Title: Applied Theory of Energy Substitution in the Southeast: An SUR Approach

Osei Yeboah

Department of Agribusiness, Applied Economics & Agriscience Education, N.C A&T State University, A-25 C.H. Moore Agricultural Research Facility. 1601 E. Market St. Greensboro, NC 27411, Phone: 336.285.4727, Fax: 336.334.7658, E-mail: oyeboah@ncat.edu

Henry Thompson

Department of Agricultural Economics Rural Sociology, Auburn University, 309 Comer Hall, Auburn, AL 36849 Tel: 334.844.2910, Fax: 334.844.5639, Email: thomps1@auburn.edu

Saleem Shaik

Department of Agribusiness & Applied Economics, 504 Richard H. Barry Hall, 811, 2nd, Avenue N. Fargo, ND 5810, Phone: 731.231.7459, Fax: 731.231.7400, Email: Saleem.Shaik@ndsu.edu

Obed Quaicoe

Graduate Research Assistant, Department of Agribusiness, Applied Economics & Agriscience Education, N.C A&T State University, A-18 C.H. Moore Agricultural Research Facility. 1601 E. Market St. Greensboro, NC 27411 Phone: 336.285.4727, Fax: 336.334.7658, Email: oquaicoe@ncat.edu

ABSTRACT

Issues on energy have recently dominated the economic decisions of several states across the U.S. economy and states in the southeastern region of U.S. are no exception. Almost all the states in the southeast import virtually all of their fuel resources from the Gulf Coast representing an annual financial diversion of several billions of dollars some of which could be used to develop domestic, alternative energy resources. The focus of this study was to determine the potential substitution between renewable energy and conventional energy forms in the southeast of U.S. We developed a system of factor share equations using translog cost function. The system of equations was estimated using a pooled iterative Non-linear Seemingly Unrelated Regression (SUR) procedure with homogeneity and symmetry restrictions imposed. Findings indicate that factor demands in the southeast energy sector are price inelastic and there is limited substitution potential when energy prices rise in fuel production. The substitution potential of renewable energy for the conventional energy forms is found to be higher than that of other conventional energy forms for renewable except renewable energy for natural gas. The substitution of renewable energy for natural gas is technically infeasible since the elasticity is negative. Since renewable energy has the potential to substitute for other forms of energy besides natural gas, federal and state governments might want to reverse the $10 billion petroleum subsidy versus the current $5 billion for renewable if the target (36 billion gallons of renewable fuel by 2022) set by 2007 Energy Independence Act is to be realized.

1. INTRODUCTION

One of the critical issues in current energy policy debates in both the U.S. and other energy consuming countries is the feasibility of substantially reducing the use of crude oil. Issues on energy have recently dominated the economic decisions of several states across the U.S. economy and states in the

southeastern region of U.S. are no exception. Merely few states in the southeast namely Louisiana and Alabama are endowed with rich energy resources such as natural gas and crude oil reserves, coal deposits and wood resources for bio-fuel production. Other states like Virginia, Arkansas, Florida, Georgia, North Carolina and South Carolina in the southeast have moderate energy resources such as dams and rivers for hydroelectric power production whereas states like Mississippi and Tennessee have minor energy resources. As far as total energy production in the U.S. is concerned, Louisiana ranks 3rd, Alabama_13[th], Virginia_16[th], Arkansas_24[th], South Carolina_25[th], Florida_27[th], North Carolina_28[th], Georgia_29[th], Tennessee_30[th] and Mississippi_32[nd] among the southeastern states relative to other states in the U.S. (Energy Information Administration, 2010).

In the year 2008, the total amount of energy produced in the southeastern region of U.S. amounted to about 12,948 trillion Btu; accounting for approximately 17.8% of U.S. total energy production with Louisiana leading the region's production with 6,241 trillion Btu (see Figure 1). Within the same period, total energy consumption in the region was about 24,463 trillion Btu constituting a share of 24.6% of U.S. total energy consumption with Florida leading the region's consumption with 4,447 trillion Btu (see Figure 2). Energy consumption among states in the southeast has increased more rapidly on a percentage basis in recent years. Apart from the state of Louisiana, the rest of the southeastern states in the U.S. are net energy consumers as reflected in Figures 1 and 2. Though natural gas and oil are known to occur in certain states in the southeast, they are not currently produced. Offshore drilling still remains controversial since some of these southeastern states often face severe hurricanes and storms. Policymakers, environmentalists, and conservationists in some of the southeastern states admit that drilling for oil or natural gas off shores poses incredible environmental and economic risks to valuable regional resources, including aquatic ecosystems and tourism. Besides prospects for drilling in the southeast, the region produces several dry tons of forest,

agricultural, urban and mill residues which can potentially generate substantial amounts of electricity each year to adequately supply the annual needs of the residential electricity use of the states in the region. In addition, wind off the coasts of many southeastern states can generate substantial wind power.

Majority of the southeastern states have not engaged in a detailed evaluation of energy in recent years. Currently, apart from Louisiana, all the states in the southeast import virtually all of their fuel resources from the Gulf Coast. These imports represent an annual financial diversion of several billions of dollars some of which could be used to develop domestic, alternative energy resources. Growth in energy consumption for the residences, commercial sectors, transportation sector and industrial sectors still remains a key focus when it comes to energy efficiency among the southeastern states. Moreover, "clean" energy for residents of the southeastern states has certainly become a critical issue recently. Several of these states face serious concerns regarding their natural environment. There have been dramatic increases in emissions of air pollutants from energy use, including nitrogen oxides (NOx), sulfur dioxide (SO_2), particulates, mercury, and greenhouse gases, such as carbon dioxide (CO_2) and methane. The cost of air pollution in terms of human health alone has been unusual among states in the southeast. The rising energy cost to certain states such as Florida in the region further complicates industrial production and operation requirements, often threatening the ability of businesses to continue in operation. In essence, it is high time states in the southeast considered appropriate types of renewable energy that are environmentally friendly and can adequately substitute for the conventional energy sources at lower costs.

The main objective of this study is to determine the potential substitution between renewable energy forms and conventional energy in the southeast of U.S. The specific objectives are to: Estimate the shares of natural gas, petroleum oil, coal, renewable energy, and electricity as inputs in the energy

sector; Develop an econometric model to estimate the system of factor share equations; and Use the estimated parameters to construct an elasticity of factor substitution matrix to determine the substitutability of energy inputs. Findings of this study will be relevant in the development of a comprehensive energy policy for the region. It will also contribute significantly to the energy policy of the entire U.S. since the southeast region contributes significantly in terms of energy production and consumption in the U.S.

The remainder of this paper is structured into four sections. Section 2 focuses on literature review on energy substitution; Section 3 outlines the theoretical model specification and assumptions underlying the model as well as the types and sources of data used for the study; Section 4 presents the empirical results and discussions and Section 5 focuses on the conclusions of the study.

2. A REVIEW OF ENERGY SUBSTITUTION

Several studies on energy substitution have examined the substitution between energy inputs and non-energy inputs, emphasizing the role of energy in production. For instance, Hudson and Jorgenson (1974), Berndt and Wood (1975), Fuss (1977), and Magnus (1979) find energy as a substitute for labor but find energy as a complement for capital. Griffin and Gregory (1976) on the other hand find energy and capital to be substitutes. Carlson, Zilberman, and Miranowski (1984) find energy and chemicals as substitutes whereas Gopalakrishnan, Khaleghi, and Shresta (1989) find energy to be a weak substitute with other inputs in cross section model. Other studies (Field and Grebensteinz, 1980; Cameron and Schwartz, 1980) find distinctive differences in energy substitution estimated across industries and countries. Caloghiro et al (1997) show electricity as a weak substitute for capital and labor in Greek manufacturing industry. Similarly, Barnett et al (1998) indicate that electricity is a weak substitute for both capital and labor in major Alabama industries. Mahmud (2000) finds a slight substitution between

4

aggregate energy and other inputs but a weak substitution between electricity and gas in Pakistani manufacturing. Thompson and Yeboah (2007) find a slightly elastic fuel substitution in U.S. corn production over a two year adjustment period using time series data from 1975 to 2005.

However, not many studies have focused on the substitutability of fuels within the energy aggregate compared to substitution between energy inputs and non-energy inputs. Fuss (1977) determined a moderate sub-stitutability among coal, gas and oil, but almost none between these fuels and electricity in Canada, while Halvorsen (1976) found greater substitutability among all forms of fuel in the United States. MacAvoy (1969) used cross sectional data for U.S. power regions to examine substitution between nuclear fuel and fossil fuel. Griffin (1974) estimated dynamic price and cross price elasticities among fuels utilizing annual time series data. Likewise, this piece of research examines the substitutability of renewable energy for the conventional forms of energy in the southeastern region of U.S. using a Non-linear Seemingly Unrelated Regression (SUR) approach.

Generally, the preference for a functional form may have an effect on the estimated cross price elasticities. The translog approach, developed by Christensen, Jorgenson, and Lau (1973), distinguishes itself from earlier studies in that it begins by positing as an analogue to the production possibility frontier. On the other hand, Chang (1994) notices a minute difference between translog and constant elasticity production functions in Taiwanese manufacturing. Goodwin and Breser (1995) utilized multi-variate gradual switching regression techniques and Bayesian inferential procedures to evaluate structural change in factor demand relationships in the U.S. food manufacturing industry. The Morishima elasticities of substitution as shown in their study indicate that nearly all factors are substitutes and that the degree of substitutability has significantly increased in recent years. Yi (2000) also finds different estimates of substitution with dynamic translog and generalized Leontief production functions across Swedish manufacturing industries. Urga and Walters (2003) also indicate that the

specification of dynamic translog functions has an effect on estimates of substitution and find coal and oil substitutes in the U.S. industry.

The time period chosen and the dynamic model of substitution are also critical (Thompson, 2006). Kuper and van Soest (2003) indicate that the time period affects estimates of substitution due to path dependencies that arise given fixed cost of input adjustments. Thompson (2006) indicates that aggregation also distorts the estimates of substitution although there has been no systematic study of its effects on estimated energy substitution. Clark et al. (1988) use separability tests to show that "labor" in U.S. manufacturing has not less than nine distinct skill groups, and there are no estimates of energy substitution at this disaggregated level. Thompson (2006) again asserts that separability on the other hand is also an issue in the sense that energy might be a weak substitute for labor in an estimated model, but would be a complement with transport labor and a strong substitute for production labor in the estimate of a disaggregated model.

3. MODEL SPECIFICATION AND ASSUMPTIONS

In this paper, the functional form for energy produced in the *ith* state in period t is posited to be $E_{it} =$ $E(G_{it}, O_{it}, C_{it}, R_{it}, L_{it})$ where $G_{it}, O_{it}, C_{it}, R_{it}$, and L_{it} are natural gas, petroleum oil, coal, renewable energy and electricity inputs converted into energy output. The model requires certain restrictive assumptions to be established about the structure of production. We assume that the individual energy inputs considered in the study are as a group weakly separable from other energy input materials. The assumption of weak separability is crucial and indicates that the marginal rate of substitution between any two of the energy inputs is independent of the quantity of other energy materials used as an input. The firm or industry is also assumed to produce the profit maximizing output of energy E_{it}^{*} employing the optimal input levels of $G_{it}, O_{it}, C_{it}, R_{it}$, and L_{it} that minimize cost of production. The model assumes

competitive price-taking in the energy input market, as well as the energy output market. The results demonstrate the comparative static substitution between energy inputs given cost minimization.

According to Shephard's lemma, input demand levels are derivatives of the cost function $\emptyset_{it}(G_{pit}, O_{pit}, C_{pit}, R_{pit}, L_{pit}; X_{it})$ with respect to input prices; thus $G_{it}^* = \delta\emptyset_{it}/\delta G_{pit}$. This link between cost minimizing inputs and input prices implies a correspondence between production and cost functions. Dual estimation of cross price elasticities begins with the translog cost function (TCF). The elasticity of cost with respect to the price of say natural gas (G_{pit}) is the partial derivative of the translog cost function (TCF) with respect to the price of natural gas. Thus, $\delta 1n\emptyset_{it}/\delta 1nG_{pit} = \beta_G + \beta_{GO}1nO_{pit} + \beta_{GC}1nC_{pit} + \beta_{GR}1nR_{pit} + \beta_{GL}1nL_{pit} + \beta_{GG}1nG_{pit} + \alpha T_{Git}$.

By Shephard's lemma, $G_{it} = \delta\emptyset_{it}/\delta G_{pit}$ and $\delta 1n\emptyset_{it}/\delta 1nG_{pit} = (\delta\emptyset_{it}/\delta G_{pit}) (G_{pit}/\emptyset_{it}) = G_{it} (G_{pit}/\emptyset_{it}) = (G_{pit}*G_{it})/\emptyset_{it}$.

For a competitive firm, cost ($\emptyset_{it}$) equals revenue ($\emptyset_{it} = G_{pit}*G_{it}$). Thus, $\delta 1n\emptyset_{it}/\delta 1nG_{pit} = (G_{pit}*G_{it})/\emptyset_{it} = \theta_{Git}$ and θ_{Git} is the natural gas energy factor share of the ith state in period t. The inclusion of interaction terms in the log linear production function improves the empirical fit and allows pairs of factors to be complements in production (Thompson, 2006). It also allows a translog production function to be estimated in a symmetric system of derived factor share equations which improves estimation properties relative to a single equation.

In general, introducing interaction terms in the translog production function (TFP) is given as

$$1n\emptyset_{it} = 1n\beta_0 + \sum_L \beta_L 1nw_{Lit} + 0.5\sum_L\sum_K \beta_{LK}1nw_{Lit}1nw_{Kit}.$$

Similarly, the systematic factor share equations for the energy inputs taking into account the interaction terms are given as:

$$\theta_{Git} = \beta_G + \beta_{GG}\ln G_{pit} + \beta_{GO}\ln O_{pit} + \beta_{GC}\ln C_{pit} + \beta_{GR}\ln R_{pit} + \beta_{GL}\ln L_{pit} + \alpha T_{Git} + 0.5[\beta_{GG}(\ln G_{pit})^2 + 2\beta_{GO}\ln G_{pit}\,\ln O_{pit} + 2\beta_{GC}\ln G_{pit}\,\ln C_{pit} + 2\beta_{GR}\ln G_{pit}\,\ln R_{pit} + 2\beta_{GL}\ln G_{pit}\,\ln L_{pit}] + \alpha T_{Git}\ln G_{pit}$$

(1)

$$\theta_{Oit} = \beta_O + \beta_{OG}\ln G_{pit} + \beta_{OO}\ln O_{pit} + \beta_{OC}\ln C_{pit} + \beta_{OR}\ln R_{pit} + \beta_{OL}\ln L_{pit} + \alpha T_{Oit} + 0.5[\beta_{OO}(\ln O_{pit})^2 + 2\beta_{OG}\ln O_{pit}\,\ln G_{pit} + 2\beta_{OC}\ln O_{pit}\,\ln C_{pit} + 2\beta_{OR}\ln O_{pit}\,\ln R_{pit} + 2\beta_{OL}\ln O_{pit}\,\ln L_{pit}] + \alpha T_{Oit}\ln O_{pit}$$

(2)

$$\theta_{Rit} = \beta_R + \beta_{RG}\ln G_{pit} + \beta_{RO}\ln O_{pit} + \beta_{RC}\ln C_{pit} + \beta_{RR}\ln R_{pit} + \beta_{RL}\ln L_{pit} + \alpha T_{Rit} + 0.5[\beta_{RR}(\ln R_{pit})^2 + 2\beta_{RG}\ln R_{pit}\,\ln G_{pit} + 2\beta_{RO}\ln R_{pit}\,\ln O_{pit} + 2\beta_{RC}\ln R_{pit}\,\ln C_{pit} + 2\beta_{RL}\ln R_{pit}\,\ln L_{pit}] + \alpha T_{Rit}\ln R_{pit}$$

(3)

$$\theta_{Lit} = \beta_L + \beta_{LG}\ln G_{pit} + \beta_{LO}\ln O_{pit} + \beta_{LC}\ln C_{pit} + \beta_{LR}\ln R_{pit} + \beta_{LL}\ln L_{pit} + \alpha T_{Lit} + 0.5[\beta_{LL}(\ln L_{pit})^2 + 2\beta_{LG}\ln L_{pit}\,\ln G_{pit} + 2\beta_{LO}\ln L_{pit}\,\ln O_{pit} + 2\beta_{LC}\ln L_{pit}\,\ln C_{pit} + 2\beta_{LR}\ln L_{pit}\,\ln R_{pit}] + \alpha T_{Lit}\ln L_{pit}$$

(4)

$$\theta_{Cit} = \beta_C + \beta_{CG}\ln G_{pit} + \beta_{CO}\ln O_{pit} + \beta_{CC}\ln C_{pit} + \beta_{CR}\ln R_{pit} + \beta_{CL}\ln L_{pit} + \alpha T_{Cit} + 0.5[\beta_{CC}(\ln C_{pit})^2 + 2\beta_{CG}\ln C_{pit}\,\ln G_{pit} + 2\beta_{CO}\ln C_{pit}\,\ln O_{pit} + 2\beta_{CR}\ln C_{pit}\,\ln R_{pit} + 2\beta_{CL}\ln C_{pit}\,\ln L_{pit}] + \alpha T_{Cit}\ln C_{pit}$$

(5)

where θ_{Git} is the factor share of natural gas; θ_{Oit} is the factor share of petroleum oil; θ_{Cit} is the factor share of coal; θ_{Rit} is factor share of renewable energy; θ_{Lit} is the factor share of electricity; G_{pit} is the price of natural gas; O_{pit} is the price of petro-leum oil; C_{pit} is the price of coal; R_{pit} is the price of renewable energy; L_{pit} is the price of electricity; and T_{it} is the technology employed.

The factor shares of natural gas, petroleum oil, coal, renewable energy and electricity are computed using $\theta_{it} = e_{it}/E_{it}$, where θ_{it} represents the factor share of the energy input; e_{it} is the energy input expenditure and E_{it} is the overall or total energy expenditure. Consistent with continuous technological change over the 39 years of data, the year *t* is added as an independent variable to represent technology (T_{it}). The N-1 (i.e. four) factor share equations are normalized by coal. The coal factor equation is recovered using the restrictions imposed (see Table 2). The systems of equations are estimated using a pooled iterative Non-linear Seemingly Unrelated Regression (SUR) technique with homogeneity and symmetry restrictions imposed. Estimates of the factor share equations provide coefficients to derive substitution elasticities matrix. The coefficients are symmetric across equations from Young's theorem. Linear homogeneity or CRS implies $\sum_i \beta_i = 1$; and $\sum_i \beta_{ki} = 0$.

The cross price elasticities are derived from the estimated coefficients in the TCF cost share system. The cross price elasticity between natural gas and petroleum oil is thus given as $\Box_{GOit} = (\beta_{GOit} + \theta_{Git} \theta_{Oit})/ \theta_{Git}$.

The derivations of the other cross price elasticities are similar. Also, the own price elasticity of natural gas is derived as $\Box_{GGit} = (\beta_{GGit} - \theta_{Git} + \theta_{Git}^2)/ \theta_{Git}$. The own price elasticities of the other energy inputs are derived in a similar manner.

Historical data covering 1970 to 2008 from the U.S. Energy Information Administration (http://www.eia.gov) on total energy expenditure (million dollars), natural gas expenditure (million dollars), petroleum oil expenditure (million dollars), coal expenditure (million dollars), renewable energy expenditure (million dollars) and electricity expenditure (million dollars) were obtained for ten (10) different states in the southeast namely Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee and Virginia. Also, historical data covering the

same period on prices (dollars/million Btu) of natural gas, petroleum oil, coal, renewable energy and electricity were obtained for the above mentioned states (http://www.eia.gov).

4. EMPIRICAL RESULTS AND DISCUSSION

The results of the SUR analysis are reported in Table 1. The estimated parameters in the four factor share equations are all significant at 1% besides the estimates for electricity in the natural gas and renewable energy in the petroleum oil equations. The results also show that besides the petroleum oil equation, the homogeneity and symmetry restrictions are all significant at 1% indicating the significance of restrictions in the improvement of estimates. There is limited substitution potential when energy prices rise in fuel production. The derived matrix of substitution elasticities are as follows:

$$
\begin{bmatrix}
\varepsilon_{GG} & \varepsilon_{GO} & \varepsilon_{GR} & \varepsilon_{GL} & \varepsilon_{GC} \\
\varepsilon_{OG} & \varepsilon_{OO} & \varepsilon_{OR} & \varepsilon_{OL} & \varepsilon_{OC} \\
\varepsilon_{RG} & \varepsilon_{RO} & \varepsilon_{RR} & \varepsilon_{RL} & \varepsilon_{RC} \\
\varepsilon_{LG} & \varepsilon_{LO} & \varepsilon_{LR} & \varepsilon_{LL} & \varepsilon_{LC} \\
\varepsilon_{CG} & \varepsilon_{CO} & \varepsilon_{CR} & \varepsilon_{CL} & \varepsilon_{CC}
\end{bmatrix}
=
\begin{bmatrix}
-1.14 & 0.79 & -0.04 & 0.44 & 0.04 \\
0.18 & -0.20 & 0.01 & 0.04 & 0.07 \\
-0.61 & 0.66 & -0.75 & 0.60 & 1.14 \\
0.15 & 0.06 & 0.01 & -0.20 & 0.06 \\
0.07 & 0.52 & 0.08 & 0.33 & -0.92
\end{bmatrix}
$$

The own price elasticity of natural gas is the largest (-1.14). The own price elasticity of (-1.14) implies a 10% price increase of natural gas reduces the use of natural gas input by 11.4% and expenditure will decrease by 1.6%. Besides natural gas, all the own price elasticities are inelastic. The own price elasticity of electricity and petroleum oil are the least (-0.20). An elasticity of -0.75 implies that a 10% increase in the price of renewable energy will reduce renewable energy use by only 7.5% and expenditure will rise by 2.5%.

There is a mild substitution of natural gas for oil. An elasticity of substitution of natural gas for petroleum oil of 0.79 implies that a 10% increase in oil price will increase natural gas input use by only 7.9%. Likewise, the elasticity of substitution of natural gas for electricity of 0.44 implies that a 10%

increase in electricity price will increase natural gas input use by 4.4%. Thus, there is a weak substitution of natural gas for electricity in the southeast.

There is a greater substitution potential between renewable energy and coal. An elasticity of substitution of 1.14 implies that a 10% increase in coal price will increase renewable input use by 11.4% and expenditure decreases by 1.4%. Besides renewable energy for coal, there is very limited substitution potential of renewable energy for the other forms of energy. An elasticity of substitution of -0.61 implies that a 10% increase in natural gas price will decrease renewable input use by 6.1% and expenditure will rise by 16.1%. This may be a situation where the plant used in processing renewable energy is run by natural gas. Therefore, an increase in price of natural gas reduces the use of renewable energy. The substitution of renewable energy for natural gas is technically infeasible since the elasticity is negative. Also, an elasticity of substitution of 0.66 also implies that a 10% increase in petroleum oil price will increase renewable input use by 6.6% and expenditure will rise by 3.4%. Likewise, an elasticity of substitution of 0.60 implies that a 10% increase in electricity price will increase renewable input use by 6.0% and expenditure rises by 4.0%.

5. CONCLUSIONS

The focus of this paper was to determine the potential substitution between renewable energy and other conventional energy forms using a pooled iterative Nonlinear Seemingly Unrelated Regression (SUR) approach. The most significant findings indicate that factor demands in the southeast energy sector are price inelastic. Therefore, as prices of energy inputs increase, total expenditures in the affected factors increase. Substitutions are very low among the energy inputs reflecting either fixity in input use in the energy sector due possibly to short run commitments to output or predetermined factor usage among

others. The substitution potential of renewable energy for the conventional energy forms is higher than that of other conventional energy forms for renewable except renewable energy for natural gas. Since renewable energy has the potential to substitute for other forms of energy besides natural gas, federal and state governments might want to reverse the $10 billion petroleum subsidy versus the current $5 billion for renewable if the target (36 billion gallons of renewable fuel by 2022) set by 2007 Energy Independence Act is to be realized.

TABLES

TABLE 1: NONLINEAR SUR PARAMETER ESTIMATES

	Constant	G_p	O_p	R_p	L_p	Technology
θ_G	0.03**	-0.03***	0.03***	-0.006***	0.009	0.002***
(Natural Gas)	(0.02)	(0.01)	(0.01)	(0.001)	(0.01)	(0.0003)
θ_O	0.77***	0.03***	0.14***	0.001	-0.17***	-0.004***
(Petroleum)	(0.01)	(0.01)	(0.01)	(0.001)	(0.01)	(0.0003)
θ_R	-0.001	-0.01***	0.001	0.002***	0.002***	0.0003***
(Renewable)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.00003)
θ_L	0.20***	0.01	-0.17***	0.002***	0.16***	0.003***
(Electricity)	(0.02)	(0.01)	(0.01)	(0.001)	(0.01)	(0.0003)

| Restrict_0	Restrict_1		Restrict_2	Restrict_3	Restrict_4
920.27***	-173.0		-2792.68***	-1319.79***	-499.20***
(196.9)	(263.5)		(941.9)	(466.6)	(207.4)

Note: Standard errors are in parentheses.   *** Significance at 1 %;   ** Significance at 5 %.

TABLE 2: RECOVERY OF COAL PARAMETER ESTIMATES

Constant	β_{CG}	β_{CO}	β_{CR}	β_{CL}	β_{CC}
0.001	-0.003	-0.001	0.005	-0.002	0.001

$(\beta_C + \beta_G + \beta_O + \beta_R + \beta_L) = 1$ $\rightarrow$ $\beta_C = 1 - (\beta_G + \beta_O + \beta_R + \beta_L)$

$(\beta_{GG} + \beta_{GO} + \beta_{GR} + \beta_{GL} + \beta_{GC}) = 0$ $\rightarrow$ $\beta_{GC} = \beta_{CG} = 0 - (\beta_{GG} + \beta_{GO} + \beta_{GR} + \beta_{GL})$

$(\beta_{OG} + \beta_{OO} + \beta_{OR} + \beta_{OL} + \beta_{OC}) = 0$ $\rightarrow$ $\beta_{OC} = \beta_{CO} = 0 - (\beta_{OG} + \beta_{OO} + \beta_{OR} + \beta_{OL})$

$(\beta_{RG} + \beta_{RO} + \beta_{RR} + \beta_{RL} + \beta_{RC}) = 0$ $\rightarrow$ $\beta_{RC} = \beta_{CR} = 0 - (\beta_{RG} + \beta_{RO} + \beta_{RR} + \beta_{RL})$

$(\beta_{LG} + \beta_{LO} + \beta_{LR} + \beta_{LL} + \beta_{LC}) = 0$ $\rightarrow$ $\beta_{LC} = \beta_{CL} = 0 - (\beta_{LG} + \beta_{LO} + \beta_{LR} + \beta_{LL})$

$(\beta_{CG} + \beta_{CO} + \beta_{CR} + \beta_{CL} + \beta_{CC}) = 0$ $\rightarrow$ $\beta_{CC} = 0 - (\beta_{CG} + \beta_{CO} + \beta_{CR} + \beta_{CL})$

FIGURES
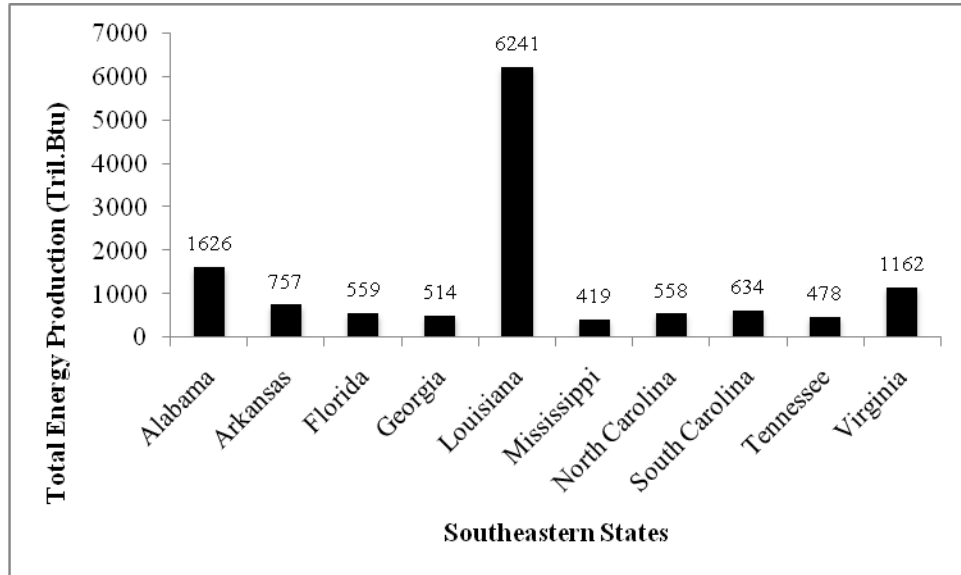
FIGURE 1: SOUTHEAST'S TOTAL ENERGY PRODUCTION IN 2008
Source: Authors' computation, 2010 (using available data from EIA, State Energy Data Report)
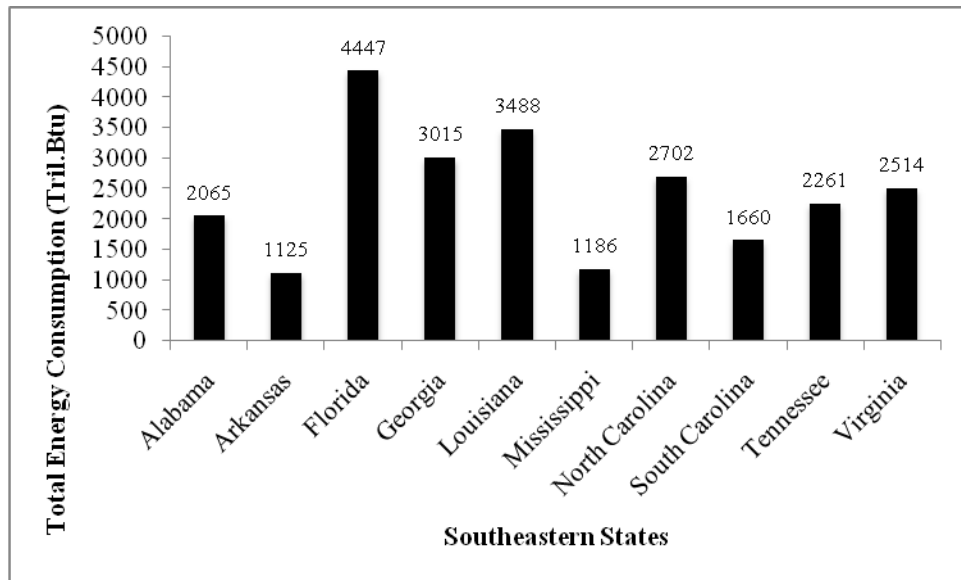
FIGURE 2: SOUTHEAST'S TOTAL ENERGY CONSUMPTION IN 2008
Source: Authors' computation, 2010 (using available data from EIA, State Energy Data Report)

REFERENCES

Barnett, A.H., K. Reutter, H. Thompson (1998) "Electricity Substitution: Some Local Industrial Evidence," *Energy Economics* 20, 411-419.

Berndt, E. R., and D. Wood (1975) "Technology, Prices, and the Derived Demand for Energy," *Review of Economic and Statistics* 57 259-268.

Caloghiro, Y., A. Mourelatos, H. Thompson (1997) "Industrial Energy Substitution during the 1980s in the Greek Economy," *Energy Economics* 19, 476-491.

Cameron, T., and S.L. Schwartz (1980) "Inflationary Expectations and the Demand for Capital, Labor and Energy in Canadian Manufacturing Industry," In: Ziemba, W.T., et al., (Eds.), Energy Policy Modeling: U.S. and Canadian Experiences, Matinus Nijhoff Publishing Boston.

Carlson, G. A., D. Zilberman, J. A. Miranwoski (1993) "Agricultural and Environmental Resource Economics," Oxford University Press.

Chang, K. (1994) "Capital-energy Substitution and the Multi-Level CES Production Function," *Energy Economics* 16, 22-26.

Christensen, L.R., D. W. Jorgenson, L. J. Lau (1973) "Transcendental Logarithmic Production Frontiers," *The Review of Economics and Statistics*, LV 28- 45.

Clark, D., R. Hofler, and H. Thompson (1988) "Separability of Capital and Labor in U.S. Manufacturing," *Economics Letters* 26, 197-201.

Energy Information Administration (2010) "State Energy Profiles," www.eia.doe.gov, U.S. Department of Energy.

Energy Information Administration (2010) "State Energy Data Report," www.eia.doe.gov, U.S. Department of Energy.

Energy Information Administration (2003) "Report on Petroleum Imports," www.eia.doe.gov, U.S. Department of Energy.

Field, B., and C. Grebensteinz (1980) "Capital Energy Substitution in U.S. manufacturing," *Review of Economics and Statistics* 62, 207-212.

Fuss, M. A. (1977)"The Demand for Energy in Canadian Manufacturing," *Journal of Econometrics* 5.

Gopalakrishnan, C., G.H. Khalegi, R.B. Shrestha (1989) "Energy-nonenergy Input Substitution in U.S. Agriculture: Some findings," *Applied Economics* 21, 673-79.

Griffin, J. M. (1974) "The Effect of Higher Prices on Electricity Consumption," Bell Journal, V 515-539.

Griffin, J. M., and P. R. Gregory (1976) "An Intercountry Translog Model of Energy Substitution Responses," *American Economic Review* 66 845-857.

Goodwin, B.K. and G.W. Brester (1995) "Structural Changes in Factor Demand Relationships in the U.S. Food and Kindred Products Industry," *American Journal of Agricultural Economics*, Vol. 77, No. 1, 69-79.

Halvorsen, R. (1976) "Energy Substitution in U.S. Manufacturing," University of Washington and National Bureau of Economic Research.

Hudson, E. A., and D. W. Jorgenson (1974) "U.S. Energy Policy and Economic Growth, 1975-2000," *The Bell Journal of Economics and Management Science*.

Kuper, G., and D. P. van Soest (2003) "Path-dependency and Input Substitution: Implications for Energy Policy Modeling," *Energy Economics* 25, 397-407.

MacAvoy, P. W. (1969) "Economic Strategy for Developing Nuclear Breeder Reactors," Cambridge: M.I.T. Press.

Magnus, J. R. (1979) "Substitution between Energy and Non- Energy Inputs in the Netherlands: 1950-1976," *Inter-national Economic Review* 20.

Mahmud, S. (2000) "The Energy Demand in the Manufacturing Sector of Pakistan: Some further Results," *Energy Economics* 22, 641-648.

Thompson, H. (2006) "The Applied Theory of Energy Substitution in Production," *ELSEVIER Energy Economics, JEL Classification: C5; Q4*.

Thompson, H. and O. Yeboah (2007) "Fuel Substitution in U.S. Corn Production: A Translog Cost Error Correction Model."

Urga, G. and C. Walters (2003) "Dynamic Translog and Linear Logit Models: A Factor Demand Analysis of Interfuel Substitution in U.S. Industrial Energy Demand," *Energy Economics* 25, 1-21.

Yeboah, O., T. Thomas, V. Ofori-Boadu, P.E. Faulkner (2008) "Fuel Prices and Substitution of Nitrogen Fertilizer input in Irrigated Corn Production," *Journal of Environmental Monitoring & Restoration 5:133-140*.

Yi, F. (2000) "Dynamic Energy-demand Models: A comparison," *Energy Economics* 22, 285-29.