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Substitution in the electric power industry: An interregional comparison in the eastern US

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ABSTRACT

The electric power industry is restructuring as regulations move from states to regional and national levels. Estimates of regional fuel and input substitution are essential for practitioners and policy makers. This paper estimates substitution under static and dynamic scenarios, examining changes in technology and total factor productivity from 2001 to 2008. Two-stage estimation reveals regional characteristics and underlying elements in fuel and factor choice processes. Substitution varies widely depending on the region, coal technology, capital investment, and R&D activities.

1. Introduction

Energy plays a crucial role in the global economy and will become the major economic issue of the coming century. A variety of policies have been initiated to promote improvements in energy efficiency and encourage development of alternative energy resources. The electric power industry is one of the largest consumers of fossil-fuel energy. Given the potential for substitution between factors of production (Söderholm, 2000a), the responsiveness of electric utilities to fluctuations in the prices of other fuel inputs and factor inputs is important for energy suppliers as well as for policy authorities to improve energy efficiency and promote energy conservation. Further, considering that the majority of emissions (particularly carbon dioxide) are caused by the combustion of hydrocarbons, the ability to switch fuels in the electric power industry becomes a major target and tool for environmental policy makers. For instance, the Energy Policy Act of 2005 supports increasing coal as an energy resource in conjunction with reducing air pollution by clean coal initiatives.

According to the Annual Energy Review of the Energy Information Administration (EIA), in 2008 the electric power sector accounted for 91% of all coal consumption and 29% of all natural gas consumption in the US, while fossil fuels (coal, petroleum, and natural gas) accounted for 71% of all electricity net generation. Fuel choices and factor alternatives in electricity generation are important issues in energy policy. Based on the fact that the electricity generation industry is restructuring and regulation is moving from state to regional and national levels, accurate estimates of fuel and factor use in interregional electricity generation are essential for policy makers and planners.

Several studies using various estimation models and samples have been devoted to the analyses of energy production and fuel/factor substitution in energy generation. Attention has been mostly given to national studies or international comparisons of interfuel substitution in the electric power industry. No previous research has estimated regional fuel or factor substitution in electricity generation specifically for the eastern regions of the US. In addition, this is the first study to apply a two-stage model to account for both energy and non-energy inputs in electric power generation under both static and dynamic scenarios.

Considerable diversity exists among electricity-producing regions due to their complex histories of energy resource development. Because regional differences would be lost in aggregation, national estimates mask this regional variation. Ignoring differences across regions could introduce bias in model estimation and lead to inappropriate policies. Uri (1977) pointed out that different regions may respond differently

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to price changes, due to the technology involved in changing existing multifuel plants from one fuel to another. Given that studies using aggregate data implicitly assume that responses are homogeneous across utilities, whereas fuel-switching capacity varies considerably across regions, Dahl and Ko (1998) recommended that analysis of substitution patterns be conducted at the more-disaggregate, regional level. Policy makers should take into consideration these different patterns of substitution in disparate regions when they decide to employ taxes or subsidies, otherwise one region could be disadvantaged by a policy that is favorable for another region.

The focus of this study is to compare regional results from the two-stage estimation method and to reveal regional characteristics and underlying elements in fuel and factor choice processes. The results show widely-varying elasticities of substitution depending on the regions considered. As a by-product of this analysis, technology changes and total factor productivity are also examined to compare production efficiencies and provide policy implications for different regions so that decision makers can efficiently allocate energy resources.

The organization of the paper is as follows. Section 2 gives a summary of previous studies on interfuel and interfactor substitution analyses. Sections 3 and 4 include discussions of the theoretical model and data sources. Section 5 presents the empirical results.

2. Literature review

Most previous studies of interfuel and interfactor substitution in the electric power industry employed aggregate data at the national level. For example, Atkinson and Halvorsen (1976b), Griffin (1977), Hudson and Jorgenson (1974), Mountain (1982), Söderholm (2000a, 2000b, 2001), Pettersson et al. (2012) and Uri (1978) all used aggregate national data. Only two studies have used US regional data and no previous regional study has focused on the eastern part of the US. Uri (1977) analyzed fuel substitution for nine US census divisions. Bopp and Costello (1990) compared elasticities for five US geographic regions with national elasticities. However, the data employed in those two regional analyses were based on geographic census divisions which did not consider the regional characteristics and regulatory structure of the electricity markets.

Among the attempts to model the energy sector, Hudson and Jorgenson (1974) were the first to conduct an econometric study of hydrocarbon demand. Using a translog cost model with US annual data from 1947 to 1971, they showed that oil demand was price elastic while coal and gas demand were inelastic. The cross elasticities suggested that the three fuels were substitutes, however coal and oil were much stronger substitutes ($e^*_{CO} = 1.09$) than oil and gas ($e^*_{OG} = 0.39$) or, coal and gas ($e^*_{CG} = 0.09$) (Table 1).

To estimate interfuel substitution elasticities in the European electric power industry, Griffin (1977) incorporated a polynomial distributed lag into the translog model and applied a translog cost function to the data from 20 OECD countries for 1955, 1960, 1965, and 1969. His results showed larger price elasticities with cross sectional data than with time series data, probably because the time series results reflect only a partial adjustment to a new equilibrium.

Uri (1977) applied pooled time series analysis to nine US census divisions from 1952 to 1974. In a subsequent paper Uri (1978) conducted a similar study with aggregate monthly data covering 1974 to 1976. He suggested that the resulting smaller elasticities were the effect of estimation in the short run compared to his earlier long run estimates.

Using pooled time series data from 1964 to 1975 for two districts in Canada, Mountain (1982) employed a translog cost function with imported electricity as an additional input variable. He demonstrated strong substitution between domestic and imported electricity, and between coal and oil in the short run.

Bopp and Costello (1990) conducted a monthly time series analysis from 1977 to 1987 with two translog cost function models: one for five US geographic regions, the other for the entire US. The empirical results showed that oil was own-price elastic while gas was inelastic. The latter result was expected as it is known that gas is typically a peak fuel for generators designed to run during busy times. The results also demonstrated that the price elasticities were lower in the regional model than in the aggregate.

Dahl and Ko (1998) estimated short-term interfuel substitution in the US electric power industry by employing the translog and logit cost share models with monthly data from 1991 to 1993. They found coal demand to be the least elastic, and gas and oil demand the most elastic. Their results also illustrated interfuel substitution varying according to market and regulatory conditions.

Söderholm (2000a) conducted a pooled annual aggregate national analysis for seven European countries using a translog cost function for the years 1978–1995. The results showed strong substitution between gas and oil. Söderholm (2000b) employed a regulatory intensity variable as an exogenous variable and estimated a generalized Leontief cost function with the same dataset. The results showed significant interfuel substitution in European electricity production and the estimation from the perspective of regulation intensities showed that it was hard to separate the individual effects of the SO_2 regulations.

Söderholm (2001) applied a restricted translog cost function to estimate short-run interfuel substitution in six west European countries by using pooled time series from 1984 to 1994 and aggregate national data. The study also included, as an independent variable in the cost function, a measure of annual system load. The results show substantial interfuel substitution especially between oil and gas, as well as a significant positive effect from the system load factor on increased use of coal and decreased use of oil saving.

Pettersson et al. (2012) employed a Generalized Leontief cost function to analyze the role of fuel switching behavior and of public policies in influencing fuel choices in the western European power sector, using pooled data across eight countries from 1978 to 2004. They found significant interfuel substitution between oil and gas and suggested that fuel substitution is intensified: 1) in dual-fired and multi-fired plant; 2) by distributing load among different mono-fuel plants; and 3) by converting existing plants to alternative fuels. They also noted that national policies such as elimination of coal subsidies and liberalization of electricity markets have had notable impacts on fuel choices.

In addition to aggregate-level analysis, some research has also been devoted to micro-level analysis in order to characterize the fuel choice in individual electricity generating plants or firms. Atkinson and Halvorsen (1976a), Considine and Larson (2006), Haimor (1981), Ko and Dahl (2001), Lee (2002), and Tuthill (2008) used micro-level data from the US, while Tauchmann (2006) analyzed firm-level data from Germany.

Table 1 compares the data, models and elasticities from the selected studies. A limitation of the estimation method in most of these studies arises when interfuel substitutions are estimated assuming exogenous energy aggregates. Because fuel price changes almost certainly stimulate substitution among both fuels and factors of production, omitting this feedback may lead to erroneous policy implications.

While the current study is the first application in the electricity sector of a two-stage translog model that incorporates feedback effects between interfactor and interfuel substitutions, this is a well-established method for determining fuel substitution elasticities in the manufacturing sector. Andrikopoulos et al. (1989), Cho et al. (2004), Ma et al. (2008) and Pindyck (1979) all used this method to examine industrial interfuel substitution. A comparison of their data and main results is shown in Table 2. All of those studies employing two-stage translog functions and panel data show inconclusive substitution results for different countries.

For the electric power industry, however, only two firm-level studies employed two-stage decisions. In a study with firm-level data from Canada, Mountain (1982) estimated the optimal quantities of imported and domestic electricity in the first stage and then, treating the quantity