Interfuel relationships of a developing and developed country: Korea vs. Japan

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1. Introduction

The potential for interfuel substitution within the industrial sector remains a topic of substantial interest to academics and policy analysts alike. Interfuel substitution can help reduce carbon emissions by contributing to the increased use of low-carbon fuel and therefore the decreased use of high-carbon ones. Since the pioneering, empirical studies of interfuel relationship by Fuss (1977) and Pindyck (1979), many researchers have investigated this topic. Since the industrial sector has been thought to have higher potential for interfuel substitution than other sectors, many studies have examined this sector (Christopoulos, 2000; Considine and Mount, 1984; Fuss, 1977; Jones, 1995; Pindyck, 1979; Serletis et al., 2010; Urga and Walters, 2003). The current study, too, focuses on the interfuel relationship within the industrial sector.

There are two interesting hypotheses on interfuel relationships, for developed and developing countries. The first hypothesis, raised by Serletis et al. (2010), is that a developed country demonstrates higher potential for interfuel substitution. This may suggest that degree of development plays an important role in defining the potential for substitution among fuel sources. Serletis et al. (2010) proves this hypothesis by comparing the cases of 15 countries; however, they do not consider the industrial structure of each country. To overcome this limitation, it is important to compare countries that have similar industrial structures, but which are at different stages of economic development.

The second hypothesis, discussed by Cho et al. (2004), is that a developing country that has experienced sudden industrialization accompanied by a rapid increase in energy consumption may alter the structure of its domestic energy markets, which would eventually induce changes in interfuel relationships. Thus, there is the chance that interfuel relationships may fluctuate more in developing countries than in developed ones. However, their study deals only with the case of South Korea, and so the implications therein may not be generalizable.

The current study investigates interfuel substitution within the industrial sector, using time-series data from the Republic of Korea (South Korea) and Japan from 1987 to 2009. South Korea and Japan were selected as representative developing and developed countries in Asia, respectively. We tested the two aforementioned hypotheses about interfuel relationships for South Korea and Japan using the energy-cost function approach. Considering the relatively high volatility of fuel prices, it is understandable that dynamic models that adjust fuel demand to price change are more frequently used than static models. Thus, we adopt the dynamic linear logit model suggested by Considine and Mount (1984).

Our study is different from the previous studies in the following manner. First, we focus on the issue of interfuel relationships in a developing country and a developed country, both in Asia. Thus, we seek to overcome the research gap largely caused by previous studies' focus on interfuel relationships in individual countries (Cho et al., 2004; Christopoulos, 2000; Considine, 1989; Considine and Mount, 1984; Fuss, 1977; Urga and Walters, 2003). Second, we compare two countries that have similar industrial structures but are in different stages of economic development; we attempt to draw meaningful implications therein. Thus, we try to improve our understanding of how economic growth and the development and implementation of new technologies have been affected by interfuel substitution.

This paper is organized into five sections. Section 2 briefly presents the model employed in this study, that is, the dynamic linear model. Section 3 provides the data description and empirical results, with discussions of our two research hypotheses. Finally, Section 4 provides some conclusions, along with policy implications.

2. Method

We assume that several types of fuels can be viewed together as an energy aggregate, and that they are weakly separable from labor, capital, and material; thus, the cost function (Fuss, 1977) can be written as:

$$C = g[p_K, p_L, p_E(p_{E_1}, \ldots, p_{E_n}), p_M, t]. \tag{1}$$

To analyze the cost function shown in Eq. (1), we apply the dynamic linear logit models proposed by Considine and Mount (1984) to estimate interfuel substitution for the industrial sectors in South Korea and Japan, from 1987 to 2009 ($T = 23$). The linear logit model can be used to specify a cost-share system that meets sufficient theoretical conditions and has proper constraints imposed. A logistic approximation of a set of n nonhomothetic cost shares (S_{it}) with nonneutral technical change is given by:

$$S_{it} = \frac{p_{it} x_{it}}{\sum_j p_{jt} x_{jt}} = \frac{\exp(f_{it})}{\sum_j f_{jt}} \quad \text{for} \quad i = 1, 2, \ldots, n, \tag{2}$$

where $f_{it} = \beta_i + \sum_j \beta_{ij} \ln p_{jt} + \beta_{iy} \ln y_t + \beta_{it} t + \lambda \ln x_{it-1} + \varepsilon_{it}$.

p_{it} and x_{it} are the price and quantity of the i^{th} input, respectively, and y_t is the level of output at time t . Also, time-trend t [1] reflects nonneutral technical change or efficiency gains, and λ measures the rate of dynamic partial adjustment. S_i is the cost share of the i^{th} input, and f_{it} is a function of n input prices, nonneutral technical change, and the level of output, Y . The adjustment process is specified in terms of lagged quantities; this ensures satisfaction of the Le Chatelier principle, which implies that short-term price elasticities cannot exceed long-term price elasticities in terms of absolute value.

The demand functions derived through the approximation in Eq. (2) may represent the demand functions for inputs of well-behaved producers, if they exhibit the following three conditions (Varian, 1992):

(a) Non-negativity: $x_i(w, y) \geq 0$

(b) Zero-degree homogeneity in prices: $x_i(tw, y) = x_i(w, y)$

(c) The Hessian matrix of the cost function: $H = D^2_{ww} c(w, y) = \nabla_w x(w, y)$ is negative, semi-definite, and symmetric

The first property of a well-behaved demand function is guaranteed by construction—that is, a logistic approximation. However, the second and third properties of demand functions impose restrictions on Eq. (1). Zero-degree price homogeneity can be imposed as $\sum_j \beta_{ij} = d \quad \forall i$, where d is some arbitrary constant (usually zero) (Considine and Mount, 1984). Concerning the third condition, symmetry conditions can be imposed *ex ante*, but the negative semi-definiteness of H cannot; therefore, the negative semi-definiteness of H —as the necessary and sufficient condition for the concavity of the cost function—is verified *ex post* without imposing it. Following Considine (1990), the symmetric conditions can be imposed either locally or globally; we imposed globally symmetric restrictions. Letting $\beta^*_{ij} = \beta_{ij} / \hat{S}_{jt}$, and the globally symmetric

[1] A deterministic time-trend also contributes to a reduction in the number of concavity violations (Jones, 1995).

conditions are defined as $\beta^*_{ij} = \beta^*_{ji}$, where $\hat{S}_{jt}$ is the predicted shares for each observation. In addition, four identifying ("adding up") restrictions are required for the estimation: $\beta_n = \beta_{ny} = \beta_{nt} = d = 0$. When zero-degree price homogeneity, global symmetry, and four identifying restrictions are accompanied by Eq. (2), the dynamic log-linear system can be rewritten as:

$$\ln\left(\frac{S_{it}}{S_{nt}}\right) = \beta_i + \sum_{j=1}^{i-1}\left(\beta^*_{ij} - \beta^*_{jn}\right)\hat{S}_{jt} \ln\left(\frac{p_{jt}}{p_{nt}}\right) - \left[\sum_{k=1}^{i-1}\beta^*_{ki}\hat{S}_{kt} + \sum_{k=i+1}^{n}\beta^*_{ik}\hat{S}_{kt} + \beta^*_{in}\hat{S}_{it}\right]\ln\left(\frac{p_{it}}{p_{nt}}\right)$$
$$+ \sum_{j=i+1}^{n-1}\left(\beta^*_{ij} - \beta^*_{jn}\right)\hat{S}_{jt} \ln\left(\frac{p_{jt}}{p_{nt}}\right) + \beta_{iy} \ln y_t + \beta_{it} t + \lambda \ln\left(\frac{x_{it-1}}{x_{nt-1}}\right) + (\varepsilon_{it} - \varepsilon_{nt}), \tag{3}$$

where $(\varepsilon_{it} - \varepsilon_{nt})$ is assumed to comprise normally distributed random disturbances. Because $\hat{S}_{jt}$ is the predicted cost share, a two-step iterative procedure is applied to estimate Eq. (3). In the first step, we substitute actual cost shares for $\hat{S}_{jt}$; we then estimate an initial set of coefficients and the predicted share. In the second step, we estimate the final set of coefficients by inserting the predicted share. This process continues until the parameter estimates converge. The sufficient condition for cost minimization, concavity, is not imposed; however, it is tested indirectly by the sign of the own-price elasticities. The nonlinear iterative and seemingly unrelated estimation procedure available in the TSP software package (v5.1) is used to derive all estimations in this paper.

The short-term price elasticities of input demand, η^{SR}_{ij} and η^{LR}_{ij}, by Eq. (3) can be derived by:

$$\eta^{SR}_{ij} = \begin{cases} (\beta^*_{ij} + 1)S_j, & \text{if} \quad i \neq j \\ (\beta^*_{ii} + 1)S_i - 1, & \text{if} \quad i = j \end{cases}, \tag{4}$$

$$\eta^{LR}_{ij} = \frac{\eta^{SR}_{ij}}{1 - \lambda}. \tag{5}$$

The dynamic linear logit model performs better than other dynamic functional forms, not only because it is derived from an explicit dynamic optimization problem, but also because it satisfies the Le Chatelier principle (Considine and Mount, 1984).

3. Estimation results

3.1 Data description

Many interfuel substitution studies classify industrial fuel consumption into four groups: coal, oil products, natural gas, and electricity (Fuss, 1977; Pindyck, 1979). Following them, we assume that energy consumption in the industrial sector can be categorized into four major energy types: 1) coal (both steam and coking), 2) oil products (all petroleum products, regardless of use), 3) natural gas, and 4) electricity. Owing to data limitations and to facilitate comparisons between South Korea and Japan, we permit fuels used by the industrial sector for nonenergy purposes—such as coking coal, petrochemical feedstocks, and lubricants—to be included as energy fuels.[2] According to the definition given by the International Energy Agency (IEA), the industrial sector defined in this paper consists of 13 subindustries: 1) iron and steel, 2) chemical and petro-chemistry, 3) nonferrous metals, 4) nonmetallic minerals, 5) transport equipment, 6) machinery, 7) mining and quarrying, 8) food and tobacco, 9) paper, pulp, and printing, 10) wood and wood products, 11) construction, 12) textile and leather, and 13) non-specified.

We use indices of prices, quantities, and cost shares for each energy input in the industrial sector in South Korea and Japan, from 1987 to 2009 ($T = 23$). The data used in this study are constructed following Jones (1995) and Serletis et al. (2010), whose sources are described in Table 1. First, annual fuel-specific consumption data from South Korea and Japan were found in the *Energy Balances of OECD Countries* (IEA, 2011a). For Japan, annual fuel-price indices were derived from the *Energy Prices and Taxes* (IEA, 2011b). By definition, these are actually paid end-use prices in the industrial sector, including prices for automotive diesel for oil products. Meanwhile, domestic data were used to calculate annual fuel prices in South Korea, as IEA data is not sufficient in covering our entire analysis period. Finally, as the output (Y) data, we took the industrial production index (IEA, 2011) for both South Korea and Japan.

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[2] Considine (1989b) asserts that the distinction between energy use for fuel combustion and material production is important, because petroleum and coal elasticities in the aggregate model may be substantially biased.

Table 1. Data sources

	South Korea	Japan
Fuel consumption	- *Energy Balances of OECD Countries* (IEA, 2011a)	- *Energy Balances of OECD Countries* (IEA, 2011a)
Fuel price	- Oil product, natural gas, electricity: Producer Price Index (PPI) (BOK, 2011) - Coal [a]: *Yearbook of Energy Statistics* (KEEI, 2010)	- *Energy Prices and Taxes* (IEA, 2011b)
Output (Y)	- *Energy Balances of OECD Countries* (IEA, 2011a)	- *Energy Balances of OECD Countries* (IEA, 2011a)

[a] We calculate the price index of coal using a discrete approximation of the Divisia index by Tornqvist (Christensen and Jorgenson, 1970) to aggregate the prices of bituminous coal and anthracite coal.

3.2. Empirical results

Before undertaking the analysis proper, we settle the issue of whether production technology is a nonhomothetic cost function with nonneutral technical change, to obtain a precise functional form. We carry out the likelihood ratio (LR), which tests the validity of linear hypotheses (Johnston and DiNardo, 2007). Our test results are presented in Table 2. First, the LR statistics cannot reject the hypothesis that $\beta_{iy} = 0, \quad \forall i$ — namely, homotheticity at the 5% level in both South Korea and Japan. We also failed to reject the hypothesis that $\beta_{it} = 0, \quad \forall i$, which indicates neutral technical change in Japan as well as in South Korea. Thus, we assume a homothetic cost function with neutral technical change, by imposing on Eq. (3) the restrictions that $\beta_{iy} = \beta_{it} = 0, \quad \forall i$.

Table 2. Test results of homotheticity and neutral technical change

Null hypothesis	South Korea	Japan
Homotheticity ($\beta_{iy} = 0 \quad \forall i$)	Accepted (LR = 4.2515)	Accepted (LR = 4.3573)
Neutral technical change ($\beta_{it} = 0 \quad \forall i$)	Accepted (LR = 3.4605)	Accepted (LR = 7.4650)

[a] The critical value is $\chi^2(3) = 7.815$ at the 5% level.

Table 3 presents the parameter estimates and summary statistics for each of the two countries. Our model shown in Eq. (3) provides a significantly better overall fit for Japan than for South Korea, and with a much higher log-likelihood. The Durbin–Watson statistics indicate that there is not yet any clear evidence of serial correlation in the equation residuals for either South Korea or Japan. Among 12 parameters, 10 parameter estimates are significant at the 1% level, at least, in South Korea, while that figure for Japan is 11. The estimate of the partial adjustment coefficient, λ, is slightly larger in South Korea than in Japan, that is, about 5%. This suggests that given the estimates of λ, while the long-term response of the first year is only 15% in South Korea, in Japan, it is up to 20%—that is, the long-term adjustment process of Japan is faster than that of South Korea, which in turn suggests that Japan has supposedly been able to cope with energy-price changes better than South Korea.

Table 3. Parameter estimates

Parameter	South Korea		Japan	
	Estimate	T-statistics	Estimate	T-statistics
β_1	0.1400	0.8158	0.0236	1.1237
β_2	–0.2127	–7.5497**	–0.0442	–2.5954**
β_3	–0.1527	–3.0194*	–0.2303	–4.9639***
β_{12}	–0.9335	–6.8818**	–0.7099	–7.4663***
β_{13}	–0.9635	–12.195**	–1.1172	–8.6243***
β_{14}	–1.1541	–12.131**	–1.1403	–26.5010***
β_{23}	–0.7364	–1.1584	2.9207	15.0170***
β_{24}	–0.7067	–13.724**	–0.9382	–14.8350***
β_{34}	–1.3868	–5.6178*	–1.6202	–6.6940***
λ	0.8447	23.4430**	0.8023	28.4980***
Summary statistics				
DW_1	1.8627		2.4024	
DW_2	2.4287		1.7498	
DW_3	2.5465		1.6777	
$\log L$	61.956		115.92	

[a] ** and * denote statistical significance at the 0.1% and 1% levels, respectively.
[b] Fuel 1, 2, 3, and 4 are coal, oil products, natural gas, and electricity, respectively.

Table 4 provides a complete list of the estimated price elasticities, measured at the sample means for each country. We found positive own-price elasticities at some sample points for both South Korea and Japan. Considering that negative own-price elasticities are necessary conditions for concavity, our results indicate the violation of concavity. One reason for the violation of concavity, supposedly, is the imposition of global symmetry, because they are in a trade-off relationship (Considine, 1990). Particularly, positive own-price elasticities of electricity at whole sample points have been drawn in common, which raises the possibility of model misspecification. It implies that demand for industrial electricity in both countries has continuously increased, although the relative price of electricity has increased. That is, for electricity, both countries, in this instance, run counter to the law of demand. However, these results also suggest that other factors may be part of electricity-demand equation. In addition, all the signs of cross-price elasticities are consistent at all sample points. In South Korea, complementarity was found between coal and electricity and between gas and electricity; it was also found between coal and gas, coal and electricity, and gas and electricity in Japan. These results correspond to the positive own-price elasticities of electricity.

Table 4. Price elasticities in South Korea and Japan

	South Korea		Japan	
	Short term	Long term	Short term	Long term
Own-price elasticity				
Coal	–0.9854 (0.0053)	–6.3436 (0.0344)	–0.0456 (0.3023)	–0.2309 (1.5295)
Oil products	0.1791 (0.2317)	1.1528 (1.4918)	–1.0835 (0.0059)	–5.4816 (0.0300)
Natural gas	–0.6541 (0.3033)	–4.2108 (1.9526)	–0.9580 (0.0148)	–4.8467 (0.0747)
Electricity	1.3896 (0.1054)	8.9455 (0.6787)	0.8879 (0.3734)	4.4920 (1.8892)
Cross-price elasticity				
Coal–oil	0.0232 (0.0046)	0.1496 (0.0294)	0.0888 (0.0063)	0.4494 (0.0319)
Coal–gas	0.0031 (0.0027)	0.0199 (0.0174)	–0.0060 (0.0021)	–0.0305 (0.0107)
Coal–elec.	–0.0867 (0.0038)	–0.5579 (0.0246)	–0.0564 (0.0112)	–0.2853 (0.0564)
Oil–coal	0.0002 (0.0001)	0.0015 (0.0006)	0.0698 (0.0221)	0.3531 (0.1118)
Oil–gas	0.0223 (0.0196)	0.1436 (0.1259)	0.2018 (0.0709)	1.0207 (0.3587)
Oil–elec.	0.1650 (0.0073)	1.0622 (0.0469)	0.0248 (0.0049)	0.1257 (0.0249)
Gas–coal	0.0001 (0.0000)	0.0008 (0.0003)	–0.0282 (0.0089)	–0.1426 (0.0452)
Gas–oil	0.0920 (0.0181)	0.5924 (0.1164)	1.2005 (0.0853)	6.0738 (0.4317)
Gas–elec.	–0.2176 (0.0096)	–1.4009 (0.0618)	–0.2492 (0.0493)	–1.2606 (0.2493)
Elec.–coal	–0.0006 (0.0002)	–0.0036 (0.0013)	–0.0338 (0.0107)	–0.1708 (0.05410)
Elec.–oil	0.1024 (0.0201)	0.6593 (0.1296)	0.0189 (0.0013)	0.0958 (0.0068)
Elec.–gas	–0.0327 (0.0287)	–0.2108 (0.1848)	–0.0319 (0.0112)	–0.1615 (0.0567)

[a] Standard deviations are denoted in parentheses.

Given the estimated value for λ of 0.8447, long-term elasticities in South Korea are approximately six times larger than the short-term elasticities there. In the same manner, long-term elasticities in Japan are about five times larger than the short-term elasticities there. The estimation results of long-term price elasticities in South Korea denote that the country's own-price elasticities are highly elastic, while only elastic responses are observed between oil products and electricity and between natural gas and electricity. The long-term price elasticities in Japan show that own-price elasticities—except those for coal—are elastic, while only cross-price elasticities between oil products and natural gas and between natural gas and electricity are elastic.

3.3. Discussions

First, we examine whether a developed country demonstrates a higher potential for interfuel substitution than a comparatively less-developed country. In comparing the price-elasticity values in substitution, estimates in Japan are generally larger than in South Korea. Specifically, for the cross-price elasticities between coal and oil and between oil and gas, Japan is more elastic than South Korea. These results support the argument of Serletis et al. (2010) that developed countries demonstrate a higher potential for interfuel substitution in their industrial sectors than is the case in developing economies. This implication is also supported by the estimates of the adjustment parameter, λ; this suggests that Japan reaches equilibrium more quickly than South Korea.

Second, we analyze whether interfuel relationships fluctuate more in a developing country than in a developed country. The degree of fluctuation can be measured through the size of standard deviations. For own-price elasticities, it is difficult to determine which country's standard deviations are larger; however, for cross-price elasticities, the standard deviations of Japan tend to be larger than those of South Korea. Thus, our empirical results fail to confirm the hypothesis set by Cho et al. (2004). However, to test the suitability of this hypothesis, the development of an index that can measure the volatility of elasticities and allow for comparisons of a greater number of countries is needed.

5. Concluding remarks

This study is the first to conduct a comparative analysis of interfuel substitution in South Korea and Japan by applying the dynamic linear logit model. South Korea and Japan are considered a representative developing country and developed country, respectively, and in particular, we investigated two hypotheses on interfuel relationships within developing and developed countries (Cho et al., 2004; Serletis et al., 2010). Our empirical results support the hypothesis that the potential for interfuel substitution is higher in developed countries than in developing countries. The current study also finds no proof to support the hypothesis that elasticity fluctuations are broader in developing countries.

Acknowledgement

This work was supported by a grant (No. 20093021020020) from the New and Renewable Energy Program of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), which was funded by the Korean Government Ministry of Knowledge Economy.

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