The Potential of Energy Substitution in the Industrial Sector

by

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Abstract

The extent of substitutability between energy and the other factors (i.e. labour and capital) and between individual fuels (coal, electricity, natural gas and petroleum) is an extremely important question and quite central to energy policy, planning and analysis. This study considers the possibilities of energy substitution in the industrial sector of 5 major energy producers of the developing world (Brazil, China, India, Indonesia and Venezuela). The theoretical model utilized in the study is the two-stage translog cost function. The model is estimated using time series data over the period 1978 to 2003. The results indicate substantial inter-factor and inter-fuel substitutions are possible in the industrial sector. Substitution possibilities were found (1) between capital and labour, between capital and energy and between energy and labour in the inter-factor model and (2) for most combinations of fuel types in the inter-fuel model. This implies that there is some flexibility in energy policy options and energy utilization.

Keywords: Energy, Inter-factor/inter-fuel substitutability, Translog cost function, Developing countries

JEL classification: Q43, D24, O57

1. Introduction

The possibilities of energy substitution have been the subject of a number of studies over the last three decades.[1] After the 1973 oil crisis, most countries began tackling the issue of energy substitution in response to the high cost of energy. The primary objective of these studies has been to examine the impact of energy price increases on economic growth.[2] Saicheau (1987), for instance, showed that the manufacturing sector in Thailand was able to reduce energy consumption in response to rising energy price. Siddayao *et al*. (1987) find that energy price increase can be partially compensated by the use of labour in Thailand and both capital and labour in the Philippines. On the other hand, McNown *et al*. (1991) show that, energy can be substituted by use of capital in Bangladesh and both capital and labour in India and Pakistan. Recently, the increases concern over the issue of global warming and climate change has made

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[1] See Fuss (1977), Pindyck (1979), Iqbal (1986) and Andrikopoulos *et al*. (1989) for early empirical studies, and Cho *et al*. (2004) and Floros and Vlachou (2005) for more recent ones.

[2] The degree of substitutability between energy and non-energy inputs is crucial for evaluating energy policies such as energy taxes, and for understanding the impacts of energy price shocks. In general, if production inputs are easily substitutable, then changes in the input mix can occur without serious impairment of economic growth in response to resource price fluctuations. For instance, if energy and capital are substitutes, then higher energy prices will increase the demand for capital in order to maintain the level of production. Likewise, capital-labour substitutability facilitates a movement toward labour intensity in the case of reduced availability of capital. On the other hand, energy-capital complementary is harmful because the discouragement of capital formation would affect long-term growth.

energy substitution an important topic for energy economists. In some cases, the possibility of fuel substitution has been examined as a measure of policy instruments for reducing pollution. Ko and Dahl (2001), for instance, show that coal to become less responsive to price and there is a tendency that coal will be substituted with gas. Floros and Vlachou (2005), in their comprehensive study, used the estimated elasticities to investigate the impact of a carbon tax on the energy-related CO_2 emissions from the manufacturing sectors in Greek. They find that the carbon tax provide an incentive to manufacturing firms to shift to the use of natural gas and is an effective instrument to mitigate global warming.

The above empirical studies show that there are two important and inter-related issues involved in the energy substitution possibilities studies. First is the degree of substitutability of energy by primary inputs of production (capital and labour), and the second is the degree of substitution between individual fuels (coal, electricity, natural gas and petroleum product). Previous empirical evidence has claimed considerable support for inter-factor and inter-fuel substitution possibilities in the industrial sector.[3] However, most of this evidence refers to the period before 1990 and ignores the feedback effect between inter-factor and inter-fuel substitution. The interaction or feedback effect refers to the fact that changes in the relative consumption of factors (e.g. energy, capital, labour) will have an effect on the relative consumption of fuels, due to changes in total energy consumption (Cho *et al.*, 2004). Similarly, the change of price of an individual fuel, for instance, will not only cause a substitution effect among individual fuels but also a substitution effect among factors of production that is transmitted through changes in aggregate energy demand. These questions are of great importance because ignoring this feedback effect may lead to unreliable conclusions due to the fact that it only yields partial elasticities rather than total elasticities.[4]

Attempting to partially fill this gap, this study therefore aim to estimate a two-stage translog model using data from 1978 to 2003 in the industrial sector of the five major energy producers of the developing world (Brazil, China, India, Indonesia and Venezuela). [5] In the first stage, input demands for various energy components are estimated and hence an aggregate price index for energy is developed. In the second stage, this index is used as an instrument variable to

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[3] The importance of the industrial sector in the energy system is highlighted by the fact that the industrial sector is the largest of the end-use sectors, consuming 50% of delivered energy worldwide in 2003 (IE0, 2006).

[4] Fuss (1977) and Pindyck (1979) were among the first to study the feedback effect in the analysis of inter-factor and inter-fuel substitution. This approach has also been followed by Kim and Labys (1988) to examine energy substitution in the Korean industrial sector, by Andrikopoulos *et al.* (1989) in the Ontario manufacturing sector and recently by Cho *et al.* (2004) and Floros and Vlachou (2005) in Korea and in the manufacturing sectors of Greece, respectively.

[5] The countries examined here reflect significant regional economic, demographic and energy resource diversity. While their circumstances vary widely, each of these countries is a large producer of energy in the world. For instance, Brazil is the world's third largest producer of hydro electricity, China is the world's sixth largest producer of oil and the world's largest producer of coal and second largest producer of hydro electricity and petroleum products, India is the world's third largest producer of coal, Indonesia is the world's sixth largest producer of natural gas and the seventh largest producer of coal and Venezuela is the world's eight largest producers of oil (IEA, 2004).

estimate aggregate input demand for aggregate energy, capital and labour along with their price and substitution possibilities.[6] Further, this study takes into account the dynamic element of the adjustment process and the long-run structure of energy demand in the industrial sector.[7]

This paper is organised as follows. Section 2 describes the underlying economic model and the methodological approach. Section 3 explains the data. Section 4 reports the statistical estimation and interprets results. Section 5 discusses a summary of the main findings and concludes.

2. Empirical Framework

An approach used in this study is based on generalized translog production function, originally developed by Christensen *et al.* (1973). The translog functional form is often used in the empirical literature on energy substitution because of its flexibility. That is, it relaxes the traditional conditions concerning the behaviour of the producer. This functional form also places no prior restrictions on substitution elasticities. Consequently, its application facilitates the level of substitution between the factors to vary and thus allowing more flexible description of the relation between the various inputs.[8]

The model used in this study requires certain assumptions. First, materials (M) are weakly separable from the other inputs (capital (K), labour (L) and energy (E)).[9] Further, it is assumed that energy aggregate is homothetic in its coal (c), electricity (e), natural gas (g) and petroleum products (p) inputs.[10] These assumptions permit the construction of an energy price index that aggregates the price of four fuels. Under these assumptions, the production function can be written as follows:

$$Y = f(K, L, E(p, e, g, c); M) \tag{1}$$

where E is a homothetic function of the four fuels.

Assuming exogenously given input prices and output level, this production structure can alternatively be described by a cost function of the form

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[6] This is consistent with producers choosing cost-minimizing factor inputs in two stages; energy costs are minimised in the choice of fuel inputs, and total costs are minimised in the choice of energy, capital and labour inputs (Pindyck, 1979).

[7] Most of the previous analyses have used a static model. Exceptions are Taheri (1994), Christopoulos (2000) and Cho *et al*. (2004). They incorporate the dynamic structure in the two-stage translog model, so that the elasticities of inter-factor and inter-fuel substitution will give reliable computed elasticities for policy design and policy making. Hogan (1989), Taheri (1994) and Cho *et al*. (2004) explained that the adjustment process might be slow during and after a period of rapid and large changes in relative prices among inputs. Therefore, by incorporating the dynamic structure, the results obtained will show adequate knowledge of the adjustment path and the long-run structure.

[8] In contrast, a Cobb-Douglas type functions have all elasticities equal to unity while a Constant Elasticity of Substitution (CES) production function has all elasticities constant.

[9] This assumption was necessary since reliable data for prices of materials cannot be obtained for all countries in this study.

[10] This means that relative input demands are independent of the level of output.

$$C = G[(P_K, P_L, P_E(P_p, P_e, P_g, P_c); P_M), Y] \tag{2}$$

where C is total cost, P_K is capital input price, P_L is labour input price and P_E is an aggregate price index of energy, that aggregates the prices of petroleum product, (P_p), electricity (P_e), natural gas (P_g) and coal (P_c).

The cost function (2) is represented by a non-homothetic translog cost function as follows:

$$\ln C = \alpha_0 + \alpha_Y \ln Y + \sum_{i=1}^{n} \alpha_i \ln P_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \gamma_{ij} \ln P_i \ln P_j + \sum_{i=1}^{n} \gamma_{iY} \ln P_i \ln Y + \frac{1}{2}\gamma_{YY}(\ln Y)^2 \tag{3}$$

where i, j = K, L, E.[11] The variable C represents total cost of production, Y is the quantity of output, P_i is price of ith input, and α_0, α and γ are parameters to be estimated and *ln* represents the natural logarithm.

The firm's system of cost minimizing input demand functions can be obtained by differentiating the cost function (equation (3)) with respect to input prices. This yields the following input share equations

$$\partial \ln C / \partial \ln P_i = P_i X_i / C = S_i \tag{4}$$

where X_i is the amount of the ith input factor employed in the production process for i, j = K, L, E. The variable S_i indicates the cost share of the ith input factor, which is given by $P_i X_i / C$ with $C = P_K X_K + P_L X_L + P_E X_E$. Thus, combining equations (3) and (4), the input demand functions in terms of cost share can be expressed as:

$$S_i = \alpha_i + \gamma_{iY} \ln Y + \sum_{j=1}^{n} \gamma_{ij} \ln P_j \tag{5}$$

where i, j = K, L, E.

As postulated in the theory, the cost function must be homogeneous of degree one in prices, and satisfy the properties of a well-behaved cost function. In addition, the system of equation (5) must satisfy the adding up condition, namely that the sum of all shares equals to unity. These conditions imply the following restrictions:

$$\sum_{i}^{n} \alpha_i = 1; \quad \sum_{i}^{n} \gamma_{ij} = 0; \quad \sum_{i}^{n} \gamma_{iY} = 0; \quad \gamma_{ij} = \gamma_{ji} \tag{6}$$

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[11] The present study disregards materials as a factor of inputs due to the absence of data on prices and quantities of materials.

The degree of substitutability between factors of production can be measured with the Allen partial elasticity of substitution (AES) and the cross price elasticity of substitution. The Allen elasticity is a share-weighted cross-price elasticity which measures the proportionate change in relative factor shares induced by proportionate changes in relative price of factors. Nevertheless, the cross-price elasticity measures the proportionate change in amount of factor use induced by a proportionate change in the price of the other factor. Therefore, the cross price elasticity is a more useful measure for policy purposes (Saicheau, 1987).

The Allen own- and cross-partial elasticities of substitution (σ_{ii}, σ_{ij}) are estimated as:

$$\begin{aligned} \sigma_{ii} &= (\gamma_{ii} + S_i^2 - S_i) / S_i^2 \\ \sigma_{ij} &= (\gamma_{ij} + S_i S_j) / S_i S_j \end{aligned} \tag{7}$$

Positive and negative signs indicate that the factors are substitutes and complements, respectively. Own- and cross-partial elasticities of factor demand (η_{ii}, η_{ij}) are estimated as:

$$\begin{aligned} \eta_{ii} &= \partial \ln X_i \big/ \partial \ln P_i = \sigma_{ii} S_i \\ \eta_{ij} &= \partial \ln X_i \big/ \partial \ln P_j = \sigma_{ij} S_j \end{aligned} \tag{8}$$

where S_i and S_j are the cost share of the *i*th and the *j*th factor relative to the total factor cost and with *i* and *j* equal to capital, labour and energy.

The model developed so far relates only an aggregate production function with three inputs (K, L and E). Since a model of industrial energy use involves the breakdown of total costs of production into expenditure shares of capital, labour and energy, the estimation of this model therefore requires a price index for aggregate energy use. As Pindyck (1979) noted, although price series for individual fuels are available, a price index that reflects the unit cost of energy will not be the same as a simple weighted average of fuel prices because fuels are not perfect substitutes. Therefore, Pindyck (1979) proposed to estimate an aggregator function that relates the aggregate price index to the component prices. This approach has been followed, among others, by Andrikopoulos *et al.* (1989) and Cho *et al.* (2004). The homothetic translog cost function is used to represent the aggregate price of energy, which takes the form

$$\ln P_E = \beta_0 + \sum_{i=1}^{n} \beta_i \ln P_i + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} \ln P_i \ln P_j \qquad i, j = p, e, g, c \tag{9}$$

where P_E is the aggregate price of energy and also can be viewed as the cost per unit of energy to the optimizing agent and P_i and P_j are the prices of the individual fuels.

The cost of each input as a proportion of the total cost of energy can be obtained by differentiating the cost function (4.10) with respect to $\ln P = (\ln P_c, \ln P_e, \ln P_g, \ln P_p)$, and can be written as

$$S_{Ei} = \beta_i + \sum_{j}^{n} \beta_{ij} \ln P_j \tag{10}$$

where S_{Ei} is the cost share of the *i*th fuel in the cost of aggregate energy. The adding up criterion and the properties of neoclassical production theory require the following restrictions:

$$\sum_{i}^{n} \beta_i = 1; \quad \sum_{i}^{n} \beta_{ij} = 0; \quad \beta_{ij} = \beta_{ji} \tag{11}$$

where the first two restrictions are implied by the adding up criteria and the third by the symmetry restriction.

The Allen-Uzawa elasticities of substitution and the price elasticities for each energy type can be calculated using equations (7) and (8), respectively. However, these elasticities account only for substitution between fuels and are based on the assumption that the total quantity of energy consumed remains constant. Thus, these elasticities are partial price elasticities and cannot be used to determine the total effect of a change in price on the demand for a particular fuel. Following Pindyck (1979) and Cho *et al.* (2004), the total price elasticities can be calculated as follows:

$$\begin{aligned} \eta_{ii}^{*} &= \eta_{ii} + \eta_{EE} S_i \\ \eta_{ij}^{*} &= \eta_{ij} + \eta_{EE} S_j \end{aligned} \tag{12}$$

where i and j are individual fuel sources and η_{EE} is the own price elasticity of aggregate energy (E), calculated from equations (3) and (5).

The factor demand systems (5) and (10) are static and hold only in equilibrium.[12] Since fuel and factor demands are relatively fixed in the short run but may vary substantially in the long run, the analysis of a static cost function may miss important substitution effects. According to Cho *et al.* (2004) and Hogan (1989), a slow adjustment process might occur during and after a period of rapid and large changes in relative prices among inputs. Furthermore, in the short-run there is uncertainty about the future cost of capital, energy and labour prices and

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[12] In the static model, which is referred to as the long-run model, it is assumed that there is no difference between consumers or producers short-run and long-run behaviour. That is, the behaviour of consumers and producers is always in "equilibrium". However, in reality, habit persistence, adjustment cost, imperfect information, incorrect expectations, and misinterpreted real price changes often prevent consumers from adjusting their expenditure instantly to price and income changes (Anderson and Blundell, 1983).

output. Thus, ignoring the dynamic element would lead to inadequate knowledge of the adjustment process and of the long-run structure.

To model the dynamic form of the cost share the partial adjustment model proposed by Nerlove (1958) is used. This dynamic structure is based on the partial adjustment mechanism in which a stochastic relationship between the desired fuel of factor cost-share (S_{it}^*) and the actual share (S_{it}) at time *t* can be explained according to the following linear function:

$$S_{it} - S_{i,t-1} = (1-\theta)(S_{it}^* - S_{i,t-1}) + v_{it} \tag{13}$$

where $(1-\theta)$ is the rate of adjustment of S_{it} to S_{it}^* (which is to be estimated), S_{it}^* is the desired level of cost share of *i*th fuel or factor at time *t* and is given by the system in (5) and (10) and v_{it} is the disturbance term. Solving for S_{it}^* in (13) and substituting in to (5) and (10), the dynamic (lagged) share system of fuels and factors are given by

$$\begin{aligned} S_{it}^{FACTOR} &= \alpha_i^* + \gamma_i^* \ln y_t + \sum_j^n \gamma_{ij}^* \ln p_{jt} + \theta_i S_{i,t-1}^{FACTOR} \qquad && i, j = K, E, L \\ S_{it}^{FUEL} &= \beta_i^* + \sum_j^n \beta_{ij}^* \ln p_{jt} + \widetilde{\theta}_i S_{i,t-1}^{FUEL} && i, j = c, e, g, p \end{aligned} \tag{14}$$

which is identical to the static version in equations (4.5) and (4.11) except for the lagged dependent variable terms, whose coefficients θ and $\widetilde{\theta}$ measures the rate of dynamic adjustment.

Taheri (1994) and Christopoulos (2000) shown that under the dynamic specification of share equations, the partial and total own-price and cross-price elasticities are calculated as:

$$\varepsilon_{ii} = \frac{\eta_{ii}}{S_i} + S_i - 1; \;\; \varepsilon_{ij} = \frac{\eta_{ij}}{S_i} + S_j; \;\; \varepsilon_{ii}^* = \eta_{ii} + \eta_{EE} S_i; \;\; \varepsilon_{ij}^* = \eta_{ij} + \eta_{EE} S_j \tag{15}$$

where $i, j = c, e, g, p$. The long-run partial and total own-price and cross-price elasticities are calculated as:

$$\varepsilon_{ii}^{LR} = \varepsilon_{ii} \big/ (1-\theta); \;\; \varepsilon_{ij}^{LR} = \varepsilon_{ij} \big/ (1-\theta); \;\; \varepsilon_{ii}^{*LR} = \varepsilon_{ii}^* \big/ (1-\theta); \;\; \varepsilon_{ij}^{*LR} = \varepsilon_{ij}^* \big/ (1-\theta) \tag{16}$$

for all i, j and the ε_{ii}'s and ε_{ij}'s are the short-run elasticities, which are calculated as in equations (15).

3. Data Description

The data on individual fuel (coal, electricity, natural gas and petroleum products) consumption levels in thousands of metric tons of oil equivalent are taken from Energy Balances of OECD and non-OECD countries. The price of individual fuels refers to energy end-use prices in industry sector for specific fuels and is taken from the Energy Prices and Taxes, International Energy Agency. The data on output, employment, wage and capital stock are obtained from the United Nations Industrial Development Organization (UNIDO), Industrial Statistics database. The data on the interest rate is obtained from the International Financial Statistics (IFS), which refers to the discount rate or bank rate and the data on the real GDP and the GDP deflator are obtained from the United Nations Statistic Divisions. The variables are constructed as follows.

Output is defined as real value of output and covers only activities of an industrial nature. Capital refers to the value of purchases and own-account construction of fixed assets during the reference year less the value of corresponding sales. Total cost is defined as the sum of compensation to labour, fuel and capital inputs. Using the formula provided in Andrikopoulos *et al.* (1989) and Cho *et al.* (2004), the total capital cost is calculated as $K_C = (\delta + r)K$ where δ is the depreciation rate, which refers to the ratio of capital consumption allowances to the gross domestic product (McNown *et al.*, 1991), r is the market interest rate and K is the real capital stock normalized by the implicit GDP deflator. The price of labour is calculated by converting nominal wages into real terms with the GDP deflator. Total labour cost is calculated by the multiplication of the total labour by the real wage, while total energy cost is computed as the sum of the coal, electricity, natural gas and petroleum product costs measured in US dollar per tons of oil equivalent.

4. Empirical Results

4.1 Inter-factor Model

The estimated regression coefficients for the inter-factor model are presented in Appendix 4. The majority of the estimated coefficients are statistically significant at a 5% level. The adjusted R^2 values suggest that the model fits to the data fairly well.

Table 1 presents own and cross price elasticities for the three factor inputs, estimated at the mean values of cost shares. Most of the countries have significant own price elasticities of energy (η_{EE}), capital (η_{KK}) and labour (η_{LL}) at 1% level in the short-run and in the long-run. These results imply that in general, increases in the price of a given factor decrease the demand for that particular factor. For instance, an increase by 1% of capital cost will decrease the demand for capital by 0.20% to 0.53 % for these countries.

The elasticities of demand for capital for most of the countries are small in magnitude, and indicate that investment will respond weakly to changes in real prices. In particular, in the case of Indonesia, the demand for capital is the least sensitive to own-price changes. Such estimates are intuitively plausible for a relatively capital-scarce country and reflect an almost general phenomenon in developing countries faced by capital deficiency. The demand for labour is relatively more responsive to changes in price, especially in India and Indonesia. These results appear related to an abundant labour supply and low wages in these two countries.

The elasticity of substitution between capital and labour is positive, as is the elasticity between capital and energy and between labour and energy, indicating substitutability. The elasticity of substitution between capital and labour is significant in all countries except Brazil and Indonesia. In regard to the elasticity of substitution between capital and energy, all countries meet the established significance level (at 5% significance level). However, the *t*-statistics for the elasticity of substitution between labour and energy suggest that the estimates are not significantly different from zero.

The cross-price elasticities, which measure the responsiveness of the quantity demanded of a good to a change in the price of another good show that all inputs are substitutes to each other, because the elasticities are found to be positive. The cross-price elasticities between capital and energy (η_{KE}) are highly significant for all countries. With regard to the energy and labour relationship, the cross-price elasticities (η_{EL}) are also significant for most of the countries, except in Indonesia. These results imply that there is a moderate responsiveness of factor inputs to changing factor prices. Energy is found to be substitutable by non-energy factors in the industrial sector of five major energy producers in the developing countries. Therefore, changes in energy prices can be accommodated by changes in the input mix, ameliorating adverse effects on economic growth. For example, energy price shocks do not lead to decrease in capital formation because higher energy prices will increase the demand for capital in order to maintain the level of production.

4.2 Inter-fuel Model

The parameters of the estimated translog cost function for inter-fuel model are reported in Appendix 5. Most of the estimated coefficients are statistically significant at the conventional level. In addition, estimates of the effect of lagged dependent variables are strongly significant for most of the countries, which provides support to the partial (lagged) adjustment response. The adjusted R square values, range between 0.78 and 0.98. These values are extremely high indicating that the dynamic versions provide significantly better overall fits than their static version.

The elasticities of substitution and partial price elasticities of the fuels are reported in Appendix 6. Table 2 presents the total price elasticities and cross-price elasticities of the fuels. Most of the own price elasticities are negative and significant at 1% level (except for petroleum product in Venezuela and electricity in China).

With regards to the cross price elasticities the results indicate that electricity and petroleum (η_{ep}) have probably been substitutes in the industrial sector of all countries, except Indonesia, where complementarity prevails since the cross price elasticity is negative. There is also some evidence of inter-fuel substitution possibilities involving gas and petroleum (η_{gp}) and coal and petroleum (η_{cp}) for Brazil and Venezuela. These findings suggest that the effect of higher petroleum prices was to provide a stimulus to consumption of electricity, natural gas and coal. Therefore, the alternative sources to petroleum were electricity (in the case of Brazil, China, India and Venezuela); natural gas and coal (in the case of Brazil and Venezuela).

The results of the cross-price elasticity also confirm a very inelastic response of electricity to a change in the price of natural gas (η_{eg}) for Venezuela and to a change in the price of coal (η_{ec}) for China. As noted by Andrikopoulos *et al.* (1989), this result can be explained by the fact that electricity is the most inflexible form of energy, because it is used mainly for lighting and motive power. Thus, the substitution possibilities are rather weak. For example, the cross-price elasticity between electricity and natural gas in Venezuela is 0.64 and therefore an increase of 1% in the relative price of natural gas would lead to only 0.64% increase in the demand for electricity by the industrial sector. On the other hand, the cross price elasticity between electricity and coal is 0.10 and this indicates that an increase of 1% in the price of coal would lead to only 0.10% increase in the demand for electricity.

There is also some evidence of substitution possibilities between gas and coal in Brazil and Indonesia, where the elasticity of substitution for coal with respect to natural gas price (η_{cg}) is larger than the elasticity of substitution for natural gas with respect to coal price (η_{gc}). These findings imply that natural gas, which is cleaner-burning and has lower environmental impact, has replaced coal as the preferred source of energy in the industrial sector for Brazil and Indonesia.

5. Conclusion

This paper examines the scope for substitution between factors of production and types of fuels, by taken into account possible feedback effects between inter-factor and inter-fuel substitution. To account for the feedback effect, the two-stage estimation method is utilized.

The empirical findings in this study show some interesting results. In the inter-factor model, substitutability is observed between capital and labour (for China, India and Venezuela), between capital and energy (for all countries) and energy and labour (for all countries, except Indonesia). These findings confirm previous evidence that production technologies in these countries allow flexibility in the capital-labour, capital-energy and energy-labour mix. In response to energy price fluctuations, these countries could substitute capital for energy, and therefore, to some extent, sustain their economic growth.

In the inter-fuel model, the findings provide evidence that petroleum products can be substituted with electricity for most of the countries and with natural gas and coal for Brazil and Venezuela. In addition, the evidence for significant inter-fuel substitution between coal and natural gas in Brazil and Indonesia may suggest that there have been changes in both the structure of production and the energy system, promoting the use of natural gas to shift away form high-carbon fuel technologies. This finding provides a better energy policy option and this is significant for current environment policy.

Table 1: Elasticities of Substitution and Price Elasticities of Demand for Factors in Industrial Sector of Developing Countries

	BRAZIL		**CHINA**		**INDIA**		**INDONESIA**		**VENEZUELA**	
	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR
Elasticities of substitution										
σ_{KL}	0.96	1.97	0.97***	0.90***	0.86***	1.85***	0.98	1.35	1.00	2.34**
	(0.39)	(0.80)	(4.18)	(3.85)	(8.06)	(17.28)	(0.81)	(1.13)	(0.94)	(2.21)
σ_{KE}	0.94**	1.94***	0.98***	0.91***	1.00***	2.15***	0.87***	1.20***	0.93	2.19**
	(2.00)	(4.12)	(4.73)	(4.36)	(9.29)	(19.91)	(9.57)	(13.25)	(1.10)	(2.57)
σ_{LE}	1.06	2.19	1.00	0.92	1.00	2.14	0.99	1.37	1.05	2.45
	(0.34)	(0.71)	(0.54)	(0.50)	(0.25)	(0.53)	(0.12)	(0.16)	(0.13)	(0.30)
Price elasticities										
η_{KK}	0.75***	1.55***	-0.35***	-0.32***	-0.25***	-0.53***	-0.15	-0.20**	0.06	0.15
	(6.45)	(13.29)	(-3.11)	(-2.87)	(-4.66)	(-9.99)	(-1.48)	(-2.04)	(0.11)	(0.25)
η_{LL}	-0.61**	-1.26***	0.24***	0.22***	-3.61***	-7.74***	-8.69***	-12.03***	-0.32***	-0.74***
	(-2.28)	(-4.71)	(4.72)	(4.35)	(-17.14)	(-36.75)	(-8.41)	(-11.63)	(-2.79)	(-6.55)
η_{EE}	0.55***	1.13***	0.03	0.03	-1.56***	-3.35***	-2.78***	-3.85***	0.51***	1.20***
	(12.49)	(25.74)	(1.22)	(1.12)	(-33.57)	(-71.99)	(-50.60)	(-70.03)	(6.99)	(16.39)
η_{KL}	0.12	0.25	0.44***	0.40***	0.12***	0.25***	0.09	0.12	0.24	0.55**
	(0.39)	(0.80)	(4.18)	(3.85)	(8.06)	(17.28)	(0.81)	(1.13)	(0.94)	(2.21)
η_{KE}	0.76**	1.57***	0.46***	0.43***	0.42***	0.90***	0.26***	0.37***	0.65	1.52**
	(2.00)	(4.12)	(4.73)	(4.36)	(9.29)	(19.91)	(9.57)	(13.25)	(1.10)	(2.57)
η_{LK}	0.06	0.12	0.08***	0.07***	0.38***	0.82***	0.59	0.82	0.07	0.16**
	(0.39)	(0.80)	(4.18)	(3.85)	(8.06)	(17.28)	(0.81)	(1.13)	(0.94)	(2.21)
η_{LE}	0.86	1.78	0.47***	0.43	0.42	0.90	0.30	0.42	0.73	1.70
	(0.34)	(0.71)	(0.54)	(0.50)	(0.25)	(0.53)	(0.12)	(0.16)	(0.13)	(0.30)
η_{EK}	0.06***	0.12***	0.08**	0.07**	0.44***	0.95***	0.53***	0.73***	0.06	0.15**
	(4.10)	(8.44)	(2.18)	(2.01)	(7.71)	(16.54)	(2.68)	(3.70)	(0.96)	(2.26)
η_{EL}	0.14***	0.28***	0.45***	0.41***	0.14**	0.29***	0.09	0.12	0.25***	0.58***
	(3.90)	(8.04)	(9.76)	(8.99)	(2.04)	(4.38)	(0.41)	(0.57)	(8.36)	(19.61)

Notes: The figures in parentheses are t-statistics.***, ** and * indicate significance at 1%, 5% and 10%, respectively

Table 3: Total Fuel Price Elasticity of Demand for Fuels in Industrial Sector of Developing Countries

	BRAZIL		**CHINA**		**INDIA**		**INDONESIA**		**VENEZUELA**	
	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR
η_{pp}	-0.50***	-1.16***	-0.79***	-0.82***	-1.47***	-2.00***	-1.86***	-4.45***	0.00	0.01
	(-6.36)	(-14.76)	(-14.74)	(-15.39)	(-30.99)	(-42.08)	(-47.56)	(-113.95)	(0.21)	(0.39)
η_{ee}	-0.20	-0.47***	-0.06	-0.06	-1.23***	-1.66***	-1.35***	-3.24***	-6.20***	-11.51***
	(-1.49)	(-3.45)	(-0.46)	(-0.48)	(-18.32)	(-24.87)	(-26.20)	(-62.78)	(-39.89)	(-74.14)
η_{gg}	-18.84***	-43.69***	-78.25***	-81.73***	-49.07***	-66.64***	-4.48***	-10.74***	-3.79***	-7.04***
	(-92.02)	(-213.42)	(-762.96)	(-796.92)	(-358.68)	(-487.11)	(-40.77)	(-97.67)	(-39.44)	(-73.29)
η_{cc}	-17.55***	-40.70***	-0.52***	-0.54***	-4.13***	-5.61***	-1.80**	-4.31***	-12.61***	-23.43***
	(-31.23)	(-72.43)	(-9.14)	(-9.55)	(-19.59)	(-26.61)	(-2.53)	(-6.06)	(-7.21)	(-13.40)
η_{pe}	0.97***	2.24***	0.93***	0.97***	0.10**	0.14***	-0.44***	-1.05***	0.26***	0.49***
	(10.38)	(24.06)	(15.55)	(16.24)	(2.12)	(2.88)	(-7.81)	(-18.71)	(13.99)	(26.00)
η_{pg}	0.06***	0.13***	-0.01***	-0.01***	-0.09***	-0.12***	-0.35***	-0.84***	0.22***	0.41***
	(3.35)	(7.77)	(-2.73)	(-2.85)	(-11.62)	(-15.78)	(-14.21)	(-34.04)	(10.38)	(19.28)
η_{pc}	0.03***	0.06***	-0.11***	-0.11***	-0.10***	-0.14***	-0.13***	-0.32***	0.02	0.04**
	(3.56)	(8.25)	(-3.06)	(-3.20)	(-6.32)	(-8.59)	(-10.15)	(-24.31)	(1.08)	(2.01)
η_{ep}	1.14***	2.64***	1.61***	1.69***	0.15**	0.20***	-0.24***	-0.57***	1.71***	3.17***
	(10.38)	(24.06)	(15.55)	(16.24)	(2.12)	(2.88)	(-7.81)	(-18.71)	(13.99)	(26.00)
η_{eg}	-0.01	-0.02	-0.03***	-0.03***	-0.32***	-0.43***	-0.34***	-0.82***	0.34***	0.64***
	(-0.21)	(-0.48)	(-5.94)	(-6.20)	(-26.83)	(-36.43)	(-12.64)	(-30.27)	(2.47)	(4.60)
η_{ec}	-0.02*	-0.06***	0.09***	0.10***	-0.08***	-0.10***	-0.08***	-0.18***	0.00	0.00
	(-1.97)	(-4.56)	(2.59)	(2.70)	(-3.58)	(-4.86)	(-4.04)	(-9.69)	(0.00)	(0.01)
η_{gp}	0.93***	2.16***	-0.34***	-0.36***	-3.27***	-4.44***	-0.80***	-1.91***	0.61***	1.14***
	(3.35)	(7.77)	(-2.73)	(-2.85)	(-11.62)	(-15.78)	(-14.21)	(-34.04)	(10.38)	(19.28)
η_{ge}	-0.09	-0.22	-0.75***	-0.79***	-7.79***	-10.58***	-1.45***	-3.47***	0.15**	0.28***
	(-0.21)	(-0.48)	(-5.94)	(-6.20)	(-26.83)	(-36.43)	(-12.64)	(-30.27)	(2.47)	(4.60)
η_{gc}	0.66***	1.53***	-0.06	-0.06	0.07	0.09	0.07	0.17***	-0.07	-0.14*
	(7.86)	(18.24)	(-1.13)	(-1.18)	(0.51)	(0.69)	(1.31)	(3.14)	(-0.93)	(-1.74)
η_{cp}	0.61***	1.41***	-0.09***	-0.09***	-0.57***	-0.77***	-1.25***	-2.99***	0.57	1.05***
	(3.56)	(8.25)	(-3.06)	(-3.20)	(-6.32)	(-8.59)	(-10.15)	(-24.31)	(1.08)	(2.01)
η_{ce}	-0.49*	-1.13***	0.04***	0.04***	-0.29***	-0.39***	-1.32***	-3.16***	0.00	0.00
	(-1.97)	(-4.56)	(2.59)	(2.70)	(-3.58)	(-4.86)	(-4.04)	(-9.69)	(0.00)	(0.01)
η_{cg}	0.95***	2.19***	0.00	0.00	0.01	0.01	0.29	0.69***	-0.67	-1.24*
	(7.86)	(18.24)	(-1.13)	(-1.18)	(0.51)	(0.69)	(1.31)	(3.14)	(-0.93)	(-1.74)

Notes: The figures in parentheses are t-statistics.***, ** and * indicate significance at 1%, 5% and 10%, respectively.

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Appendix 1

Estimation Procedure and Estimation Technique

The parameters to be estimated are contained in the two systems of equations (5) and (10) for the static model and two systems of equations (14) for the dynamic model. This system of share equations can be specified in a stochastic framework if an error term is introduced as follows:

$$S_i = \alpha_i + \gamma_{iy} \ln y + \sum_j^n \gamma_{ij} \ln p_j + u_i \qquad i,j = K,E,L \qquad \text{(A.1)}$$

$$S_{Ei} = \beta_i + \sum_j^n \beta_{ij} \ln p_{Ej} + \varepsilon_i \qquad i,j = c,e,g,p \qquad \text{(A.2)}$$

$$S_{it}^{FACTOR} = \alpha_i^* + \gamma_i^* \ln y_t + \sum_j^n \gamma_{ij}^* \ln p_{jt} + \theta_i S_{i,t-1}^{FACTOR} + u_i \qquad i,j = K,E,L \qquad \text{(A.3)}$$

$$S_{it}^{FUEL} = \beta_i^* + \sum_j^n \beta_{ij}^* \ln p_{jt} + \widetilde{\theta}_i S_{i,t-1}^{FUEL} + \varepsilon_i \qquad i,j = c,\, e,\, g,\, p \qquad \text{(A.4)}$$

where u_i and ε_i are error terms. With the additive errors appended, the system of share equations (4.21) to (4.24) can be written out in full as shown in Appendix 2. The technical details of this procedure are given in the Appendix 3.

The econometric methods used to estimate the systems in these equations need to allow for an adequate treatment of measurement errors in share equations as well as the imposition of the theoretical restrictions. As the sum of the factor shares sums to unity (adding-up criterion) the sum of the disturbances across the three (four) share factor input (energy) equations is zero at each observation. This implies a singular disturbance covariance matrix. In addition, due to the existence of contemporaneous correlation between the error terms in the share equations, OLS estimates are no longer efficient.[13]

An alternative estimation procedure, and the approach used here, is to estimate jointly the cost share equations as a multivariate regression system. The complete system of share equations is estimated using Zellner's methods for Seemingly Unrelated Regression Equations (SURE).[14] To avoid singularity of the variance-covariance matrix of errors, one of the equations need to be left out of the estimation and parameters of the omitted equation are calculated using the additivity restrictions.

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[13] Note that the Zellner method is no more efficient than OLS when there are no restrictions and all the equations contain the same set of regressors (Johnston and Dinardo, 1997)

[14] The iterative SURE estimator is also known as the iterative Zellner's seemingly unrelated estimator. In brief, the iterative SURE method involves the following steps. Initially each of the equations is estimated using OLS. From these estimates the residuals are calculated and the covariance matrix of the residuals is estimated. The coefficients arrived at the initial stage are then revised to take into account the covariance between the residual. The residuals are recalculated and the same procedure is repeated till convergence is achieved.

This procedure is satisfactory since it yields estimates which converge to maximum likelihood parameter estimates. An important property of the SURE estimates is that the parameters are unique and independent of the share equation that is dropped.[15] Invariance can be obtained by iterating Zellner's method so that the parameter estimates and residual covariance matrix converge (Berndt and Wood, 1975).

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[15] The estimation method will normally not be invariant to the equation deleted. Kmenta and Gilbert (1968) have demonstrated that iteration of the Zellner estimation procedure until convergence results in maximum-likelihood estimates and is a computationally efficient method. Barten (1969) has shown that maximum-likelihood estimates of a set of share equations are invariant to which equation is omitted.

Appendix 2

The System of Share Equations

With the additive errors appended, the system of share equations (A.1) to (A.4) can be written out in full as:

$$\left.\begin{aligned}
S_K &= \alpha_K + \gamma_{KK} \ln P_K + \gamma_{KE} \ln P_E + \gamma_{KL} \ln P_L + \gamma_{Ky} \ln y + u_K, \\
S_E &= \alpha_E + \gamma_{EK} \ln P_K + \gamma_{EE} \ln P_E + \gamma_{EL} \ln P_L + \gamma_{Ey} \ln y + u_E, \\
S_L &= \alpha_L + \gamma_{LK} \ln P_K + \gamma_{LE} \ln P_E + \gamma_{LL} \ln P_L + \gamma_{Ly} \ln y + u_L.
\end{aligned}\right\} \tag{A.5}$$

$$\left.\begin{aligned}
S_p &= \beta_p + \beta_{pp} \ln p_p + \beta_{pe} \ln p_e + \beta_{pg} \ln p_g + \beta_{pc} \ln p_c + \varepsilon_p, \\
S_e &= \beta_e + \beta_{ep} \ln p_p + \beta_{ee} \ln p_e + \beta_{eg} \ln p_g + \beta_{ec} \ln p_c + \varepsilon_e, \\
S_g &= \beta_g + \beta_{gp} \ln p_p + \beta_{ge} \ln p_e + \beta_{gg} \ln p_g + \beta_{gc} \ln p_c + \varepsilon_g, \\
S_c &= \beta_c + \beta_{cp} \ln p_p + \beta_{ce} \ln p_e + \beta_{cg} \ln p_g + \beta_{cc} \ln p_c + \varepsilon_c.
\end{aligned}\right\} \tag{A.6}$$

$$\left.\begin{aligned}
S_K^{FACTOR} &= \alpha_K^* + \gamma_{KK}^* \ln P_K + \gamma_{KE}^* \ln P_E + \gamma_{KL}^* \ln P_L + \gamma_{Ky}^* \ln y + \theta_K S_{K-1} + u_K, \\
S_E^{FACTOR} &= \alpha_E^* + \gamma_{EK}^* \ln P_K + \gamma_{EE}^* \ln P_E + \gamma_{EL}^* \ln P_L + \gamma_{Ey}^* \ln y + \theta_E S_{E-1} + u_E, \\
S_L^{FACTOR} &= \alpha_L^* + \gamma_{LK}^* \ln P_K + \gamma_{LE}^* \ln P_E + \gamma_{LL}^* \ln P_L + \gamma_{Ly}^* \ln y + \theta_L S_{L-1} + u_L.
\end{aligned}\right\} \tag{A.7}$$

$$\left.\begin{aligned}
S_p^{FUEL} &= \beta_p^* + \beta_{pp}^* \ln p_p + \beta_{pe}^* \ln p_e + \beta_{pg}^* \ln p_g + \beta_{pc}^* \ln p_c + \theta_p S_{p-1} + \varepsilon_p, \\
S_e^{FUEL} &= \beta_e^* + \beta_{ep}^* \ln p_p + \beta_{ee}^* \ln p_e + \beta_{eg}^* \ln p_g + \beta_{ec}^* \ln p_c + \theta_e S_{e-1} + \varepsilon_e, \\
S_g^{FUEL} &= \beta_g^* + \beta_{gp}^* \ln p_p + \beta_{ge}^* \ln p_e + \beta_{gg}^* \ln p_g + \beta_{gc}^* \ln p_c + \theta_g S_{g-1} + \varepsilon_g, \\
S_c^{FUEL} &= \beta_c^* + \beta_{cp}^* \ln p_p + \beta_{ce}^* \ln p_e + \beta_{cg}^* \ln p_g + \beta_{cc}^* \ln p_c + \theta_c S_{c-1} + \varepsilon_c.
\end{aligned}\right\} \tag{A.8}$$

Appendix 3

Technical Details on the Statistical Estimation

A.3.1: The estimation of the sub-energy model (inter-fuel)

In the first stage of the estimation (inter-fuel model), the unrestricted system of four input cost shares equations can be written as:

$$\begin{aligned} S_p &= \beta_p + \beta_{pp}\ln p_p + \beta_{pe}\ln p_e + \beta_{pg}\ln p_g + \beta_{pc}\ln p_c \\ S_e &= \beta_e + \beta_{ep}\ln p_p + \beta_{ee}\ln p_e + \beta_{eg}\ln p_g + \beta_{ec}\ln p_c \\ S_g &= \beta_g + \beta_{gp}\ln p_p + \beta_{ge}\ln p_e + \beta_{gg}\ln p_g + \beta_{gc}\ln p_c \\ S_c &= \beta_c + \beta_{cp}\ln p_p + \beta_{ce}\ln p_e + \beta_{cg}\ln p_g + \beta_{cc}\ln p_c \end{aligned} \tag{A.9}$$

where β's are parameter to be estimated. Since the cost shares sum to unity at each observation, the parameter estimates must satisfy the following relations:

$$\begin{aligned} &\beta_p + \beta_e + \beta_g + \beta_c = 1, \\ &\beta_{pp} + \beta_{ep} + \beta_{gp} + \beta_{cp} = 0, \\ &\beta_{pe} + \beta_{ee} + \beta_{ge} + \beta_{ce} = 0, \\ &\beta_{pg} + \beta_{eg} + \beta_{gg} + \beta_{cg} = 0, \\ &\beta_{pc} + \beta_{ec} + \beta_{gc} + \beta_{cc} = 0. \end{aligned} \tag{A.10}$$

Of the twenty estimated parameters, only fifteen are free. The free parameters can be estimated by arbitrarily dropping one equation. The choice of the equation to be dropped does not affect the results. The parameter estimates from the dropped equation can be derived from the parameter estimates of the other three equations. However, equations (4.II.1) can be considered a well defined production function if and only if their partial derivatives are symmetric in the inputs, i.e if β_{pe} in S_p is equal to β_{ep} in S_e, etc. Hence, when the six cross equation symmetry conditions are imposed ($\beta_{pe} = \beta_{ep}, \beta_{pg} = \beta_{gp}, \beta_{pc} = \beta_{cp}, \beta_{eg} = \beta_{ge}, \beta_{ec} = \beta_{ce}, \beta_{gc} = \beta_{cg}$), the number of parameters drops to 14. Thus, equations (4.II.2) can be written as:

$$\begin{aligned} &\beta_p + \beta_e + \beta_g + \beta_c = 1 \\ &\sum_{i=1}^{n} \beta_{ij} = 0 \ \ (\textit{column sums equal zero}) \\ &\sum_{j=1}^{n} \beta_{ij} = 0 \ \ (\textit{row sums equal zero}) \end{aligned} \tag{A.11}$$

The stochastic version of the model, which provides the basis for estimation, introduces a random disturbance term ε_i to each share equation, $i = c, e, g, p$. Since the sum of shares equal one, the sum of the disturbances across equations must always equal zero. This implies that the disturbance covariance matrix is singular and non-diagonal. To solve the problem of singularity of the disturbance covariance matrix of the share equations, the common procedure is to drop an arbitrary equation. In this work, the coal equation was deleted. After imposing the symmetry restrictions and dropping the coal equation the resulting system to be estimated is:

$$\begin{aligned}
S_p &= \beta_p + \beta_{pp}\ln(p_p/p_c) + \beta_{pe}\ln(p_e/p_c) + \beta_{pg}\ln(p_g/p_c) + \varepsilon_p,\\
S_e &= \beta_e + \beta_{pe}\ln(p_p/p_c) + \beta_{ee}\ln(p_e/p_c) + \beta_{eg}\ln(p_g/p_c) + \varepsilon_e,\\
S_g &= \beta_g + \beta_{pg}\ln(p_p/p_c) + \beta_{eg}\ln(p_e/p_c) + \beta_{gg}\ln(p_g/p_c) + \varepsilon_g.
\end{aligned} \tag{A.12}$$

The parameters in the deleted equations can be calculated in accordance with the adding-up and symmetry restrictions. In other words, indirect estimates of the four other parameters in the omitted coal share equation may then be estimated in terms of the directly estimated parameters as follows:

$$\begin{aligned}
\beta_c &= 1 - \beta_p - \beta_e - \beta_g,\\
\beta_{pc} &= -\beta_{pp} - \beta_{pe} - \beta_{pg},\\
\beta_{ec} &= -\beta_{pe} - \beta_{ee} - \beta_{eg},\\
\beta_{cg} &= -\beta_{pg} - \beta_{eg} - \beta_{gg},\\
\beta_{cc} &= -\beta_{pc} - \beta_{ec} - \beta_{cg}.
\end{aligned} \tag{A.13}$$

Since these indirectly estimated parameters are linear combinations of the directly estimated coefficients, variances of the indirectly estimated parameters can be calculated as a linear combination of the directly estimated variances and covariances.

The parameter estimates of the coal equation may also be obtained by eliminating another equation while keeping the coal equation. In testing the translog estimation system the author considered it prudent to estimate, one by one, all the possible share equation combinations, and thereby ascertain that the system is invariant to the equation omitted. The parameter estimates were found to be invariant to the choice of equation that was dropped.

With regards to the dynamic model, the corresponding system of three input cost shares equations can be written as:

$$\begin{aligned}
S_p^{FUEL} &= \beta_p^* + \beta_{pp}^*\ln(p_p/p_c) + \beta_{pe}^*\ln(p_e/p_c) + \beta_{pg}^*\ln(p_g/p_c) + \theta S_{p-1} + \varepsilon_p,\\
S_e^{FUEL} &= \beta_e^* + \beta_{pe}^*\ln(p_p/p_c) + \beta_{ee}^*\ln(p_e/p_c) + \beta_{eg}^*\ln(p_g/p_c) + \theta S_{e-1} + \varepsilon_e,\\
S_g^{FUEL} &= \beta_g^* + \beta_{pg}^*\ln(p_p/p_c) + \beta_{eg}^*\ln(p_e/p_c) + \beta_{gg}^*\ln(p_g/p_c) + \theta S_{g-1} + \varepsilon_g.
\end{aligned} \tag{A.14}$$

and the parameters in the deleted equations can be calculated with the adding-up and symmetry restrictions as follows:

$$\begin{aligned}
&\beta_c = 1 - \beta_p - \beta_e - \beta_g - \theta, \\
&\beta_{pc} = -\beta_{pp} - \beta_{pe} - \beta_{pg}, \\
&\beta_{ec} = -\beta_{pe} - \beta_{ee} - \beta_{eg}, \\
&\beta_{cg} = -\beta_{pg} - \beta_{eg} - \beta_{gg}, \\
&\beta_{cc} = -\beta_{pc} - \beta_{ec} - \beta_{cg}, \\
&\theta_c = \theta_p = \theta_e = \theta_g = \theta
\end{aligned} \tag{A.15}$$

Note that the coefficient of the lagged share (theta) needs to be the same in each equation because of adding-up restrictions.

A.3.2: The estimation of the aggregate-energy model (inter-factor)

The estimated parameters from the sub-energy model are used to estimate the aggregate price index for energy. Thus, an aggregate price index is obtained which serves as an instrumental variable for the price of energy in the estimation of the system of the shares of total cost. The remaining procedure is the same as that applied in the first stage.

Appendix 4

Parameter Estimates of the Dynamic Translog Factor Cost-Share Model in Industrial Sector

	BRAZIL	CHINA	INDIA	INDONESIA	VENEZUELA
$\hat{\alpha}_K$	-2.1566***	0.6689***	-2.9779***	-2.7023**	-1.9004*
	(-3.1728)	(2.9825)	(-4.2672)	(-2.4180)	(-1.9448)
$\hat{\gamma}_{KK}$	0.1038***	0.0459***	0.1366***	0.1508**	0.0688*
	(4.8612)	(5.9861)	(6.8858)	(2.5312)	(1.6480)
$\hat{\gamma}_{KE}$	-0.0604	-0.0174**	0.0021	-0.1296***	-0.0655
	(-0.8578)	(-2.4770)	(0.0316)	(-7.7326)	(-1.6001)
$\hat{\gamma}_{KL}$	-0.0434**	-0.0285***	-0.1387***	-0.0213	-0.0033
	(-2.2208)	(-3.4273)	(-21.3521)	(-0.3244)	(-0.1929)
$\hat{\gamma}_{Ky}$	0.1093**	-0.0245***	0.1870***	0.1346**	0.0959*
	(2.5683)	(-2.2879)	(7.0834)	(2.1666)	(1.8180)
$\hat{\alpha}_E$	0.8635***	-0.0352	0.0431***	3.0964***	1.8532*
	(6.4426)	(-0.1184)	(2.9603)	(2.7019)	(1.8355)
$\hat{\gamma}_{EE}$	-0.0035	0.0190	-0.0003	0.1377***	0.0195
	(-0.3093)	(1.2972)	(-0.1744)	(8.2444)	(0.3841)
$\hat{\gamma}_{EL}$	0.0639**	-0.0016	-0.0018	-0.0081	0.0460**
	(2.2444)	(-0.0740)	(-0.0653)	(-0.1231)	(2.2417)
$\hat{\gamma}_{Ey}$	-0.0404***	0.7029***	-0.0026***	-0.1139*	-0.0678
	(-5.5139)	(6.0591)	(-6.1044)	(-1.8108)	(-1.2662)
$\hat{\alpha}_L$	2.2931***	0.3662	3.9348***	0.6058***	1.0473
	(7.1415)	(0.9431)	(16.9408)	(3.0197)	(0.7777)
$\hat{\gamma}_{LL}$	-0.0206	0.0301	0.1405***	0.0294	-0.0427
	(-0.5953)	(1.2986)	(4.8648)	(0.3161)	(-1.5921)
$\hat{\gamma}_{Ly}$	-0.0690	-0.6783*	-0.1844	-0.0207	-0.0281
	(-0.2100)	(-1.7364)	(-0.7751)	(-0.0736)	(-0.0209)
θ	0.5148***	-0.0853	0.5336***	0.2774***	0.5736***
	(6.8694)	(-0.7245)	(10.7478)	(4.0022)	(6.1582)
$\bar{R}^2$	0.9381	0.8330	0.9098	0.9282	0.7740

Notes: The figures in parentheses are t-statistics.***, ** and * indicate significance at 1%, 5% and 10%, respectively.

Appendix 5

Parameter Estimates of the Dynamic Translog Fuel Cost-Share Model

	BRAZIL	**CHINA**	**INDIA**	**INDONESIA**	**VEVEZUELA**
$\hat{\beta}_p$	0.1196***	-0.0160	0.2308***	-0.1105***	0.1669***
	(2.6710)	(-0.8329)	(8.4541)	(-5.3859)	(3.8227)
$\hat{\beta}_{pp}$	-0.1508***	-0.0533***	-0.1830***	-0.0979***	0.0200
	(-3.7386)	(-2.8248)	(-7.3130)	(-8.5493)	(1.3002)
$\hat{\beta}_{pe}$	0.1505***	0.2549***	0.2093***	0.1564***	0.0730***
	(3.1553)	(12.0382)	(8.2149)	(9.4854)	(6.0038)
$\hat{\beta}_{pg}$	0.0044	-0.0056***	-0.0105**	-0.0355***	-0.0825***
	(0.5020)	(-5.6429)	(-2.5492)	(-4.9088)	(-6.0753)
$\hat{\beta}_{pc}$	-0.0040	-0.1960***	-0.0158*	-0.0229***	-0.0105
	(-1.0721)	(-15.9320)	(-1.8126)	(-5.8971)	(-0.7802)
$\hat{\beta}_e$	0.1919***	0.1938***	0.2547***	0.2306***	0.2081***
	(3.0555)	(10.4396)	(7.0627)	(3.4551)	(5.3860)
$\hat{\beta}_{ee}$	-0.1010*	-0.1746***	-0.1218***	-0.0840***	-0.0688***
	(-1.6952)	(-7.0816)	(-5.0472)	(-2.9790)	(-4.4419)
$\hat{\beta}_{eg}$	-0.0241*	-0.0076***	-0.0073*	-0.0615***	-0.0004
	(-1.6852)	(-7.5920)	(-1.7123)	(-4.1597)	(-0.0274)
$\hat{\beta}_{ec}$	-0.0254***	-0.0727***	-0.0802***	-0.0109	-0.0038
	(-4.6759)	(-10.0965)	(-10.3468)	(-1.0607)	(-0.3056)
$\hat{\beta}_g$	0.0548***	0.0407***	0.0597***	0.2332***	0.1596***
	(3.4967)	(23.8562)	(8.1627)	(6.8468)	(3.4359)
$\hat{\beta}_{gg}$	0.0087	0.0171***	0.0151***	0.0807***	0.1089***
	(1.3515)	(21.1929)	(7.5269)	(5.6887)	(4.9416)
$\hat{\beta}_{gc}$	0.0110	-0.0040***	0.0027	0.0163**	-0.0260
	(4.1603)	(-10.2715)	(1.4016)	(2.3629)	(-1.4195)
$\hat{\beta}_c$	0.6338***	0.7815***	0.4549***	0.6467***	0.4654***
	(12.7855)	(42.7382)	(11.9535)	(12.0915)	(9.7256)
$\hat{\beta}_{cc}$	0.0185	0.2726***	0.0934***	0.0175	0.0404
	(1.4991)	(11.0396)	(4.5526)	(0.7783)	(0.8975)
θ	0.5688***	0.0426	0.1039*	0.5826***	0.4619***
	(10.1947)	1.1162	(1.6644)	(13.1606)	(7.4472)
$\overline{R}^2$	0.7853	0.9058	0.8064	0.9826	0.8597

Notes: The figures in parentheses are t-statistics.***, ** and * indicate significance at 1%, 5% and 10%, respectively.

Appendix 6

Elasticities of Substitution and Partial Price Elasticities of Demand for Fuels

	BRAZIL		**CHINA**		**INDIA**		**INDONESIA**		**VENEZUELA**	
	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR
Elasticities of substitution										
σ_{pe}	1.68***	3.89***	4.53***	4.73***	1.85***	2.51***	1.98***	4.73***	2.13***	3.97***
	(7.82)	(18.14)	(15.45)	(16.13)	(13.79)	(18.73)	(19.20)	(46.01)	(11.29)	(20.99)
σ_{pg}	1.27***	2.95***	-1.00***	-1.04***	-4.64***	-6.30***	0.06	0.15	0.44***	0.82***
	(2.34)	(5.44)	(-2.82)	(-2.94)	(-8.69)	(-11.81)	(0.32)	(0.76)	(4.82)	(8.96)
σ_{pc}	0.64*	1.49***	-0.28***	-0.29***	0.49***	0.66***	-1.47***	-3.52***	0.37	0.68
	(1.92)	(4.45)	(-3.44)	(-3.59)	(2.86)	(3.89)	(-3.51)	(-8.41)	(0.45)	(0.84)
σ_{eg}	-0.76	-1.77*	-3.73***	-3.89***	-20.04***	-27.21***	0.13	0.30	0.98	1.83***
	(-0.73)	(-1.69)	(-5.99)	(-6.25)	(-24.88)	(-33.79)	(0.60)	(1.44)	(1.63)	(3.03)
σ_{ec}	-1.67***	-3.88***	0.18**	0.19**	0.77***	1.05***	0.37	0.88	-0.49	-0.91
	(-2.93)	(-6.78)	(2.22)	(2.31)	(3.50)	(4.76)	(0.62)	(1.47)	(-0.10)	(-0.19)
σ_{gc}	29.54***	68.50***	-0.16	-0.16	2.25*	3.06**	5.00***	11.99***	-3.41	-6.34***
	(7.72)	(17.91)	(-1.40)	(-1.46)	(1.66)	(2.25)	(2.95)	(7.08)	(-1.10)	(-2.04)
Price elasticities										
η_{pp}	-0.78***	-1.81***	-0.80***	-0.83***	-0.65***	-0.88***	-1.04***	-2.49***	-0.32***	-0.60***
	(-9.93)	(-23.03)	(-14.94)	(-15.60)	(-13.62)	(-18.49)	(-26.65)	(-63.86)	(-13.61)	(-25.29)
η_{ee}	-0.44***	-1.02***	-0.06***	-0.06***	-0.66***	-0.90***	0.16***	0.39***	-6.25***	-11.61***
	(-3.22)	(-7.46)	(-0.51)	(-0.53)	(-9.88)	(-13.42)	(3.18)	(7.61)	(-40.22)	(-74.74)
η_{gg}	-18.85***	-43.73***	-78.25***	-81.73***	-49.05***	-66.61***	-4.13***	-9.89***	-3.91***	-7.26***
	(-92.11)	(-213.62)	(-762.96)	(-796.92)	(-358.51)	(-486.88)	(-37.51)	(-89.87)	(-40.66)	(-75.55)
η_{cc}	-17.56***	-40.73***	-0.53***	-0.56***	-3.98***	-5.40***	-1.71***	-4.10***	-12.62***	-23.45***
	(-31.25)	(-72.47)	(-9.37)	(-9.79)	(-18.87)	(-25.63)	(-2.41)	(-5.76)	(-7.22)	(-13.41)
η_{pe}	0.73***	1.69***	0.92***	0.97***	0.67***	0.91***	1.08***	2.58***	0.21***	0.40***
	(7.82)	(18.14)	(15.45)	(16.13)	(13.79)	(18.73)	(19.20)	(46.01)	(11.29)	(20.99)
η_{pg}	0.04**	0.09***	-0.01***	-0.01***	-0.07***	-0.09***	0.01	0.02	0.10***	0.19***
	(2.34)	(5.44)	(-2.82)	(-2.94)	(-8.69)	(-11.81)	(0.32)	(0.76)	(4.82)	(8.96)
η	0.01*	0.03***	-0.12***	-0.12***	0.05***	0.06***	-0.05***	-0.11***	0.01	0.02

	(1.92)	(4.45)	(-3.44)	(-3.59)	(2.86)	(3.89)	(-3.51)	(-8.41)	(0.45)	(0.84)
η_{ep}	0.86***	1.99***	1.60***	1.67***	0.97***	1.32***	0.58***	1.39***	1.38***	2.56***
	(7.82)	(18.14)	(15.45)	(16.13)	(13.79)	(18.73)	(19.20)	(46.01)	(11.29)	(20.99)
η_{eg}	-0.02	-0.06*	-0.03***	-0.03***	-0.29***	-0.40***	0.02	0.04	0.23	0.42***
	(-0.73)	(-1.69)	(-5.99)	(-6.25)	(-24.88)	(-33.79)	(0.60)	(1.44)	(1.63)	(3.03)
η_{ec}	-0.04***	-0.08***	0.08**	0.08**	0.08***	0.10***	0.01	0.03	-0.01	-0.02
	(-2.93)	(-6.78)	(2.22)	(2.31)	(3.50)	(4.76)	(0.62)	(1.47)	(-0.10)	(-0.19)
η_{gp}	0.65**	1.51***	-0.35***	-0.37***	-2.45***	-3.32***	0.02	0.04	0.29***	0.53***
	(2.34)	(5.44)	(-2.82)	(-2.94)	(-8.69)	(-11.81)	(0.32)	(0.76)	(4.82)	(8.96)
η_{ge}	-0.33	-0.77*	-0.76***	-0.79***	-7.23***	-9.82***	0.07	0.17	0.10	0.18***
	(-0.73)	(-1.69)	(-5.99)	(-6.25)	(-24.88)	(-33.79)	(0.60)	(1.44)	(1.63)	(3.03)
η_{gc}	0.65***	1.50***	-0.07	-0.07	0.22*	0.30**	0.16***	0.38***	-0.09	-0.16**
	(7.72)	(17.91)	(-1.40)	(-1.46)	(1.66)	(2.25)	(2.95)	(7.08)	(-1.10)	(-2.04)
η_{cp}	0.33*	0.76***	-0.10***	-0.10***	0.26***	0.35***	-0.43***	-1.03***	0.24	0.44
	(1.92)	(4.45)	(-3.44)	(-3.59)	(2.86)	(3.89)	(-3.51)	(-8.41)	(0.45)	(0.84)
η_{ce}	-0.73***	-1.68***	0.04**	0.04**	0.28***	0.38***	0.20	0.48	-0.05	-0.09
	(-2.93)	(-6.78)	(2.22)	(2.31)	(3.50)	(4.76)	(0.62)	(1.47)	(-0.10)	(-0.19)
η_{cg}	0.93***	2.15***	0.00	0.00	0.03*	0.04**	0.65***	1.55***	-0.78	-1.45**
	(7.72)	(17.91)	(-1.40)	(-1.46)	(1.66)	(2.25)	(2.95)	(7.08)	(-1.10)	(-2.04)

Notes: The figures in parentheses are t-statistics.***, ** and * indicate significance at 1%, 5% and 10%, respectively.