Substitution in electricity generation: A state level analysis of structural change from hydraulic fracturing technology

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Electricity sector plays a crucial role for economic growth in high as well as low income economies (Dalgaard and Strulik, 2011; Apergis and Payne, 2011). Electric power industry also is one of the major contributors to greenhouse gas emissions. In the US electricity production constitutes roughly a third of greenhouse gas emissions via fossil fuel consumption (EPA, 2014). Numerous policies have been introduced to improve energy efficiency and/or promote renewable/clean energy development initiatives including but not limited to Energy Policy Act of 2005, Climate Action Plan of 2013, and Clean Power Plan of 2014. In 2015 the EPA finalized the carbon dioxide emission standards for existing as well as new power plants pursuant to section 111(d) of the Clean Air Act. Aiming at 30% reduction in carbon dioxide emissions relative to 2005 levels by 2030, the guidelines set state specific limits in terms of pounds of carbon dioxide emissions per megawatt-hour of net electricity generation. Richels and Blanford (2008) argue that low carbon electricity production can facilitate the efforts to reduce carbon emissions and decrease the costs of achieving carbon emission reductions in other sectors of the economy. Because of the ability of the electric power industry to respond to changes in regulatory environment and relative fuel prices, in part by adjusting fuel mix in electricity generation, it is important for the policy makers as well as industry to understand evolving fuel substitution capabilities. State level estimates of fuel price and substitution elasticities in electricity generation sector are important for policy making and planning purposes because policies like the Clean Power Plan of 2014 are often state specific, and because institutional and regulatory contexts differ across states. Furthermore, because of significant regional differences in terms resource endowments, historical evolution of energy sectors and policy, and technological differences, regional heterogeneities can have significant implications for policy effectiveness. Studies using aggregate data to evaluate substitutability of fuels in electricity generation implicitly assume homogeneity of policy implications across regions and can produce biased estimates at regional and sub-regional levels potentially leading to policies which may be suboptimal at regional levels. Consequently, understanding regional and sub-regional patterns of substitution at disaggregate, sub-regional, scales is important and has been recommended (Uri, 1977; Dahls and Ko, 1998; Gao et al 2013).

In this study we estimate state level cross price and fuel substitution elasticities in electricity generation sector in the US. Substitution patterns of fossil fuel utilization in electricity generation has been studied at regional levels. Gao et al. (2013) examined substitutability between oil, natural gas, and coal in electricity generation across seven electricity generation regions in the US using annual region level data from 2001 to 2008. However, none of the previous studies examined state level patterns of substitution. We also examine the state level structural change in fuel utilization in electricity generation due to recent increase in shale gas extraction using hydraulic fracturing technology. Estimates from previous literature suggest that from 2001 to 2008 oil was the most price elastic while coal was the least price elastic fuel at the regional level (Gao et al. 2013). It was also found that natural gas was a substitute input for coal as well as for oil to various degrees across the seven electricity generation regions in the US as considered in Gao et al. (2013). We examine whether significant heterogeneity also exists at the state level taking into account recent growth in natural gas sector in the US.

In 2015 energy in the United States was generated from coal (33%), natural gas (33%), Nuclear (20%), hydropower (6%), and other renewable sources (7%) including biomass, geothermal, solar and wind (EIA 2016a). Total electricity production in the US has increased by approximately 10% from 2001 to 2014 (Figure 1). During this period electricity generation from fossil fuels (coal, natural gas, and Oil) increased by approximately 3% while the rest of the increase is attributable to increase in renewable energy sources. In this study we focus on substitution patterns between fossil fuels and defer examination of electricity generation from renewable sources for a later study. From 2005 to 2014 extraction of natural gas has increased by 42% in the US as a result of developments in hydraulic fracturing technology. On the other hand, coal production has decreased by 17% from 2008 to 2014 (Figure 2). The decrease in coal production started before Climate Action Plan of 2013. Coal consumption in electricity generation has been declining since 2008 while utilization of natural gas has been increasing since 2005 (Figure 3). Prior to 2008 some of the increase in coal consumption has been attributed to factors like decrease in railroad freight rates and power plants' elastic demand for coal (Gerking and Hamilton, 2008). Natural gas consumption in electricity generation has been increasing since 2005. These adjustments are not surprising considering recent increase in relative costs of coal-based versus natural gas-based electricity generation (Van Kooten et al. 2012). Utilization of coal, natural gas, and coal for electricity generation at the state level is presented in figure 4. Noticeable changes can be observed in fuel mix over the past few years in Alabama, Florida, Georgia, North Carolina, New York, Ohio, and Pennsylvania. In these states increase in utilization of natural gas and decrease in utilization of coal can be observed. These states have been some of the largest electricity producing states in recent years. Figure 5 shows total electricity production by state from 2001 to 2014.

Methodology

For a cost function $C = f(P_c, P_{NG,} P_o, Y, t)$ following Shephard's Lemma (1970) cost minimizing factor demands are obtained by $x_i^* = \partial C(\mathbf{P}, Y)/\partial P_i$. Alternatively, by logarithmic differentiation we obtain factor cost share equations $s_i = \partial \ln C(\mathbf{P}, Y)/\partial \ln P_i$ (Christensen and Green, 1976; Berndt and Wood, 1975). In this study we use Translog cost function and associated cost share equations following numerous previous studies which have relied on this method to estimate elasticities of substitution (Griffin and Gregory, 1976; Taheri 1994; Berndt and Wood, 1975; Bentzen 2004). Similar to Gao et al. (2013), considering potential for the effects of time and state level heterogeneity, the full system of the cost function and corresponding cost share equations is formulated as

$$\ln C = \alpha_0 + \sum_s \alpha_s D_s + \sum_i \left(\alpha_i + \sum_s \alpha_{is} D_s \right) \ln P_i + \left(\alpha_y + \sum_s \alpha_{ys} D_s \right) \ln Y + \frac{1}{2} \left(\alpha_{yy} + \sum_s \alpha_{yys} D_s \right) (\ln Y)^2 + \sum_i \left(\alpha_{iy} + \sum_s \alpha_{iys} D_s \right) \ln P_i \ln Y + \frac{1}{2} \sum_i \sum_j \left(\alpha_{ij} + \sum_s \alpha_{ijs} D_s \right) \ln P_i \ln P_j + \left(\alpha_t + \sum_s \alpha_{ts} D_s \right) t + \frac{1}{2} \left(\alpha_{tt} + \sum_s \alpha_{tts} D_s \right) t^2 + \left(\alpha_{yt} + \sum_s \alpha_{yts} D_s \right) t \ln Y + \sum_i \left(\alpha_{it} + \sum_s \alpha_{its} D_s \right) t \ln P_i \qquad (1)$$

$$S_i = \beta_i + \sum_s \beta_{is} D_s + \left(\beta_{iy} + \sum_s \beta_{iys} D_s \right) \ln Y + \sum_j \left(\beta_{ij} + \sum_s \beta_{ijs} D_s \right) \ln P_j + \left(\beta_{it} + \sum_s \beta_{its} D_s \right) t \qquad (2)$$

with the following parameter restrictions consistent with homogeneity and symmetry assumptions (Bentzen, 2004; Christensen and Green 1976, Christopoulos ans Tsionas, 2002):

$$\sum_i \left(\alpha_i + \sum_s \alpha_{is} D_s \right) = 1; \; \sum_i \left(\alpha_{iy} + \sum_s \alpha_{iys} D_s \right) = 0; \; \sum_j \left(\alpha_{ij} + \sum_s \alpha_{ijs} D_s \right) = \sum_i \left(\alpha_{ij} + \sum_s \alpha_{ijs} D_s \right) = 0;$$

$\alpha_{ij} = \alpha_{ji} = \beta_{ij} = \beta_{ji}$; $\alpha_{ijs} = \alpha_{jis} = \beta_{ijs} = \beta_{jis}$; $\alpha_i = \beta_i$; $\alpha_{is} = \beta_{is}$; $\alpha_{iy} = \beta_{iy}$; $\alpha_{iys} = \beta_{iys}$; $\alpha_{it} = \beta_{it}$; $\alpha_{its} = \beta_{its}$.

In this specification the cost function represents electricity production at the national level, assuming factors or production across states are utilized with the objective of minimizing national costs of electricity generation from fossil fuels. Similar representation can be found in Gao et al. (2013) where a single cost function was used to represent electricity production across seven electricity producing regions.

In this study, because of limited number of observations (14 years), reduced forms of equations (1) and (2) are used. Specifically, to reduce the number of parameters to be estimated and assure sufficient degrees of freedom we estimate the system of equations where $\alpha_{ys} = \alpha_{yys} = \alpha_{iys} = \beta_{iys} = \alpha_{ts} = \alpha_{tts} = \alpha_{yts} = 0$. These restriction reduce the dimensionality of the problem by suppressing the state level interaction terms for electricity production (Y) and time (t) variables. These restrictions imply that these variables have no state specific impacts. Similar assumptions were used by Gao et al. (2013) where interaction forms of factor prices were assumed constant across production regions.   In this study, because we are interested in state level substitution, cross price, and own price elasticities we allow for heterogeneity of factor price interactions across states. However, we assume constancy of interaction between factor price and electricity generation, constancy of interaction between electricity generation and time, and constancy of the quadratic effects of electricity generation and time across states. These assumptions, though restrictive, allow for estimation of the elasticities of interest under a limited number of observations.   Hence, the system of equations used in this study reduces to:

$$\ln C = \alpha_0 + \sum_s \alpha_s D_s + \sum_i \left(\alpha_i + \sum_s \alpha_{is} D_s \right) \ln P_i + \alpha_y \ln Y + \frac{1}{2} \alpha_{yy} \left(\ln Y \right)^2 + \sum_i \alpha_{iy} \ln P_i \ln Y +$$

$$\frac{1}{2} \sum_i \sum_j \left(\alpha_{ij} + \sum_s \alpha_{ijs} D_s \right) \ln P_i \ln P_j + \alpha_t t + \frac{1}{2} \alpha_{tt} t^2 + \alpha_{yt} t \ln Y + \sum_i \left(\alpha_{it} + \sum_s \alpha_{its} D_s \right) t \ln P_i \quad (3)$$

$$S_i = \beta_i + \sum_s \beta_{is} D_s + \beta_{iy} \ln Y + \sum_j \left(\beta_{ij} + \sum_s \beta_{ijs} D_s \right) \ln P_j + \left(\beta_{it} + \sum_s \beta_{its} D_s \right) t \quad (4)$$

Seeming unrelated regression (SUR) technique is used to estimate 3 equations as a system consisting of the cost function, share equation for coal, and share equation for natural gas. Oil share equation is omitted from the estimation.

Allen partial elasticities of substitution are given by $\sigma_{ij} = CC_{ij} / C_i C_j$ where subscripts indicate partial derivatives with respect to prices of inputs i and j (Allen 1938, Uzawa 1962, Cristensen and Green, 1976). For the translog cost function, taking into account potential heterogeneity across states, elasticties of substitution are given by (Griffin and Gregory, 1976; Binswanger, 1974; Christensen and Green, 1976; Christopoulos and Tsionas 2002; Bentzen 2004; Debertin et al. 1990):

$$\sigma_{ijs} = \left(\alpha_{ij} + \alpha_{ijs} D_s + S_i S_j \right) / \left(S_i S_j \right) \quad (5)$$

while cross price and own price elasticities are given by

$$\sigma_{ijs} = \left(\alpha_{ij} + \alpha_{ijs} D_s + S_i S_j \right) / \left(S_i \right) \quad (6)$$

and

$$e_{iis} = \left(\alpha_{ii} + \alpha_{iis} D_s + S_i \left(S_j - 1 \right) \right) / \left(S_i \right) \quad (7)$$

Data

The dataset in this study is a panel of annual state level observations from 2001 to 2014 including prices and quantities of fossil fuels utilized for electricity generation, as well as total electricity generated from fossil fuels. State level use of coal, natural gas, and oil based fuels for electricity generation is obtained from EIA (2016b) and is measured in million British thermal unit (MMBTU). Oil based fuels include petroleum liquids and petroleum coke aggregated into a single variable representing oil based fuels measured in MMBTU. State level total electricity production from coal, NG, and/or oil (MWH) across production types (electric generators, commercial and industrial combined heat and power facilities) is obtained from EIA's state level data (EIA 2016c). State level prices for coal, NG, and oil in electric power sector ($/MMBTU) are obtained from EIA's SEDS database (EIA 2016d). Cost shares are computed using state level fuel prices, respective quantities used in electricity generation, and total expenditures on coal, natural gas, and oil in electricity generation at the state level. Four states (Hawaii, Idaho, Road Island, and Vermont) are excluded from the analysis because at least one of the three fuels was not used for electricity generation, and no prices are available for those fuels. These states are some of the smallest in terms of electricity generation (figure 5).

Results

Non-stationarity of the data is common in the fields of economics and finance (Hendry and Massmann, 2007; Bentzen 2004). Following previous literature we test the data for stationarity properties of the variables (Antras, 2004, Gao et al. 2013). Dickey-Fuller and Phillips-Perron tests are commonly used for stationarity tests in economic and financial time series. However, the shortcoming of these tests is the potential confusion of structural breaks in the series with nonstationarity . Therefore, in addition to Dickey-Fuller and Phillips-Perron tests we report the results of Zivot-Andrews test for stationarity which takes into consideration structural breaks that can occur in the intercept and/or the trend of the series (Zivot and Andrews, 1992). The results presented in Table 1 show outcomes of Augmented Dickey-Fuller, Philips Perron, and Zivo-Andrews test. Many of the series are non-stationary in levels as well as in first differences. First panel of table 1 shows states for which particular series are non-stationary at the state level based on ADF and PP tests. The results show that most of the data series are non-stationary for most of the states. In fact coal prices are non-stationary in all states. However, based on Zivot-Andrews test some of the series are stationary in several states taking into account potential structural breaks. The second panel shows states for which differenced data series are non-stationary. In the case of differenced data, the series for most of the states at state level are stationary. However, non-stationarity in the data at state level is still present. In this case Zivot-Andrews test detects more non-stationary series than ADF and PP tests. Regressing one non-stationary variable on the other can produce spurious results (Lim and Shumway, 1997).

Further differencing the data in this study would be problematic due to limited time span of the series. The typical approach for handling nonstationarity, like cointegration and linear error correction models, are not applicable in this study due to non-linearity in relative prices in the translog cost function. Furthermore, in the estimation of system of equations consistent with microeconomic theory implies that cross equation restrictions need to be imposed (Lewbel and Ng, 2005). In this study we do not investigate the statistical relationships on state-by-state level. Instead, the data is analyzed in a panel structure. Similar to Gao et al. (2013) we find that the variables used in the SUR estimation are stationary based on the Levin-Lin-Chu panel unit root test (Levin et al. 2002) which accounts for the effects of panel structure of the data. Table 1 provides results.

Figure 6 shows distributions of structural breaks in state time series of the data as obtained from Zivot-Andrews unit root test. 2011 was identified in 27 states as the date with the structural break in oil price series. 2009 was identified as the date for potential structural break in natural gas prices in 40 states. Overall, from 368 data series with potential structural breaks (electricity production from natural gas, coal, and petroleum products, prices of coal, natural gas, and petroleum inputs in power generation, costs of electricity production, and cost shares of coal, natural gas and petroleum in 46 states) 2009 was identified most frequently in 137 series. Therefore, in the analysis of electricity generation costs and cost shares we examine differences in elasticities before 2009 and after 2009.

To facilitate interpretation of the elasticities of substitution let relative input cost share be: $S_{ij} = p_i x_i / p_j x_j$. Then $\frac{dS_{ij}}{d(p_i/p_j)} = \frac{x_2}{x_1} + \frac{p_2}{p_1}\frac{d\left(x_i/x_j\right)}{d\left(p_i/p_j\right)} = \frac{x_2}{x_1}\left[1 + \frac{d\left(x_2/x_1\right)}{d\left(p_2/p_1\right)}\right] = \frac{x_2}{x_1}\left(1-\sigma_{ij}\right)$.

Hence, when elasticity of substitution is greater less than one the cost share of input i relative to input j increases as price of input i increases relative to input j. In other words, there is little opportunity for substitution. On the other hand, if elasticity of substitution is greater than one then increase in the price of input i relative to input j leads to the decrease in expenditure share on input i relative to input j. In this case, inputs i and j are more substitutable. Table 2 shows estimated elasticities of substitution at the state scale for the 2001-2014, 2001-2008, and 2009-2014 periods. States where none of the elasticities turned out to be statistically significant even at 10% are omitted from the table. Natural gas and coal are most substitutable for the entire sample in TN. During 2001-2008 natural gas and coal are most substitutable in DE while during 2009-2014 they are most substitutable in MT. In both, MT and TN NG-coal substitution elasticities are statistically insignificant during 2001-2008 but positive and statistically different from zero during 2009-2014. Elasticities of substitution increased noticeably in OH and PA with increased capacity for gas-fired generators and retiring or retrofitting the coal-fired plants to meet emission standards (FERC 2012, Gao et al. 2013).

Substitution elasticity between natural gas and oil declined during 2009-2014 period relative to 2001-2008 period in CT, FL, MA, MD, NH, NY, VA. Oil and coal were not easily substitutable in either 2001-2008 or 2009-2014 periods, although substitution elasticity seems to have increased in DE. Table 3 show test statistics for a null hypothesis that elasticity of substitution is equal across 2001:2008 and 2009-2014 periods. Elasticity of substitution between natural gas and coal decreased in AL, CT, DE, GA, IN, NM, NV, NY, SC, and VA, and increased in AR, IL, KS, MD, MI, NH, SD, and TX. Natural gas and oil elasticity of substitution decreased in AK, CT, FL, MA, MD, NH, NY, and VA, and increased in IA, ME, and NE. Elasticity of substitution between coal and oil declined in AR, CT, IA, MA, NC, NJ, NV, NY, SD, and WI, and increased only in OH.

Table 4 shows cross price elasticities for natural gas and coal. With the exception of IA, NE, and NH, natural gas and coal appear to be substitutes in all states across all three sample periods with statistically stronger substitution appearing in MA, MT, NC, NE, OH, PA, and TN, in 2009-2014 period then in 2001-2008 period. Similarly, table 5 shows cross price elasticities for natural gas and oil, and oil and coal respectively. All statistically significant cross price elasticities for natural gas and oil, with the exception of AK, indicate that natural gas and oil are substitutes. IN 29 out of 46 states the elasticities of substitution between natural gas and oil are not statistically different from zero. Similarly, table 6 shows that in most states cross price elasticities for oil and coal are not statistically different from zero in any of the sample periods. Most of the statistically significant cross price elasticities between oil and coal are negative suggesting complementary relationship. However, some of the elasticities in DE, KS, and HN are positive suggesting substitutability.

Table 7 reports test statistics for the null hypothesis that cross price elasticities in 2001-2008 period equal corresponding cross price elasticities in 2009-2014 period. Elasticity of demand for natural gas with respect to coal prices declined in AL, CT, DE, IA, NE, NJ, NM, NV, NY, SD, and WI, and increased in ARM FL, MA, MD, MN, MS, NH, PA, SC, and UT. ON the other hand, elasticity of demand for coal with respect to natural gas price declined in AK, IA, IL, NE, NH, NV, SD, and WI, and increased in AL, DE, FL, GA, MA, MD, MN, MS, NC, NY, OH, SC, TN, UT, and VA. Elasticity of demand for natural gas with respect to oil price decreased in AK, CT, FL, KS, MA, MD, MN, MS, NH, NJ, NV, NY UT, and VA, and increased in IA, ME, NE, NM, SD, and WI. On the other hand, elasticity of demand for oil with respect to natural gas price declined only in NE, and increased in AK, CT, IA, MD, NH, NV, NY, SD, UT, VA, and WI. Elasticity of demand for oil with respect to coal prices declined in AR, IA, MA, NV, NY, SD, UT, and WI, and increased in NE, and OH. Elasticity of demand for coal with respect to prices of oil decreased FL, KS, KY, MA, MD, MI, MN, MS, NV, NY, PA, and VA, and increased in IA, MT, NE, and SD. These results suggest that cross price elasticities changed during 2009-2014 period as compared to 2001-2008 period. Furthermore, the changes in cross price elasticities vary across states.

Own price elasticities are reported in table 8. The majority of own price elasticities are negative consistent with theoretical expectations. However, few of the elasticities are positive contrary to theory. Such results have been detected in previous literature with reported positive own price elasticities of fossil fuel demands (Gao et al. 2013). With the exceptions AK, IA, and NH, all own price elasticities for natural gas are negative. On the other hand most of the statistically significant own price elasticities for coal are positive. This result is detected in states where coal consumption for electricity generation is low as well as states where coal consumption for electricity generation is high. These results are plausible in the context where both prices of coal and the utilization of coal in electricity generation have been increasing until 2008 and decreasing after 2011. States which depend heavily on coal for electricity generation have limited ability to substitute fuels when prices favor substitution (Gao et al. 2012, EIA 2012). It also should be taken into account that coal is used in baseload generators that never shut down. In most states however, own price elasticities for coal are not statistically different from zero confirming limited ability to switch away from coal during both periods.

Table 9 shows test statistics for the null hypothesis that own price elasticities during 2001-2008 period equal own price elasticities during 2009-2014 period. Own price elasticities for natural gas declined in LA, ME, and SC, and increased in AK, AL, CT, DE, FL, IA, IL, MA, MS, NE, NJ, NV, NY, and VA. Coal own price elasticity decreased in AL, GA, IN, MN, MT, NC, NY, OH, PA, and TN, and increased in AK, CT, DE, IL, KS, MA, MD,MI, NE, NH, NJ, and NY. Oil own price elasticities decreased in MI, MS, and OH, and increased in AR, and TN. These results also suggest that changes in own price elasticities before and after 2009 vary across states.

Conclusions

This study estimates state level elasticities of substitution as well cross and own price elasticities for natural gas, coal, and oil as inputs in electricity generation. Zivot-Andrews test is used to identify potential structural change in the state level data series from 2001 to 2014. The results indicate that 2009 is identified as the date of potential structural shift in most of the data series. This date can be associated with the recession caused by the collapse of several large financial institutions as well as significant increase oil and natural gas production using hydraulic fracturing technology. Elasticities of substitution, own and cross price elasticities are estimated for 2001-2008 and 2009-2014 periods.

Natural gas and coal act as substitutes, with positive cross price elasticities, in most of the states during both periods. However, degree of price responsiveness decreased in 2009-2014 period relative to 2001-2008 period in many states. Elasticities of substitution showed limited substitutability between natural gas and coal in either period, with positive elasticities of substitution consistent with prior findings (Gao et al. 2013). However, the degree of substitutability increased in some states and decreased in others in 2009-2014 period vs. 2001-2008 period. Natural gas and oil also act as substitutes in both periods with positive statistically significant cross price elasticities. However, the direction of change in cross price elasticities of substitution in 2009-2014 vs. 2001-2008 periods differs across states. Elasticities of substitution again show limited potential for substitution in both periods with positive elasticities of substitution similar to previous literature. The directions of statistically significant change in elasticities of substitution vary across states. Oil and coal cross price elasticities are statistically insignificant in most states and negative for most of the states with statistically significant cross price elasticities. For most states with statistically significant changes in cross price elasticities 2009-2014 elasticities are less than 2001-2008 elasticities. Own price elasticities are negative for natural and oil and positive for coal in most of the states. Natural gas own price elasticity increased for most of the states, while direction of change in coal and oil own price elasticities varied across states.

These results highlight heterogeneity in patterns of price elasticities and elasticities of substitution at the state level. Heterogeneity in elasticities across seven electricity production regions in the US has been documented n previous literature (Gao et al. 2013). This study shows that the differences ate present not only across regions but also within regions across states. Such heterogeneity can be present due to differences in resource endowments, historical evolution institutions as well as state level policies. Such state level differences imply that national or regional policies can have diverse state level implications with potentially suboptimal state level outcomes.

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Table 1. Unit Root Tests

	Augmented Dickey-Fuller	Phillips-Perron	Zivot-Andrews
Panel I: Stationary state series using levels data at 5% significance			
Electricity production	SD	SD	IL, KS, ME, MI, ND, NH, NJ, NV, NY, SD, TN, UT, VA, WI, WV
Coal Prices	--	--	DE, LA, MA, UT, VA, WV, WY
NG prices	CA	--	CA, CO, ND, OH, PA, WA
Oil prices	LA	LA	CA, KY, LA, OR, SC, WI
Costs of prduction	CA	CA	AL, AR, AZ, CA, DE, IA, KS, MD, MN, MS, NY, OK, SD, TX, WI, WV
Coal cost share	MA, WA	MS, NH	KS, MI, MO, MS, NE, NH, NM, NV, OH, TN, VA, WY
NG cost share	CT, MS	CT, FL, MS	CT, MD, MI, MO, MS, ND, NJ, NM, NV, OH, TN, WY
Oil cost share	Al, AR, ZA, CO, CT, IL, LA, MO, MS, NV, OK, OR, TN, TX, WA	AR, ZA, CO, CT, IL, LA, MO, MS, NV, OK, OR, TN, TX, WA	AL, AR, ZA, CO, CT, FL, IL, IN, KS, KY, LA, MI, MS, MT, NV, OH, OK, PA, SD, WA
Panel II: Non-stationary state series using differenced data at 5% significance			
Electricity production	AK, AZ, MN, NH, OK, UT	AK, AZ, MN, NH, OK, UT	AK, AL, CA, CT, DE, GA, IN, KY, LA, MN, NJ, OR, SC, TN, TX, UT, WY
Coal Prices	FL, GA, LA, MI, MN, MO, MS, NC, ND, NE, NJ, NM, NY, OH, OK, OR, PA, SC, TN, TX, VA, WI, WV	FL, GA, IN, LA, MI, MN, MO, MS, NC, ND, NE, NJ, NM, NY, OH, OK, PA, SC, TN, TX, VA, WI, WV	AZ, CA, FL, GA, IN, LA, MI, MN, MO, MS, NC, ND, NE, NY, OH, OK, OR, PA , SC, TN, TX, VA, WI, WV
NG prices	FL, SD	FL, SD	WY
Oil prices	AR, CT, GA, MA, ME, MI, MN, MS, OR, TN	AR, CT, GA, MA, ME, MI, MN, MS, OR, TN	AK, AL, AZ, GA, IA, IL, KS, MA, ME, MO, MS, MT, ND, NH, MN, NV, NY, OH, OK, OR, SC, SD, TN, UT, VA,
Costs of prduction	AK, FL, ND,	AK, FL, ND,	AK, GA, ND, NE, CS, TN, VA, WA
Coal cost share	AK, AZ, FL, GA, IA, NC, UT,	AK, AZ, FL, GA, IA, NC, NH, UT,	CT, GA, IA, ND, NJ, UT
NG cost share	AK, AZ, GA, IA, NC, UT, WV	AK, AZ, GA, IA, NC, NV, UT, WV	AK, FL, GA, IA, NJ, UT, VA, WV
Oil cost share	--	--	AK, IA, ND, NH, SC, UT, WI, WY

Panel III: Levin-Lin-Chu panel unit root test

	Adjusted t*	p-value
Coal prices	-5.0861	0
NG prices	-6.4264	0
Oil prices	-7.9053	0
Cost share of Coal	-5.4286	0
Cost share of NG	-5.292	0
Cost share of Oil	1.8666	0.969
Costs	-8.5287	0
Electricity ptoduction	-2.63	0.0043

Table 2. Elasticities of Substitution

	2001-20014						2001-2008						2009-2014					
	NG-Coal		NG-Oil		Oil-Coal		NG-Coal		NG-Oil		Oil-Coal		NG-Coal		NG-Oil		Oil-Coal	
	σ	se	σ	se	σ	se	σ	se	σ	se	σ	se	σ	se	σ	se	σ	se
AK	-6.08	4.39	-0.22	0.05 ***	-0.12	2.92	-3.77	2.94	-0.13	0.03 ***	-0.24	3.21	-19.1	12.5	-0.71	0.16 ***	0.01	2.60
AL	0.19	0.05 ***	0.00	0.00	-0.91	5.53	0.21	0.06 ***	0.00	0.00	-0.88	5.66	0.16	0.04 ***	0.00	0.00	-0.93	5.33
AR	0.09	0.04 **	0.00	0.00	-2.52	1.25 **	0.08	0.04 **	0.00	0.00	-1.56	0.81 *	0.11	0.04 **	0.00	0.00	-7.71	3.56 **
CA	0.00	0.00	0.00	0.00 *	-0.02	0.02	0.00	0.00	0.00	0.00 *	-0.01	0.02	0.00	0.00	0.00	0.00 *	-0.02	0.03
CT	0.01	0.01 **	0.04	0.01 ***	-0.02	0.04	0.02	0.01 **	0.07	0.02 ***	-0.01	0.04	0.01	0.00	0.01	0.01 ***	-0.04	0.05
DE	0.22	0.02 ***	-0.01	0.01	0.48	0.20 **	0.31	0.04 ***	-0.01	0.03	0.47	0.16 ***	0.13	0.01 ***	0.00	0.00	0.73	0.39 *
FL	0.00	0.01	0.03	0.01 ***	-0.03	0.07	0.00	0.01	0.07	0.02 ***	0.00	0.05	0.01	0.01	0.01	0.00 **	-0.18	0.24
GA	0.28	0.07 ***	0.00	0.00	0.23	5.10	0.27	0.10 ***	0.00	0.00	0.34	4.99	0.25	0.05 ***	0.00	0.00	0.10	5.31
IA	-0.35	0.20 *	0.03	0.01 ***	-4.51	1.24 ***	-0.17	0.15	0.03	0.01 ***	-4.18	1.14 ***	-0.90	0.32 ***	0.05	0.02 ***	-4.98	1.37 **
IL	0.30	0.18 *	0.01	0.01	-1.16	1.31	0.32	0.14 **	0.01	0.01	-0.76	0.99	0.22	0.25	0.01	0.00	-2.30	2.19
KS	0.10	0.13	0.00	0.00	0.61	0.46	0.09	0.12	0.00	0.01	0.57	0.31 *	0.10	0.14	0.00	0.00	0.67	1.20
KY	-0.15	0.58	0.00	0.01	1.25	0.69 *	-0.13	0.56	0.00	0.01	1.20	0.62 *	-0.17	0.59	0.00	0.01	1.33	0.82
MA	0.01	0.01 *	0.06	0.01 ***	-0.10	0.05 *	0.01	0.01	0.11	0.02 ***	-0.06	0.04	0.01	0.01 **	0.02	0.00 ***	-0.29	0.14 **
MD	0.21	0.16	0.15	0.06 **	0.22	0.40	0.16	0.15	0.21	0.08 **	0.25	0.28	0.28	0.17	0.07	0.03 **	-0.02	0.81
ME	0.00	0.00	0.03	0.01 ***	0.00	0.00	0.00	0.00	0.01	0.01 ***	0.00	0.00	0.00	0.00	0.05	0.01 ***	0.00	0.00
MI	0.31	0.09 ***	0.00	0.00	0.82	0.72	0.28	0.08 ***	0.00	0.00	0.68	0.55	0.34	0.13 ***	0.00	0.00	1.09	1.11
MN	0.10	0.10	0.00	0.00 *	-0.72	1.26	0.09	0.10	0.00	0.00 *	-0.44	0.99	0.12	0.09	0.00	0.00 *	-1.48	2.01
MS	0.06	0.01 ***	0.00	0.00	-0.61	0.68	0.05	0.01 ***	0.01	0.01	-0.32	0.39	0.06	0.01 ***	0.00	0.00	-8.17	8.11
MT	1.21	0.91	-0.02	0.05	0.56	1.08	1.92	2.57	-0.04	0.11	0.57	1.23	0.97	0.47 **	-0.01	0.03	0.53	0.92
NC	0.40	0.19 **	-0.01	0.01	3.55	2.41	0.30	0.35	-0.02	0.01	3.83	2.55	0.38	0.11 ***	-0.01	0.00	3.19	2.21
NE	-0.21	0.19	0.01	0.01 **	-4.16	1.83 **	0.01	0.12	0.01	0.00 **	-4.16	1.79 **	-1.49	0.48 ***	0.03	0.01 **	-4.12	1.87 **
NH	-0.08	0.01 ***	0.03	0.01 ***	0.13	0.11	-0.11	0.02 ***	0.06	0.01 ***	0.15	0.09 *	-0.06	0.01 ***	0.01	0.00 ***	0.12	0.18
NJ	0.02	0.01 ***	0.00	0.00 *	-0.14	0.19	0.03	0.01 ***	0.01	0.00 **	-0.12	0.19	0.01	0.00 ***	0.00	0.00 *	-0.16	0.20
NM	0.17	0.08 **	0.00	0.00	-6.85	4.66	0.17	0.08 **	0.00	0.00	-9.53	6.37	0.17	0.08 **	0.00	0.00	-4.92	3.42
NV	0.01	0.01	0.00	0.00 ***	-2.41	1.19 **	0.01	0.01	0.00	0.00 ***	-1.98	0.98 **	0.00	0.01	0.00	0.00 ***	-3.79	1.86 **
NY	0.01	0.01 **	0.07	0.01 ***	-0.06	0.04 *	0.01	0.01 **	0.12	0.02 ***	-0.04	0.03	0.01	0.00 **	0.03	0.01 ***	-0.12	0.06 *
OH	0.41	0.21 *	0.01	0.01	-1.53	1.13	0.27	0.35	0.02	0.01	-2.02	1.41	0.44	0.13 ***	0.01	0.01	-1.09	0.87
PA	0.13	0.07 *	0.00	0.01	0.64	0.66	0.07	0.09	0.01	0.02	0.65	0.51	0.15	0.05 ***	0.00	0.00	0.74	1.22
SC	0.20	0.06 ***	0.00	0.00	-0.26	0.90	0.19	0.07 ***	0.00	0.00	-0.29	0.95	0.20	0.06 ***	0.00	0.00	-0.23	0.83
SD	0.10	0.16	0.05	0.02 ***	-4.61	1.10 ***	0.14	0.12	0.05	0.01 ***	-3.42	0.83 ***	-0.09	0.26	0.05	0.02 ***	-7.43	1.73 **
TN	0.89	0.37 **	-0.02	0.02	1.45	1.71	1.03	0.78	-0.04	0.04	1.59	1.89	0.77	0.21 ***	-0.01	0.02	1.29	1.49
UT	0.12	0.15	0.00	0.00 **	-9.68	3.74 ***	0.11	0.16	0.00	0.00 **	-9.67	3.74 ***	0.12	0.15	0.00	0.00 **	-9.68	3.73 **
VA	0.16	0.04 ***	0.10	0.02 ***	-0.12	0.33	0.17	0.06 ***	0.16	0.04 ***	-0.02	0.28	0.14	0.03 ***	0.05	0.01 ***	-0.34	0.47
WI	-0.09	0.08	0.01	0.00 ***	-2.67	1.19 **	-0.06	0.07	0.01	0.00 ***	-2.09	0.96 **	-0.16	0.10	0.00	0.00 ***	-3.96	1.68 **

Note: *, **, and *** denote statistical significance at 10%, 5%, and 1% respectively

Table 3. Elasticities of Substitution (2001-2009 minus 2009-2014)

	NG-Coal		Subst. NG-oil		Subst. Coal-oil	
	Diff.	se	Diff.	se	Diff.	se
AK	12.26	9.59	0.57	0.13 ***	-0.25	0.61
AL	0.12	0.02 ***	0.00	0.00	0.05	0.32
AR	-0.05	0.01 ***	0.00	0.00	6.15	2.75 **
CA	0.00	0.00	0.00	0.00 **	0.00	0.00
CT	0.02	0.01 ***	0.05	0.01 ***	0.03	0.01 **
DE	0.21	0.02 ***	-0.01	0.02	-0.26	0.23
FL	0.00	0.00 **	0.06	0.01 ***	0.18	0.19
GA	0.20	0.05 ***	0.00	0.00	0.23	0.32
IA	0.04	0.17	-0.02	0.01 ***	0.81	0.23 ***
IL	-0.35	0.11 ***	0.00	0.00 *	1.54	1.20
IN	0.05	0.03 *	0.00	0.00	0.51	0.58
KS	-0.06	0.02 ***	0.00	0.00	-0.10	0.90
KY	0.00	0.03	0.00	0.00	-0.13	0.19
MA	0.00	0.00	0.09	0.02 ***	0.23	0.10 **
MD	-0.10	0.02 ***	0.14	0.05 ***	0.28	0.54
ME	0.00	0.00	-0.03	0.01 ***	0.00	0.00
MI	-0.28	0.05 ***	0.00	0.00	-0.41	0.56
MN	0.02	0.01	0.00	0.00 **	1.03	1.02
MS	0.00	0.00 ***	0.01	0.01	7.85	7.72
MT	1.58	2.09	-0.03	0.09	0.03	0.31
NC	0.25	0.23	-0.01	0.01	0.64	0.33 *
NE	-0.46	0.36	-0.02	0.01 **	-0.04	0.08
NH	-0.04	0.01 ***	0.04	0.01 ***	0.03	0.09
NJ	0.02	0.00 ***	0.00	0.00 **	0.03	0.01 ***
NM	0.01	0.00 ***	0.00	0.00	-4.61	2.96
NV	0.01	0.00 ***	0.00	0.00 ***	1.82	0.88 **
NY	0.01	0.00 ***	0.10	0.01 ***	0.07	0.03 **
OH	0.20	0.22	0.01	0.00	-0.93	0.54 *
PA	0.07	0.04	0.00	0.01	-0.09	0.71
SC	0.06	0.01 ***	0.00	0.00	-0.06	0.13
SD	-0.40	0.15 ***	0.00	0.00	4.02	0.90 ***
TN	0.78	0.57	-0.03	0.03	0.30	0.40
TX	-0.06	0.01 ***	0.00	0.00	0.65	0.85
UT	0.02	0.01	0.00	0.00 **	0.00	0.01
VA	0.10	0.03 ***	0.11	0.03 ***	0.32	0.19
WI	-0.03	0.02	0.00	0.00 ***	1.87	0.72 ***

Note: *, **, and *** denote statistical significance at 10%, 5%, and 1% respectively

Table 4. Cross price elasticities for Natural Gas and Coal

	2001-2014						2001-2008						2008-2014					
	NG-Coal			Coal-NG			NG-Coal			Coal-NG			NG-Coal			Coal-NG		
	e	se		e	se		e	se		e	se		e	se		e	se	
AL	0.33	0.08	***	0.23	0.06	***	0.34	0.09	***	0.19	0.05	***	0.30	0.07	***	0.27	0.06	***
AR	0.17	0.07	**	0.13	0.06	**	0.15	0.07	**	0.13	0.06	**	0.18	0.07	**	0.13	0.05	**
CT	0.11	0.05	**	0.60	0.28	**	0.14	0.06	**	0.54	0.22	**	0.07	0.04		0.66	0.43	
DE	0.56	0.06	***	0.69	0.07	***	0.68	0.08	***	0.55	0.06	***	0.44	0.05	***	0.90	0.09	***
GA	0.39	0.10	***	0.14	0.04	***	0.35	0.13	***	0.09	0.03	***	0.39	0.07	***	0.22	0.04	***
IA	-0.43	0.24	*	-0.08	0.04	*	-0.21	0.19		-0.05	0.05		-1.04	0.37	***	-0.12	0.04	***
IL	0.36	0.21	*	0.07	0.04	*	0.40	0.18	**	0.09	0.04	**	0.26	0.29		0.03	0.04	
MA	0.08	0.04	*	0.32	0.18	*	0.07	0.05		0.25	0.18		0.09	0.04	**	0.41	0.18	**
MI	0.45	0.14	***	0.18	0.06	***	0.43	0.12	***	0.22	0.06	***	0.45	0.17	***	0.14	0.05	***
MN	0.14	0.13		0.05	0.05		0.12	0.14		0.04	0.04		0.17	0.12		0.06	0.05	
MS	0.20	0.04	***	0.46	0.09	***	0.19	0.04	***	0.44	0.09	***	0.21	0.04	***	0.49	0.09	***
MT	1.31	0.99		0.05	0.04		2.03	2.72		0.03	0.04		1.10	0.54	**	0.08	0.04	**
NC	0.49	0.24	**	0.10	0.05	**	0.34	0.39		0.04	0.04		0.52	0.15	***	0.17	0.05	***
NE	-0.26	0.22		-0.04	0.04		0.01	0.16		0.00	0.04		-1.62	0.52	***	-0.11	0.04	***
NH	-0.27	0.05	***	-0.52	0.09	***	-0.33	0.05	***	-0.47	0.08	***	-0.24	0.04	***	-0.67	0.11	***
NJ	0.13	0.03	***	0.55	0.13	***	0.16	0.03	***	0.54	0.11	***	0.09	0.03	***	0.54	0.17	***
NM	0.26	0.13	**	0.14	0.07	**	0.26	0.13	**	0.14	0.07	**	0.26	0.13	**	0.14	0.07	**
NY	0.09	0.05	**	0.61	0.29	**	0.11	0.05	**	0.54	0.26	**	0.08	0.04	**	0.69	0.35	**
OH	0.47	0.24	*	0.06	0.03	*	0.29	0.38		0.02	0.03		0.55	0.17	***	0.11	0.03	***
PA	0.19	0.10	*	0.08	0.04	*	0.10	0.13		0.03	0.04		0.25	0.08	***	0.14	0.04	***
SC	0.26	0.08	***	0.08	0.03	***	0.24	0.09	***	0.07	0.03	***	0.28	0.08	***	0.10	0.03	***
TN	0.98	0.41	**	0.07	0.03	**	1.10	0.83		0.04	0.03		0.90	0.24	***	0.12	0.03	***
VA	0.32	0.08	***	0.22	0.06	***	0.30	0.10	***	0.16	0.06	***	0.31	0.07	***	0.30	0.07	***

Note *, **, and *** denote statistical significance at 10%, 5%, and 1% respectively

Table 5. Cross Price Elasticities for Natural gas and oil

	2001-2014				2001-2008				2008-2014			
	NG-Oil		Oil-NG		NG-Oil		Oil-NG		NG-Oil		Oil-NG	
	e	se	e	se	e	se	e	se	e	se	e	se
AK	-15.53	3.52 ***	-14.76	3.35 ***	-10.45	2.37 ***	-16.35	3.71 ***	-44.05	9.99 ***	-13.08	2.97 ***
CA	0.04	0.02 *	5.08	2.83 *	0.04	0.02 *	5.22	2.93 *	0.04	0.02 *	4.91	2.72 *
CT	0.25	0.07 ***	1.17	0.34 ***	0.32	0.08 ***	0.96	0.25 ***	0.16	0.06 ***	1.68	0.64 ***
FL	0.24	0.07 ***	1.07	0.30 ***	0.32	0.07 ***	0.86	0.20 ***	0.13	0.06 **	2.04	0.94 **
IA	1.00	0.35 ***	4.53	1.58 ***	0.80	0.28 ***	4.44	1.53 ***	1.50	0.53 ***	4.66	1.64 ***
MA	0.41	0.08 ***	1.87	0.36 ***	0.51	0.09 ***	1.43	0.25 ***	0.29	0.07 ***	3.81	0.91 ***
MD	1.11	0.45 **	1.15	0.47 **	1.17	0.46 **	0.88	0.34 **	1.03	0.44 **	2.06	0.88 **
ME	0.20	0.06 ***	1.38	0.39 ***	0.16	0.06 ***	1.62	0.55 ***	0.26	0.06 ***	1.19	0.28 ***
MN	0.15	0.08 *	1.80	0.99 *	0.16	0.09 *	1.44	0.77 *	0.13	0.08 *	2.77	1.59 *
NE	0.68	0.30 **	5.32	2.36 **	0.48	0.21 **	5.68	2.50 **	1.56	0.70 **	4.88	2.20 **
NH	0.28	0.08 ***	1.43	0.38 ***	0.35	0.09 ***	1.11	0.28 ***	0.19	0.06 ***	2.41	0.77 ***
NJ	0.11	0.06 *	1.95	1.01 *	0.12	0.06 **	1.72	0.85 **	0.09	0.05 *	2.39	1.35 *
NV	0.14	0.05 ***	15.29	5.50 ***	0.15	0.05 ***	11.65	4.12 ***	0.13	0.05 ***	26.92	9.91 ***
NY	0.43	0.08 ***	1.83	0.33 ***	0.53	0.09 ***	1.44	0.24 ***	0.31	0.07 ***	3.13	0.68 ***
SD	1.10	0.34 ***	5.12	1.60 ***	0.90	0.28 ***	4.28	1.31 ***	1.63	0.52 ***	7.11	2.27 ***
UT	0.48	0.23 **	11.85	5.66 **	0.49	0.24 **	11.77	5.63 **	0.47	0.23 **	11.94	5.71 **
VA	0.79	0.20 ***	2.34	0.59 ***	0.99	0.25 ***	1.84	0.46 ***	0.61	0.16 ***	3.58	0.93 ***
WI	0.34	0.12 ***	4.71	1.71 ***	0.32	0.11 ***	4.00	1.43 ***	0.38	0.14 ***	6.28	2.32 ***

Note: *, **, and *** denote statistical significance at 10%, 5%, and 1% respectively

Table 6. Cross price elasticities for Oil and Coal

	2001-2014				2001-2008				2008-2014			
	Oil-Coal		Coal-Oil		Oil-Coal		Coal-Oil		Oil-Coal		Coal-Oil	
	e	se	e	se	e	se	e	se	e	se	e	se
AR	-4.57	2.27 **	-0.18	0.09 **	-2.96	1.54 *	-0.18	0.09 *	-13.2	6.11 **	-0.18	0.08 **
DE	1.22	0.52 **	0.38	0.16 **	1.03	0.36 ***	0.40	0.14 ***	2.35	1.27 *	0.37	0.20 *
IA	-5.51	1.51 ***	-0.22	0.06 ***	-5.37	1.47 ***	-0.23	0.06 ***	-5.72	1.58 ***	-0.21	0.06 ***
KS	0.79	0.60	0.04	0.03	0.76	0.41 *	0.05	0.03 *	0.83	1.50	0.02	0.03
KY	1.35	0.75 *	0.04	0.02 *	1.30	0.67 *	0.04	0.02 *	1.42	0.87	0.03	0.02
MA	-0.60	0.33 *	-0.55	0.31 *	-0.36	0.23	-0.48	0.31	-1.78	0.85 **	-0.64	0.31 **
NE	-4.98	2.19 **	-0.11	0.05 **	-5.38	2.31 **	-0.12	0.05 **	-4.49	2.03 **	-0.10	0.04 **
NH	0.42	0.35	0.16	0.13	0.43	0.26 *	0.20	0.12 *	0.48	0.71	0.11	0.16
NV	-13.2	6.51 **	-0.54	0.27 **	-9.82	4.88 **	-0.49	0.24 **	-23.9	11.72 **	-0.63	0.31 **
NY	-0.55	0.33 *	-0.84	0.50 *	-0.35	0.24	-0.66	0.44	-1.28	0.68 *	-1.12	0.59 *
SD	-6.12	1.46 ***	-0.36	0.08 ***	-4.94	1.20 ***	-0.38	0.09 ***	-8.91	2.07 ***	-0.33	0.08 ***
UT	-12.8	4.95 ***	-0.16	0.06 ***	-12.7	4.92 ***	-0.16	0.06 ***	-12.9	4.99 ***	-0.17	0.06 ***
WI	-3.63	1.61 **	-0.09	0.04 **	-2.93	1.34 **	-0.09	0.04 **	-5.15	2.18 **	-0.09	0.04 **

Note: *, **, and *** denote statistical significance at 10%, 5%, and 1% respectively

Table 7. Cross price elasticities (2001-2009 vs. 2009-2014)

	NG-coal		Coal-NG		NG-oil		Oil-Ng		Oil-coal		Coal-oil	
	Diff.	se	Diff.	se	Diff.	se	Diff.	se	Diff.	se	Diff.	se
AK	15.62	9.76	0.01	0.00 ***	33.60	7.62 ***	-3.27	0.74 ***	-0.26	0.67	0.00	0.00 ***
AL	0.04	0.02 *	-0.07	0.01 ***	-0.01	0.04	0.33	1.08	0.37	1.17	0.01	0.02
AR	-0.03	0.01 ***	0.00	0.01	0.01	0.01 *	-4.84	4.61	10.26	4.57 **	0.00	0.01
CA	0.00	0.00 ***	-0.17	0.44	0.00	0.00 ***	0.31	0.21	-0.15	0.24	-0.19	0.31
CT	0.07	0.01 ***	-0.12	0.21	0.15	0.02 ***	-0.72	0.38 *	0.43	0.39	0.40	0.31
DE	0.24	0.03 ***	-0.36	0.03 ***	0.02	0.07	1.02	0.86	-1.32	0.91	0.02	0.06
FL	-0.06	0.01 ***	-0.21	0.02 ***	0.19	0.02 ***	-1.18	0.74	0.80	0.85	0.15	0.02 ***
GA	-0.04	0.06	-0.13	0.01 ***	-0.10	0.14	1.31	2.06	0.26	2.00	0.00	0.02
IA	0.82	0.18 ***	0.06	0.00 ***	-0.70	0.25 ***	-0.22	0.11 **	0.36	0.11 ***	-0.03	0.01 ***
IL	0.14	0.11	0.06	0.00 ***	-0.15	0.12	-1.77	1.28	1.68	1.26	0.01	0.00 *
KS	-0.01	0.01	0.00	0.00	0.04	0.01 ***	0.23	1.14	-0.07	1.09	0.04	0.00 ***
KY	0.04	0.03	0.00	0.00 ***	0.01	0.02	0.03	0.22	-0.12	0.20	0.01	0.00 ***
MA	-0.02	0.01 *	-0.16	0.00 ***	0.22	0.02 ***	-2.38	0.67 ***	1.42	0.62 **	0.17	0.00 ***
MD	-0.12	0.01 ***	-0.02	0.01 ***	0.14	0.02 ***	-1.17	0.54 **	0.40	0.63	0.10	0.01 ***
ME	0.00	0.00	-3.46	3.95	-0.09	0.01 ***	0.43	0.27	0.16	0.27	-3.28	5.60
MI	-0.02	0.05	0.08	0.01 ***	0.04	0.03	0.61	0.57	-0.40	0.63	0.02	0.01 ***
MN	-0.05	0.02 ***	-0.03	0.00 ***	0.03	0.01 ***	-1.32	0.83	1.45	1.45	0.01	0.00 ***
MS	-0.02	0.00 ***	-0.05	0.00 ***	0.06	0.01 ***	-14.15	20.25	26.46	26.01	0.04	0.02 ***
MT	0.94	2.18	-0.05	0.00 ***	-0.87	2.19	-0.12	0.17	-0.01	0.26	-0.01	0.00 **
NC	-0.18	0.24	-0.14	0.01 ***	-0.63	0.39	0.07	0.14	0.00	0.13	-0.02	0.01
NE	1.63	0.36 ***	0.11	0.01 ***	-1.08	0.49 **	0.81	0.30 ***	-0.89	0.28 ***	-0.02	0.01 ***
NH	-0.09	0.02 ***	0.19	0.03 ***	0.16	0.03 ***	-1.30	0.50 ***	-0.05	0.46	0.09	0.05 *
NJ	0.07	0.00 ***	0.01	0.06	0.03	0.01 ***	-0.67	0.50	0.54	0.53	0.12	0.11
NM	0.01	0.00 ***	0.00	0.00 **	-0.01	0.00 ***	3.95	4.62	-7.00	4.49	0.00	0.00 ***
NV	0.03	0.00 ***	0.09	0.06 *	0.01	0.00 ***	-15.27	5.78 ***	14.09	6.84 **	0.14	0.07 **
NY	0.03	0.01 **	-0.15	0.09 *	0.22	0.02 ***	-1.69	0.44 ***	0.92	0.44 **	0.47	0.15 ***
OH	-0.25	0.22	-0.08	0.00 ***	0.43	0.31	0.68	0.53	-0.87	0.48 *	0.00	0.00
PA	-0.15	0.05 ***	-0.11	0.01 ***	0.05	0.09	-0.12	1.18	-0.28	1.26	0.04	0.01 ***
SC	-0.04	0.01 ***	-0.03	0.00 ***	0.00	0.02	-0.02	0.12	-0.06	0.11	0.00	0.00
SD	0.30	0.15 **	0.09	0.01 ***	-0.73	0.24 ***	-2.82	0.96 ***	3.97	0.87 ***	-0.05	0.02 ***
TN	0.20	0.58	-0.08	0.00 ***	-1.14	1.16	-0.35	0.27	0.18	0.27	-0.01	0.01
UT	-0.02	0.01 *	-0.01	0.00 ***	0.02	0.01 **	-0.17	0.08 **	0.20	0.07 ***	0.00	0.00 ***
VA	0.00	0.04	-0.14	0.01 ***	0.38	0.09 ***	-1.74	0.47 ***	0.69	0.51	0.11	0.03 ***
WI	0.12	0.02 ***	0.03	0.00 ***	-0.06	0.03 **	-2.28	0.89 **	2.21	0.84 ***	0.00	0.00

Note: *, **, and *** denote statistical significance at 10%, 5%, and 1% respectively

Table 8. Own price elasticities

	2001-2014						2001-2008						2008-2014					
	NG		Coal		Oil		NG		Coal		Oil		NG		Coal		Oil	
	e	se	e	se	e	se	e	se	e	se	e	se	e	se	e	se	e	se
AK	20.7	5.04 ***	-0.03	0.08	1.15	7.68	13.6	3.39 ***	-0.03	0.08	1.38	8.50	60.4	14.28 ***	-0.02	0.08	0.91	6.80
AL	-0.33	0.09 ***	-0.11	0.14	-1.02	17.3	-0.34	0.10 ***	-0.09	0.13	-1.02	16.5	-0.30	0.08 ***	-0.14	0.15	-1.03	18.63
AR	-0.13	0.08 *	-0.15	0.18	6.14	3.65 *	-0.13	0.08 *	-0.16	0.19	3.87	2.48	-0.13	0.08	-0.13	0.17	18.2	9.82 *
CT	-0.21	0.05 ***	3.40	1.32 **	-1.35	0.67 **	-0.29	0.05 ***	2.54	1.04 **	-1.17	0.50 **	-0.10	0.04 **	5.70	2.04 ***	-1.87	1.26
DE	-0.74	0.07 ***	0.05	0.16	-0.84	0.85	-0.93	0.09 ***	0.02	0.14	-0.79	0.59	-0.53	0.05 ***	0.14	0.20	-0.84	2.09
FL	-0.19	0.07 ***	0.20	0.54	-0.84	1.00	-0.23	0.08 ***	0.23	0.56	-0.77	0.66	-0.12	0.06 *	0.16	0.51	-0.90	3.12
GA	-0.50	0.11 ***	0.06	0.07	-11.6	13.2	-0.49	0.15 ***	0.10	0.07	-10.5	11.8	-0.47	0.09 ***	0.02	0.08	-13.5	15.56
IA	0.51	0.23 **	0.73	0.35 **	-4.70	3.11	0.27	0.18	0.74	0.37 **	-4.59	3.02	1.17	0.35 ***	0.73	0.33 **	-4.86	3.24
IL	-0.38	0.19 **	-0.04	0.19	-5.07	3.44	-0.43	0.16 ***	-0.07	0.20	-4.18	2.70	-0.27	0.26	0.00	0.18	-7.44	5.43
IN	-0.63	0.37 *	-0.14	0.13	-2.90	4.00	-0.63	0.38 *	-0.14	0.13	-3.34	4.93	-0.64	0.35 *	-0.15	0.13	-2.51	3.20
KS	-0.38	0.18 **	-0.10	0.18	-1.58	1.58	-0.39	0.17 **	-0.12	0.19	-1.37	1.09	-0.37	0.18 **	-0.08	0.17	-2.54	3.97
LA	-0.01	0.05	-0.03	0.32	8.04	1.73 ***	0.03	0.04	0.12	0.42	8.94	1.91 ***	-0.05	0.06	-0.12	0.24	7.07	1.54 **
MA	-0.21	0.05 ***	0.33	0.49	-1.13	0.63 *	-0.27	0.05 ***	0.33	0.49	-0.97	0.43 **	-0.13	0.04 ***	0.34	0.49	-1.66	1.62
MD	-1.09	0.25 ***	0.19	0.09 **	-2.71	0.82 ***	-1.09	0.25 ***	0.18	0.09 *	-2.18	0.61 ***	-1.08	0.24 ***	0.22	0.08 ***	-4.41	1.55 **
ME	-0.12	0.04 ***	18.8	28.13	-2.29	0.85 ***	-0.08	0.04 **	15.1	22.86	-2.90	1.19 **	-0.16	0.04 ***	27.5	40.6	-1.85	0.61 **
MI	-0.48	0.13 ***	-0.09	0.23	-4.10	3.09	-0.47	0.11 ***	-0.12	0.25	-3.53	2.53	-0.48	0.16 ***	-0.05	0.21	-5.41	4.38
MN	-0.27	0.14 **	-0.07	0.25	-3.58	1.87 *	-0.26	0.14 *	-0.06	0.25	-2.99	1.46 **	-0.29	0.13 **	-0.07	0.25	-5.18	3.02 *
MS	-0.20	0.04 ***	-0.26	0.27	-2.20	3.03	-0.21	0.05 ***	-0.25	0.27	-1.67	1.80	-0.18	0.04 ***	-0.26	0.26	-15.4	35.29
MT	-1.55	1.14	-0.08	0.08	-1.64	4.08	-2.58	3.13	-0.05	0.08	-1.72	4.52	-1.25	0.62 **	-0.11	0.09	-1.55	3.61
NC	-0.88	0.27 ***	0.27	0.12 **	-0.92	6.07	-0.97	0.45 **	0.30	0.11 ***	-0.92	5.96	-0.78	0.18 ***	0.24	0.13 *	-0.92	6.22
NE	0.32	0.26	0.10	0.07	-5.94	5.18	0.03	0.18	0.06	0.07	-6.24	5.48	1.79	0.61 ***	0.16	0.06 **	-5.60	4.82
NH	0.14	0.06 **	1.34	0.29 ***	-3.14	0.76 ***	0.15	0.07 **	1.13	0.25 ***	-2.48	0.55 ***	0.16	0.05 ***	1.75	0.36 ***	-5.50	1.54 **
NJ	-0.15	0.04 ***	0.25	0.33	-0.67	2.17	-0.18	0.04 ***	0.13	0.28	-0.71	1.82	-0.10	0.03 ***	0.53	0.43	-0.58	2.90
NM	-0.22	0.15	-0.21	0.12 *	12.3	###	-0.22	0.15	-0.21	0.12 *	17.1	16.90	-0.22	0.15	-0.21	0.12 *	8.78	9.14
NV	-0.09	0.06	-0.27	0.73	-6.19	###	-0.11	0.06 *	-0.30	0.67	-4.89	8.43	-0.07	0.06	-0.21	0.84	-10.4	20.24
NY	-0.40	0.05 ***	2.11	0.86 **	-1.92	0.52 ***	-0.49	0.06 ***	1.79	0.77 **	-1.55	0.37 ***	-0.28	0.04 ***	2.69	1.03 ***	-3.18	1.07 **
OH	-0.84	0.29 ***	0.07	0.07	4.30	6.93	-0.85	0.46 *	0.10	0.07	5.32	8.28	-0.81	0.20 ***	0.03	0.08	3.37	5.70
PA	-0.36	0.11 ***	0.07	0.14	0.09	1.62	-0.31	0.14 **	0.09	0.14	-0.18	1.18	-0.36	0.09 ***	0.06	0.16	1.09	3.25
SC	-0.30	0.10 ***	-0.10	0.09	-2.84	4.77	-0.28	0.10 ***	-0.08	0.09	-2.91	4.96	-0.32	0.09 ***	-0.12	0.10	-2.75	4.54
SD	-0.25	0.25	0.55	0.15 ***	-1.06	3.04	-0.31	0.20	0.56	0.17 ***	-1.03	2.49	-0.04	0.37	0.55	0.14 ***	-1.11	4.31
TN	-1.20	0.47 **	0.04	0.07	-0.99	4.12	-1.52	0.95	0.07	0.07	-1.00	4.39	-1.05	0.28 ***	0.00	0.07	-0.99	3.81
UT	-0.23	0.23	-0.12	0.18	22.7	### **	-0.23	0.23	-0.12	0.18	22.6	10.92 **	-0.24	0.22	-0.12	0.18	22.9	11.07 **
VA	-0.61	0.09 ***	0.07	0.18	-4.40	1.05 ***	-0.67	0.12 ***	0.07	0.17	-3.61	0.82 ***	-0.52	0.07 ***	0.08	0.20	-6.50	1.66 **

Note: *, **, and *** denote statistical significance at 10%, 5%, and 1% respectively

Table 9. Own price elasticities (2001-2008 vs. 2009-2014)

	NG			Coal			Oil		
	Diff.	se		Diff.	se		Diff.	se	
AK	-46.82	10.89	***	-0.01	0.00	***	0.47	1.71	
AL	-0.04	0.02	*	0.05	0.03	*	0.00	2.15	
AR	0.00	0.01		-0.03	0.02		-14.30	7.34	*
CT	-0.19	0.01	***	-3.17	1.00	***	0.70	0.76	
DE	-0.40	0.04	***	-0.12	0.06	*	0.05	1.51	
FL	-0.11	0.02	***	0.08	0.05		0.13	2.45	
GA	-0.02	0.07		0.08	0.02	***	2.99	3.73	
IA	-0.91	0.17	***	0.01	0.04		0.27	0.22	
IL	-0.16	0.10	*	-0.07	0.02	***	3.25	2.73	
IN	0.01	0.03		0.01	0.00	***	-0.83	1.72	
KS	-0.02	0.01		-0.04	0.01	***	1.17	2.88	
LA	0.09	0.01	***	0.24	0.18		1.87	0.36	
MA	-0.14	0.01	***	-0.01	0.00	**	0.68	1.18	
MD	-0.01	0.01		-0.04	0.01	***	2.23	0.95	
ME	0.08	0.00	***	-12.46	17.75		-1.05	0.58	
MI	0.01	0.04		-0.07	0.03	**	1.88	1.85	***
MN	0.03	0.02		0.01	0.01	**	2.18	1.56	
MS	-0.04	0.00	***	0.01	0.01		13.77	33.49	*
MT	-1.33	2.51		0.06	0.01	***	-0.16	0.90	
NC	-0.19	0.27		0.06	0.02	***	0.00	0.26	
NE	-1.76	0.42	***	-0.10	0.01	***	-0.64	0.66	
NH	-0.01	0.02		-0.63	0.10	***	3.02	0.99	
NJ	-0.08	0.00	***	-0.40	0.15	***	-0.12	1.07	
NM	0.00	0.00		0.00	0.00	***	8.29	7.76	
NV	-0.04	0.00	***	-0.09	0.18		5.47	11.81	
NY	-0.22	0.01	***	-0.90	0.27	***	1.63	0.69	
OH	-0.05	0.26		0.08	0.01	***	1.95	2.57	***
PA	0.04	0.06		0.04	0.02	*	-1.27	2.07	
SC	0.04	0.02	**	0.03	0.00	***	-0.17	0.42	
SD	-0.27	0.17		0.01	0.03		0.08	1.82	
TN	-0.47	0.67		0.07	0.01	***	-0.01	0.59	**
UT	0.01	0.01		0.01	0.00	***	-0.33	0.15	
VA	-0.15	0.04	***	-0.01	0.03		2.89	0.84	

Note: *, **, and *** denote statistical significance at 10%, 5%, and 1% respectively

Figure 1. Total and fossil fuel based electricity generation in the US.

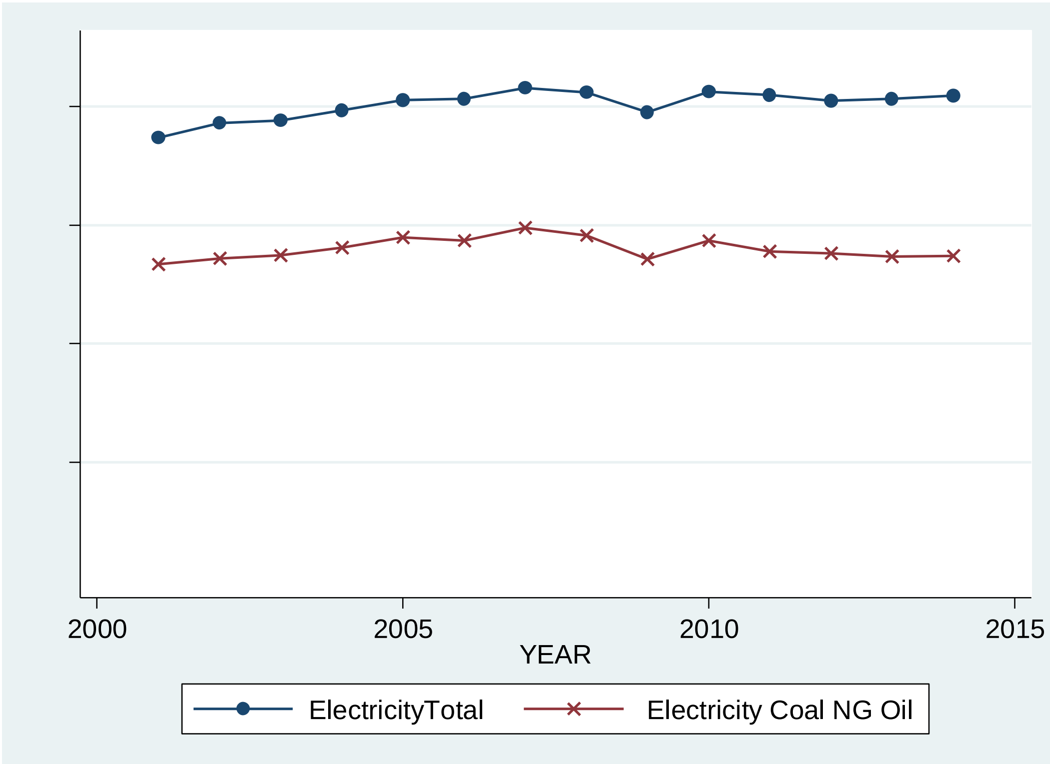

Figure 2. Natural gas and coal production in the US.

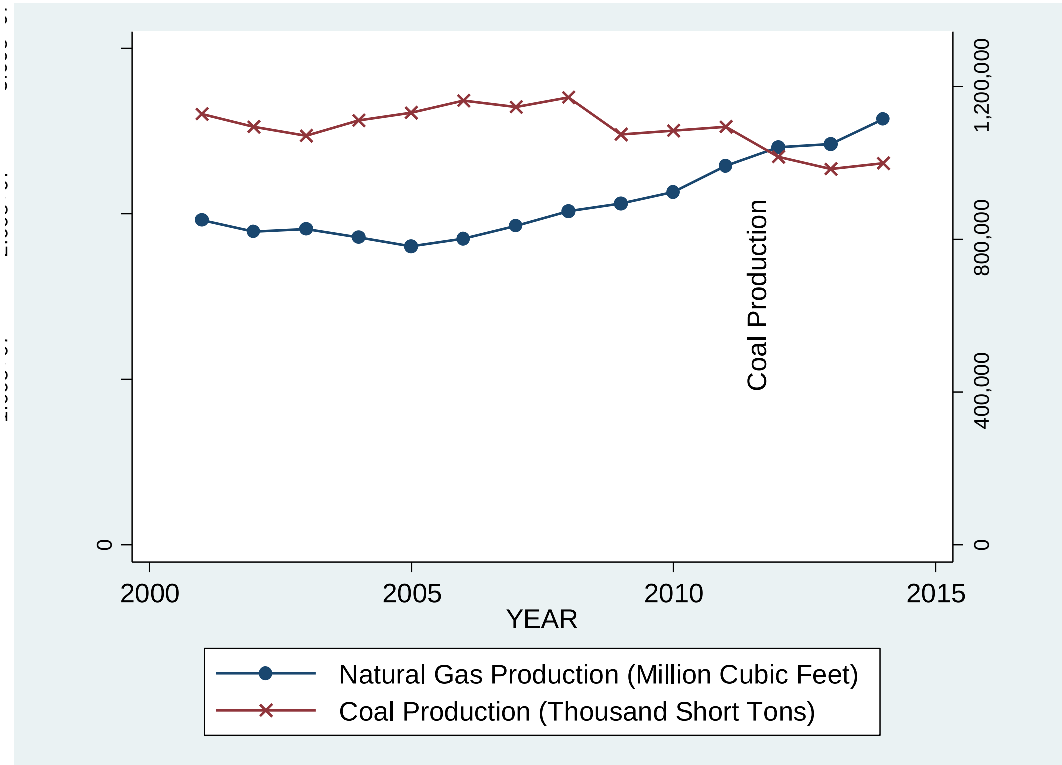

Figure 3. Fuel use for electricity production in the US (Million BTUs).

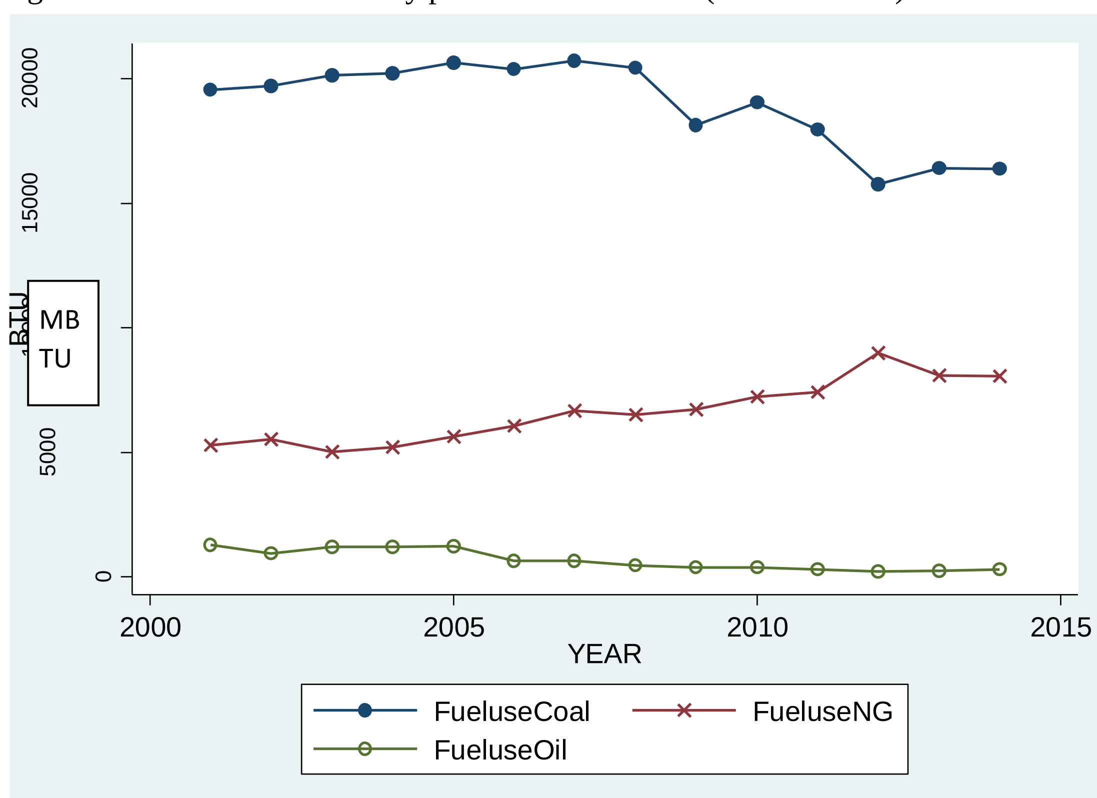

Figure 4. Utilization of coal, NG and oil in electricity production in MMBTU across states.

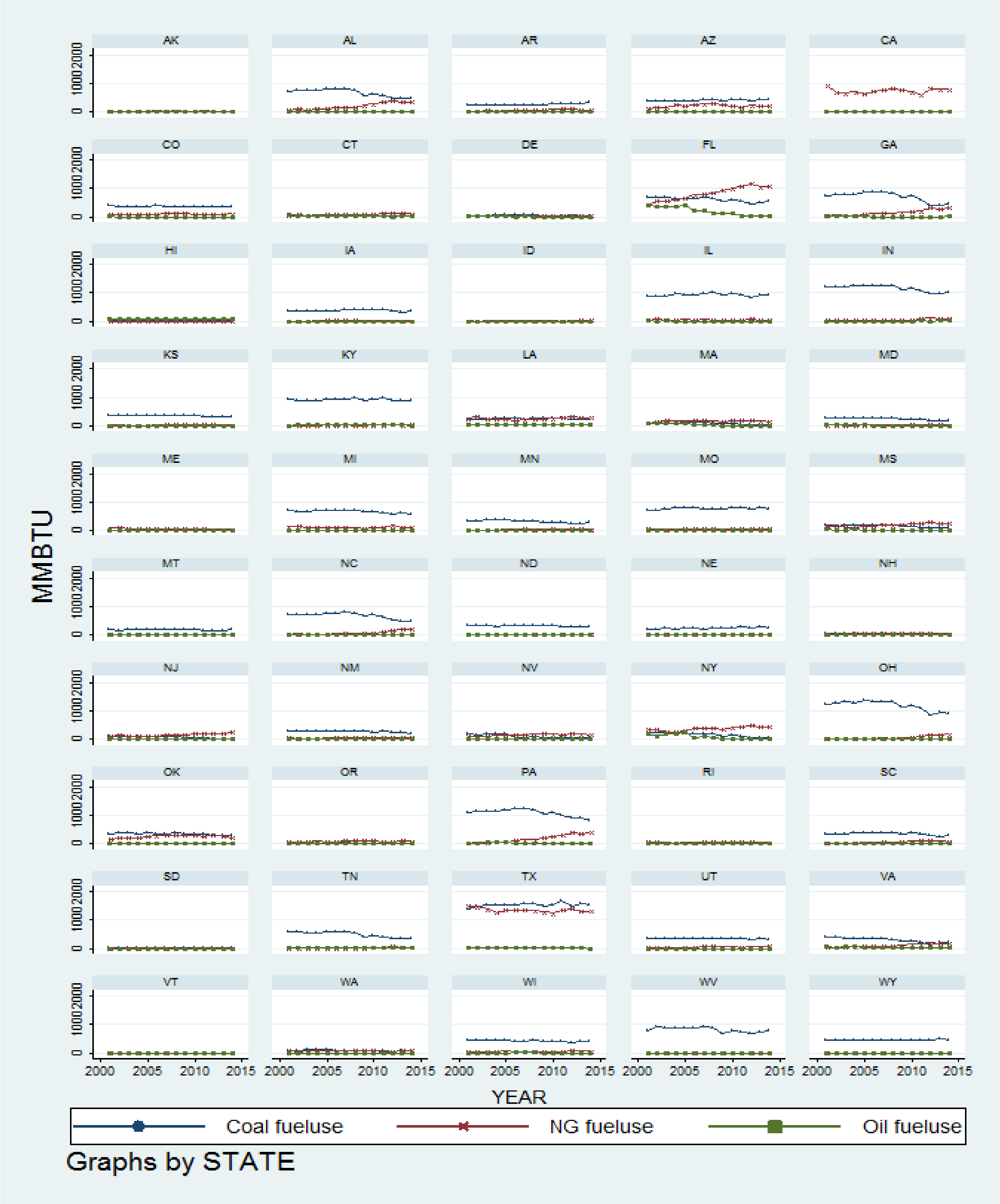

Figure 5. Total production of electricity (MWH) over the period from 2001 to 2014 by states.

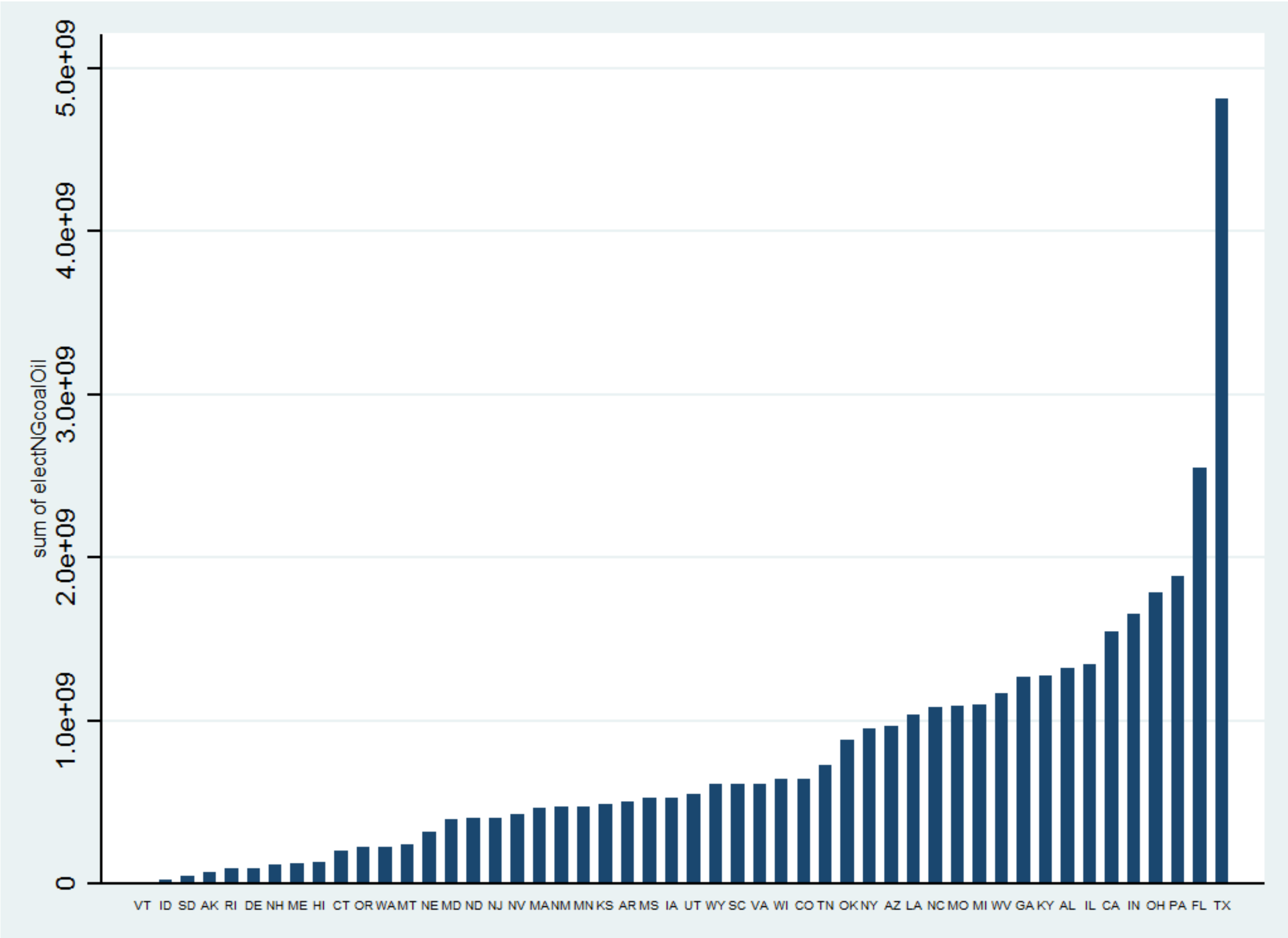

Figure 6. Distribution of Zivot-Andrews structural breaks