}=β\_{0}+β\_{1}P\_{c,it}+β\_{2}P\_{g,it}+β\_{3}W\_{it}+β\_{4}W\_{it}P\_{it}+δD\_{w,it}+\sum\_{k=2}^{n=8}θ\_{k}N\_{k}W\_{it}+a\_{i}+ϵ\_{it}$$

Where *Cit* is electricity generation from coal (in state *i* in year *t*), *Pg* is the natural gas price, *P­c* is the coal price, *Wit* is electricity generation from wind, *Dw,it*is an indicator variable for positive wind generation, *Nk* is an indicator variable equal to one for NERC region *k*, *a­i* is a collection of unobserved (and time-invariant) fixed effects for each state, and *ϵit* is the error. This model is estimated using two main specifications: one which uses logged variables and another which uses share variables for coal and wind generation. It is also assumed that there are fixed effects across states, as there are certain time-invariant characteristics which vary, such as policies, resource endowments, and other unique characteristics.

Due to the inclusion of interaction terms, the total effects on coal generation cannot be directly interpreted from their coefficients, however, it is expected that their total effects will be less than zero. That is, it is expected that $\frac{∂C\_{it}}{∂W\_{it}}=β\_{3}+β\_{4}P\_{it}+θ\_{k}<0$ and $\frac{∂C\_{it}}{∂P\_{cit}}=β\_{1}+β\_{4}W\_{it}<0$. It is also expected that the signs on the natural gas price and the wind indicator variable are positive and negative, respectively.

## Results

Using panel data with electricity generation-related variables from the US Energy Information Administration for 46 states over the period from 1997-2011 (15 years), the results indicate that the expectations of the overall effect of increasing wind generation is correct (i.e. negative) for the model using the share specification for most of the NERC regions, however, the effect in the NPCC is positive (and significant). This implies that increasing wind generation actually increases coal generation in the NPCC. Specifically, a 1 unit increase in the wind generation share (i.e. from 10 to 11 percent) yields a .72 unit *increase* in the coal share for states in that region. The expected signs are found for the other variables in the model, although none of the other NERC interaction terms are significant.

The log specification is different, showing that the effect in the NPCC is negative (the other NERC regions have positive effects, but none of them are significantly different from zero). For the NPCC, the elasticity of coal generation with respect to wind is estimated to be -.11. For all regions, the elasticity with respect to the relative price is -.301. Both of these estimates are highly inelastic, particularly the estimates for the elasticity with respect to wind generation.

Additionally, a Hausman test confirms that the fixed effects estimation methodology is appropriate.

## Conclusions

The results confirmed the expected result that increasing wind generation decreases coal generation, and does so by more in certain NERC regions than in others. Specifically, the log model found that in the NPCC, increasing wind generation by 10 percent leads to a decrease in generation from coal by .11 percent, compared to insignificant increases for other regions. This analysis gives a detailed account of the differences between the different NERC regions and compares the differences in the results from the log and share models. In addition, a simple sensitivity analysis is carried out for the share model by altering the values of the wind share for evaluating effects of price on coal generation and by altering the values of the relative price for evaluating effects of the wind share. Overall, the paper is successful in developing a model which accounts for some of the impacts of increasing wind generation on the coal industry.

## Selected References

Kaffine, Daniel T., Brannin J. McBee, Jozef Lieskovsky (2013), “Emissions savings from wind power generation in Texas,” *Energy Journal*, Vol. 34, No. 1.