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Interfactor and Interfuel Substitution in the Industrial Sector of Three Major Energy Producer in Developing Countries

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The purpose of this paper is to investigate the extent of energy substitution among input factors (labor and capital) and among the fuel types used in the industrial sector of three major energy producers of the developing world; China, India and Indonesia. 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 for these countries. Substitution possibilities were found (i) between capital and energy and between labor and energy in the inter-factor model and (ii) for most combinations of fuel types in the inter-fuel model. This suggests there is some flexibility in energy policy options and energy utilization.

JEL Codes: Q43, D24 and O57

1. Introduction

The possibilities of energy substitution have been the subject of a number of studies over the last three decades (see Fuss (1977), Pindyck (1979), Iqbal (1986), Andrikopoulos *et al*. (1989), Cho *et al*. (2004) for early empirical studies, and Ma *et al*. (2008), Koetse *et al*. (2008), Bulok and Koc (2010) for more recent ones. 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 in the developing countries. 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 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. Therefore, the impact of price on energy demand and energy substitution

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should be examined in order to determine the effectiveness of fuel costs for the reduction of pollution in a region and in a country as a whole.

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). 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 example, if it is found that energy and capital are substitute inputs, 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. Similarly, if capital and labour are complements, then income and economic growth will be seriously affected in response to scarcity of capital.

According to IEO (2006), the industrial sector is the largest of the end-use sectors, consuming 50% of delivered energy worldwide in 2003. For the industrial sector, energy demand depends on the characteristics of production and the extent to which capital, labour and energy will be substituted for each other as their relative prices change. Energy demand in the industrial sector also depends on the extent to which individual fuels can be substituted for each other in response to changes in the prices of these fuels. Pindyck (1979) and McNown (1991) claimed that these substitution patterns not only have an important impact on energy demand for the industrial sector, but also have major implications for growth and economic planning. Therefore, the extent of inter-factor and inter-fuel substitution is important and needs to be addressed because it will contribute to our understanding of the energy demand in the industrial sector and also its relationship with the economic growth.

In the current study the focus is on investigating the interfactor and interfuel substitutions by taking into account the feedback effect between the interfactor and interfuel substitution in the industrial sector of three developing countries - China, India and Indonesia. While the countries examined here reflect significant regional economic, demographic and energy resource diversity, yet each of these countries shares the same characteristics. These countries are not only the world’s largest energy producer but also the largest energy consumer in the world. 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, second largest consumer of oil. India is the world’s third largest producer of coal and the world’s sixth largest consumer of oil. Indonesia is the world’s sixth largest producer of natural gas and the seventh largest producer of coal (IEA, 2004). Moreover, the rapidly industrializing economies of China and India, in particular, are projected to increase their consumption of petroleum fuels dramatically in the coming decades as levels of consumer spending and population rise. Given the similarities and also differences between these countries, it is therefore of value to understand the impacts of rising prices of energy commodities and the security of international energy supplies on the degree of interfactor and interfuel substitution possibilities in the industrial sector.

Using annual data from 1978 to 2003, an interfactor and interfuel substitution possibilities is estimated with a translog specification. 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 estimate aggregate input demand for aggregate energy, capital and labour along with price and substitution elasticities.

The empirical estimates of this study show that the dynamic two-stage translog model is consistent with the principle of cost minimising factor demand theory. The translog cost function satisfied the monotonicity and concavity conditions. Importantly, substitution possibilities are observed between capital and energy and labour and energy, hence confirming previous evidence that there is flexibility of input mix in the industrial sector. In other instances, this study provides evidence of substitutability among the fuels. Especially, there is a shift towards cleaner fuels such as natural gas.

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

2. Literature Review

There is an extensive empirical literature on energy substitution of the industrial sector for developing countries, but the vast majority of these studies usually assume no correlation between the interfactor and interfuel substitution effects. Most studies estimated interfactor substitution effects by assuming a given aggregate output and investigated interfuel substitution effects by a given consumption level of energy aggregates.

A major inconvenience of the above mentioned interfactor substitution effects and interfuel substitution effects when it is estimated individually it 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.

The earliest study to propose the two-stage approach is the classic paper on Canadian energy by Fuss (1977). Using the data for Canadian total manufacturing over the period 1961 to 1971, he found that the inter-fuel substitution indicate that the own price elasticity estimates are negative and, apart from motor gasoline, significant at the 1 per cent level. Furthermore, there is considerable inter-fuel substitution among fuels, except for electricity and motor gasoline. The cross price elasticities are found to be positive and this indicates that there is a possible substitution among the fuels. With regards to the share equations of the inter-factor substitution model, it was found that for all factor inputs, the own price elasticities of demand are negative and significant at 1 per cent level and all factors have a price inelastic demand. In general, factors are found to be substituted, although there is a slight complementarity between energy and materials and between energy and capital. It was also found that the own price elasticities of demand for the aggregate factor are in the inelastic range (for instance, the own price elasticity of demand for aggregate energy is -0.5). However, the cross price elasticities are low in all cases. Comparing to the inter-fuel substitution, only slight substitution exists between aggregate energy and other aggregate inputs in the Canadian manufacturing sector.

An early example of estimation of inter-factor and inter-fuel substitution potential in developing countries is the work of Uri (1979). Based on a pooled annual dataset for the period over 1960 to 1971, he examined the extent to which shifts in the composition of energy consumption in the commercial sector can be explained by changes in relative prices during the decade of the 1960s and the early 1970s in the commercial sector in India. He divided the commercial sector into five sub-sectors: (1) mining and manufacture, (2) transportation, (3) domestic, (4) agriculture and (5) government and commercial. He used a static translog cost function model for capital, labour and energy inputs (coal, oil and electrical energy). In general, he found that energy price across the commercial sector has significant effects on energy consumption. He also found that coal and electrical energy are significantly more price responsive than what has been found by other similar studies in other countries. However, for oil the responsiveness is about the same. He also explained that the effect of higher oil prices will trigger a significant stimulus to the consumption of coal and less to the consumption of electrical energy. Thus, he concluded that coal will be the primary alternative to the consumption of oil, when the oil prices increase. In addition, he also claimed that since this study dealt with cross-section data, the interpretation of the estimated elasticities reflect the long-run effects of prices on energy demand. Nevertheless, these results can be questioned since the standard errors of these estimates are not reported.

The analysis of inter-fuel substitution and the industrial demand for energy was also considered by Pindyck (1979). Using an international data set, he applied a two-stage approach similar to that of Fuss (1977). Because of data deficiencies (a lack of material price data), he assumed that capital, labour and energy are weakly separable from materials. He used pooled time-series data for a cross-section of ten countries; Canada, France, Italy, Japan, the Netherlands, Norway, Sweden, the United States, the United Kingdom and Germany. The results for the share equations of the inter-fuel model show that thirteen of the sixteen coefficients are statistically significant. The fuel price elasticities are substantial, except for electricity where he stated that electricity is the most expensive fuel on a thermal basis and so it is only used when necessary. The own price elasticities for coal range from -1.04 in France to about -2.00 in Canada, Norway and the United States. Natural gas own price elasticities are large for Europe and Japan where the range between -1.3 and -2.3. In Canada and the United States, it was found that the own price elasticity for oil is substantial, even though they had relatively low prices. Pindyck (1979) explained this on the basis of a greater availability of alternative fuels at low prices, for instance natural gas. Thus, producers can choose technologies that allow for greater possibilities in inter-fuel substitution. For the share equations of inter-factor substitution, the parameters are also found to be significant. The elasticities of substitution indicate that all factors are substitutes for energy (i.e. elasticity of substitution for energy and capital and for energy and labour are positive).

The two-stage translog model was also used by Andrikopoulos et al. (1989) to study the inter-fuel and inter-factor substitution in Ontario manufacturing. Although their approach is similar to that adopted by Fuss (1977) and Pindyck (1979), this work deviates in two ways: first, the level of disaggregation of the manufacturing sector and second, the time period considered in this study. Using yearly data from 1962 to 1982, the manufacturing sector is disaggregated for seven two-digit manufacturing industries: food and beverages, paper and allied products, non-metallic minerals, primary metals, chemical products, transport equipment, and other manufacturing. The energy inputs considered were coal, electricity, fuel oil and natural gas. With respect to other factor inputs, they analysed only capital and labour. The result for the inter-fuel model shows that the there are substitution possibilities between fuel oil and electricity, between fuel oil and natural gas and between coal and natural gas. With regard to the inter-factor model, there was substitutability between capital and labour for all industries (except in the transportation equipment industry), between capital and energy (except in food and beverages and other manufacturing) and between labour and energy in all four sectors. However, compared to other similar studies, the elasticity estimates are high. As explained by Andrikopoulos et al. (1989), the high estimates of the elasticity suggest an increased flexibility both in energy policy options and energy utilization. Consequently, the empirical finding from this work revealed that the two-stage translog model is consistent with the principles of cost-minimizing factor demand theory, since it was found that all own-price elasticities were negative and statistically significant, both in the inter-fuel model and the inter-factor model.

A recent study by Cho et al. (2004) is an example of the more innovative recent work that investigates the inter-factor and inter-fuel substitution via the impact of increases in oil consumption and changes in wage rates. Even though the two-stage estimation method used in this study is similar to the approach taken by Fuss (1979), Pindyck (1979) and Andrikopoulos et al. (1989), it deviates in the sense that they considered the feedback effect of fuel price changes between the inter-factor and the inter-fuel substitution models. As Cho et al. (2004) explained, ignoring the feedback effect will only yields partial elasticities rather than total elasticities. This is because any changes in fuel price will not only have a substitution effect among individual fuels but also among factors of production. The latter substitution effect takes place through changes in total energy consumption. They further explained that the effect from inter-factor substitution will be transmitted into inter-fuel substitution due to the changes in aggregate energy demand.

Using Korea as a representative developing country, a static and dynamic translog cost function is examined by employing quarterly aggregate data over the period 1981 to 1997. The parameter estimates of the translog factor cost share equations indicate that for the static model, the own price elasticity for capital and labour is found to be negative whilst it is positive for energy. Cho et al. (2004) explained that the positive own-price elasticity of energy could be indicative of the administrative control on energy prices and market imperfections, which tend to prevent the energy prices from functioning within the market system. In addition, it was also found that there is substitutability between capital and labour, and between capital and energy whereas, labour and energy are found to be complements. For the dynamic model, it was found that labour and energy are complementary. According to Cho et al. (2004), this result reflects the impact of the sharp increase in wages in Korea after 1989. For the dynamic adjustment model, it was found that there is substitutability between coal and oil and complementarity between coal and electricity and between oil and electricity. Cho et al. (2004) concluded that the sudden increase in oil consumption and the upward shift in wage rate since 1989 have had an important impact on the inter-factor and inter-fuel substitution, reflected in the clear differences in elasticity estimates for both periods.

3. The Methodology and Model

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.

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)). This assumption was necessary since reliable data for prices of materials cannot be obtained for all countries in this study. Further, it is assumed that energy aggregate is homothetic in its coal (c), electricity (e), natural gas (g) and petroleum products (p) inputs. 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:

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

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

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

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:

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

Where *i, j* = K, L, E. The variable *C* represents total cost of production, *Y* is the quantity of output, P_i is price of *i*th 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

$$\partial \ln C / \partial \ln P_i = P_i X_i / C = S_i \qquad (4)$$

Where X_i is the amount of the *i*th input factor employed in the production process for *i*, *j* = K, L, E. The variable S_i indicates the cost share of the *i*th 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:

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

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:

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

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:

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

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:

$$\eta_{ii} = \partial \ln X_i / \partial \ln P_i = \sigma_{ii} S_i$$
$$\eta_{ij} = \partial \ln X_i / \partial \ln P_j = \sigma_{ij} S_j \qquad (8)$$

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

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

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 with respect to $\ln P = (\ln P_c, \ln P_e, \ln P_g, \ln P_p)$, and can be written as

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

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:

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

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:

$$\eta_{ii}^{*} = \eta_{ii} + \eta_{EE} S_i$$
$$\eta_{ij}^{*} = \eta_{ij} + \eta_{EE} S_j \qquad (12)$$

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. 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 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:

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

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 ith fuel or factor at time t and is given by the system in (5) and (10) and ν_{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

$$S_{it}^{FACTOR} = \alpha_i^{*} + \gamma_i^{*} \ln y_t + \sum_{j}^{n} \gamma_{ij}^{*} \ln p_{jt} + \theta_i S_{i,t-1}^{FACTOR} \qquad i,j = K,E,L$$
$$S_{it}^{FUEL} = \beta_i^{*} + \sum_{j}^{n} \beta_{ij}^{*} \ln p_{jt} + \tilde{\theta}_i S_{i,t-1}^{FUEL} \qquad i,j = c,e,g,p \qquad (14)$$

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:

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

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

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

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).

Data

The study covers the industry sector for the period 1978 to 2003. The selection of this time period is largely guided by the availability of data. The data on individual fuel (coal, electricity, natural gas and petroleum products) consumption levels, which are 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. Data on output, employment, wage and capital stock are obtained from the United Nations Industrial Development Organization (UNIDO), Industrial Statistics database. Data on the interest rate is obtained from the International Financial Statistics (IFS), which refers to the discount rate or bank rate and data on the real GDP and the GDP deflator are obtained from the United Nations Statistic Divisions.

4. The Findings

Inter-Factor Model

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.

Table 1: Elasticities of Substitution and Price Elasticities of Demand for Factors in Industrial Sector of China, India and Indonesia

	CHINA		**INDIA**		**INDONESIA**	
	SR	LR	SR	LR	SR	LR
	Elasticities of substitution					
	0.97***	0.90***	0.86***	1.85***	0.98	1.35
σ_{KL}	(4.18)	(3.85)	(8.06)	(17.28)	(0.81)	(1.13)
	0.98***	0.91***	1.00***	2.15***	0.87***	1.20***
σ_{KE}	(4.73)	(4.36)	(9.29)	(19.91)	(9.57)	(13.25)
	1.00	0.92	1.00	2.14	0.99	1.37
σ_{LE}	(0.54)	(0.50)	(0.25)	(0.53)	(0.12)	(0.16)
	0.97***	0.90***	0.86***	1.85***	0.98	1.35
	Price elasticities					
η_{KK}	-0.35***	-0.32***	-0.25***	-0.53***	-0.15	-0.20**
	(-3.11)	(-2.87)	(-4.66)	(-9.99)	(-1.48)	(-2.04)
η_{LL}	0.24***	0.22***	-3.61***	-7.74***	-8.69***	-12.03***
	(4.72)	(4.35)	(-17.14)	(-36.75)	(-8.41)	(-11.63)
η_{EE}	0.03	0.03	-1.56***	-3.35***	-2.78***	-3.85***
	(1.22)	(1.12)	(-33.57)	(-71.99)	(-50.60)	(-70.03)
η_{KL}	0.44***	0.40***	0.12***	0.25***	0.09	0.12
	(4.18)	(3.85)	(8.06)	(17.28)	(0.81)	(1.13)
η_{KE}	0.46***	0.43***	0.42***	0.90***	0.26***	0.37***
	(4.73)	(4.36)	(9.29)	(19.91)	(9.57)	(13.25)
η_{LK}	0.08***	0.07***	0.38***	0.82***	0.59	0.82
	(4.18)	(3.85)	(8.06)	(17.28)	(0.81)	(1.13)
η_{LE}	0.47***	0.43	0.42	0.90	0.30	0.42
	(0.54)	(0.50)	(0.25)	(0.53)	(0.12)	(0.16)
η_{EK}	0.08**	0.07**	0.44***	0.95***	0.53***	0.73***
	(2.18)	(2.01)	(7.71)	(16.54)	(2.68)	(3.70)
η_{EL}	0.45***	0.41***	0.14**	0.29***	0.09	0.12

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

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 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 these three 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.

Inter-fuel Model

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 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. 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 China and India.

Table 2: Total Fuel Price Elasticity of Demand for Fuels in Industrial Sector of China, India and Indonesia

	CHINA		INDIA		INDONESIA	
	SR	LR	SR	LR	SR	LR
η_{pp}	-0.79***	-0.82***	-1.47***	-2.00***	-1.86***	-4.45***
	(-14.74)	(-15.39)	(-30.99)	(-42.08)	(-47.56)	(-113.95)
η_{ee}	-0.06	-0.06	-1.23***	-1.66***	-1.35***	-3.24***
	(-0.46)	(-0.48)	(-18.32)	(-24.87)	(-26.20)	(-62.78)
η_{gg}	-78.25***	-81.73***	-49.07***	-66.64***	-4.48***	-10.74***
	(-762.96)	(-796.92)	(-358.68)	(-487.11)	(-40.77)	(-97.67)
η_{cc}	-0.52***	-0.54***	-4.13***	-5.61***	-1.80**	-4.31***
	(-9.14)	(-9.55)	(-19.59)	(-26.61)	(-2.53)	(-6.06)
η_{pe}	0.93***	0.97***	0.10**	0.14***	-0.44***	-1.05***
	(15.55)	(16.24)	(2.12)	(2.88)	(-7.81)	(-18.71)
η_{pg}	-0.01***	-0.01***	-0.09***	-0.12***	-0.35***	-0.84***
	(-2.73)	(-2.85)	(-11.62)	(-15.78)	(-14.21)	(-34.04)
η_{pc}	-0.11***	-0.11***	-0.10***	-0.14***	-0.13***	-0.32***
	(-3.06)	(-3.20)	(-6.32)	(-8.59)	(-10.15)	(-24.31)
η_{ep}	1.61***	1.69***	0.15**	0.20***	-0.24***	-0.57***
	(15.55)	(16.24)	(2.12)	(2.88)	(-7.81)	(-18.71)
η_{eg}	-0.03***	-0.03***	-0.32***	-0.43***	-0.34***	-0.82***
	(-5.94)	(-6.20)	(-26.83)	(-36.43)	(-12.64)	(-30.27)
η_{ec}	0.09***	0.10***	-0.08***	-0.10***	-0.08***	-0.18***
	(2.59)	(2.70)	(-3.58)	(-4.86)	(-4.04)	(-9.69)
η_{gp}	-0.34***	-0.36***	-3.27***	-4.44***	-0.80***	-1.91***
	(-2.73)	(-2.85)	(-11.62)	(-15.78)	(-14.21)	(-34.04)
η_{ge}	-0.75***	-0.79***	-7.79***	-10.58***	-1.45***	-3.47***
	(-5.94)	(-6.20)	(-26.83)	(-36.43)	(-12.64)	(-30.27)
η_{gc}	-0.06	-0.06	0.07	0.09	0.07	0.17***
	(-1.13)	(-1.18)	(0.51)	(0.69)	(1.31)	(3.14)
η_{cp}	-0.09***	-0.09***	-0.57***	-0.77***	-1.25***	-2.99***
	(-3.06)	(-3.20)	(-6.32)	(-8.59)	(-10.15)	(-24.31)
η_{ce}	0.04***	0.04***	-0.29***	-0.39***	-1.32***	-3.16***
	(2.59)	(2.70)	(-3.58)	(-4.86)	(-4.04)	(-9.69)
η_{cg}	0.00	0.00	0.01	0.01	0.29	0.69***
	(-1.13)	(-1.18)	(0.51)	(0.69)	(1.31)	(3.14)

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

The results of the cross-price elasticity also confirm a very inelastic response of electricity 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.

There is also some evidence of substitution possibilities between gas and coal in 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 Indonesia.

5. Summary and Conclusions

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 energy and between labour and energy for all countries. This result supports the capital – energy substitutability finding of Cho et al. (2004). These findings confirm previous evidence that production technologies in these countries allow flexibility in the capital-energy and labour-energy mix. Therefore, in response to energy price fluctuations, these countries could substitute labour and 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 China and India and with natural gas and coal for Indonesia. In addition, the evidence for significant inter-fuel substitution between coal and natural gas in 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 from high-carbon fuel technologies. This finding provides a better energy policy option and this is significant for current environment policy.

Of course, these findings are subject to some caveats. Since the approach applied in this study involves several forms of aggregation, each of which might be questioned. In particular, the aggregate price of energy was constructed from the prices of the individual fuels. As Pindyck (1979) noted, although price series for individual fuels are available, a price index that reflects the unit costs of energy will not be the same as a simple weighted average of fuel prices because fuels are not perfect substitutes. Therefore, an aggregator function that relates the aggregate price index to the component prices is developed. However, this approach helps to illustrate the importance of using the two-stage estimation method to incorporate the feedback effect between the interfactor and interfuel substitution.

References

Andrikopoulos, AA, Brox, JA and Paraskevopoulos, CC, 1989, 'Interfuel and interfactor substitution in Ontario manufacturing', 1962-82, *Applied Economics, Vol.21, pp.1667-1681*.

Azlina, AA 2007, 'Energy demand, energy substitution and economic growth: Evidence from developed and developing countries', Unpublished Ph.D Dissertation, Leicester University, Leicester, United Kingdom.

Boluk, G and Koc AA 2010, 'Electricity demand of manufacturing sector in Turkey: A translog cost approach', *Energy Economics, Vol.32, pp.609-615*.

Cho, WG, Nam, K and Pagán, JA, 2004, 'Economic growth and interfactor/interfuel substitution in Korea', *Energy Economics, Vol. 26, pp. 31-50.*

Christensen, LR, Jorgenson, DW and Lau, LJ, 1973, 'Transcendental logarithmic production frontiers', *Review of Economics and Statistics, Vol. 55, pp. 28-45.*

Christopoulos, DK, 2000, 'The demand for energy in Greek manufacturing', *Energy Economics, Vol. 22, pp.569-586*.

Floros, N and Vlachou, A, 2005, 'Energy demand and energy-related CO_2 emissions in Greek manufacturing: Assessing the impact of a carbon tax', *Energy Economics, Vol. 27, pp.387-413.*

Fuss, MA, 1977, 'The demand for energy in Canadian manufacturing: an example of the estimation of production structures with many inputs', *Journal of Econometrics, Vol. 5, pp. 89-116*.

Hogan, WW, 1989, 'A putty-semi-putty model of aggregate energy demand', *Energy Economics*, *Vol.11, pp. 53-69.*

IEA (International Energy Agency), 2004, *Key World Energy Statistic*, International Energy Agency, Paris.

IEO (International Energy Outlook), 2006, *Energy Consumption by End-Use Sector* [Homepage of EIA (Energy Information Administration)], viewed 18 December 2012,
< http://www.eia.doe.gov/oiaf/ieo/pdf/enduse.pdf >.

Iqbal, M, 1986, 'Substitution of labour, capital and energy in the manufacturing sector of Pakistan', *Empirical Economics, Vol. 11, pp. 81-95.*

Ko, J and Dahl, C, 2001, 'Interfuel substitution in US electricity generation', *Applied Economics, Vol. 33, pp.1833-1843.*

Koetse, MJ, de Groot, HLF and Florax, RJGM 2008, 'Capital-energy substitution and shifts in factor demand: A meta analysis', *Energy Economics, Vol. 30, pp.2236-225.*

Ma, H, Oxley, L, Gibson, J and Kim, B, 'China's energy economy: Technical change, factor demand and interfactor/interfuel substitution', *Energy Economics, Vol.30, pp.2167-2183.*

McNown, RF, Pourgerami, A and von Hirschhausen, CR, 1991, 'Input substitution in manufacturing for three LDCs: Translog estimates and policy implications', *Applied Economics, Vol.23, pp. 209-218.*

Nerlove, M, 1958, 'Adaptive expectations and Cobweb phenomena', *The Quarterly Journal of Economics, Vol. 72, pp. 227-240.*

Pindyck, RS, 1979, 'Interfuel substitution and the industrial demand for energy: An international comparison', *Review of Economics and Statistics, Vol. 61, pp 169-179.*

Saicheua, S, 1987, 'Input substitution in Thailand's manufacturing sector: Implications for energy policy', *Energy Economics, Vol. 9, pp.55-63*.

Siddayao, CM, Khaled, M, Ranada, JG and Saicheua, S, 1987, 'Estimates of energy and non-energy elasticities in selected Asian manufacturing sectors: Policy implications', *Energy Economics, Vol.9, pp. 115-128.*

Taheri, AA, 1994, 'Oil shocks and the dynamics of substitution adjustments of industrial fuels in the U.S', *Applied Economics, Vol. 26, pp.751-756.*

Uri, ND, 1979, 'Energy substitution in the UK, 1948-64', *Energy Economics, Vol.1, pp241-244.*