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INTER-ENERGY SUBSTITUTION IN KOREA, 1962-1975

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ABSTRACT

In Korea, oil composed only 8.2 percent of total energy consumption in 1962. But oil consumption has grown rapidly through the first and second five-year economic development plan, comprising 52.7 percent of total energy consumption in 1971. One of the most important reasons of the change in the composition of energy consumption through time is the change in the relative price of energy sources. This paper utilizes a translog unit cost function to examine the substitution possibilities among electricty, oil, and coal in Korea. The estimation results with the 1962-1975 aggregate national time-series data shows that the three energy sources are all substitutable and that electricity and coal are the best substitutes.

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I. Introduction

Korea is poorly endowed with energy sources. Coal is the only indigenous fossil fuel discovered so far, and its reserve is very limited.[1] So the increase in energy demand following rapid industrialization made it inevitable for Korea to increase the import of energy from abroad. In 1972, Korea imported 52.3 percent of energy consumed in that year. This was a big jump from the import share of 10.7 percent in 1962. Out of 22.8 million tons of coal equivalent energy import in 1972, only 42,000 tons were coal and the rest were crude oil. The 1973-74 world oil crisis quadrupled the price of crude oil in two years. This dramatic increase in the price of oil seriously affected Korea which imported all of its required crude oil from abroad. From 1972 to 1974, expenses for the import of crude oil rose as much as five times from 221 million to 1,108 million and the cost share of crude oil among total import rose from 8.8 percent to 16.2 percent.

Up to the early 1960s, wood and charcoal were the main energy sources in Korea. In 1961, wood and charcoal composed 56.7 percent of total energy consumption while coal composed 33.4 percent, oil 8.2 percent, and hydro electricity 1.6 percent.[2] During the first five-year economic planning period of 1962 to 1966, wood and charcoal were gradually replaced by coal and oil. In 1966, coal composed 46.9 percent, wood and charcoal 34.6 percent, oil 16.6 percent, and hydro electricity 1.8 percent of total energy consumption. During the second five-year economic development planning period of 1967 to 1971, oil replaced coal as the chief energy source in Korea. In 1971, oil composed 52.7 percent of total energy consumption compared to 27.5 by coal, 18.3 by wood and charcoal, and 1.5 percent by hydro electricity.

The change in the composition of energy consumption through time could have been the result of rapid industrialization, changes in government energy policy, changes in life style, etc. But one of the most important reasons is the change in the relative price of energy sources. This paper examines how the mix of energy consumption can be affected by changing relative energy prices. For this purpose, a translog cost function is employed to derive a system of derived demand equations. Section 2 discusses the model. Section 3 explains how the data are constructed for the translog analysis. In section 4, estimated price elasticities are reported with the results of various tests. Section 5 is the concluding remarks.

II. The Model

Suppose there exists a twice differentiable aggregate production function for the Korean economy as follows:

$$Y = F(E,O,C,\underline{X}), \tag{1}$$

where Y is gross national product, E is electricity, O is fuel oil, C is coal, and $\underline{X}$ is a vector of all other inputs.[3] If the energy inputs are homothetically weakly separable from all other inputs, the

aggregate production function can be written as

$$Y = H(R^{*}(E,O,C),\underline{X}), \tag{2}$$

where R^{*} is an energy input function. Dual to this energy input function is an energy cost function:

$$V = J(R,P_E,P_O,P_C), \tag{3}$$

where V is total cost of energy, R is aggregate energy input, and P_E, P_O, P_C are prices of electricity, fuel oil, and coal, respectively. If the energy input function is a positive, nondecreasing, positively linear homogeneous, concave function, then the energy cost function can be written as

$$V = R \cdot G(P_E,P_O,P_C), \tag{4}$$

where G is a unit cost function satisfying the same regularity conditions and is a function of energy prices only.

To investigate the substitution possibilities among energy sources in Korea, a translog cost function is employed.[4] The translog cost function does not place <u>a priori</u> restrictions on Allen partial elasticities of substitution and provides a second order approximation to an arbitrary functional form. The translog unit energy cost function will be as follows:

$$\begin{aligned} \ln G = {} & \alpha_G + \alpha_E \ln P_E + \alpha_O \ln P_O + \alpha_C \ln P_C \\ & + 1/2\beta_{EE}(\ln P_E)^2 + \beta_{EO}\ln P_E \ln P_O + \beta_{EC}\ln P_E \ln P_C \\ & + 1/2\beta_{OO}(\ln P_O)^2 + \beta_{OC}\ln P_O \ln P_C \end{aligned}$$

$$+ 1/2\beta_{CC}(\ln P_C)^2 . \tag{5}$$

By differentiating equation (5) logarithmically, we get

$$\frac{\partial \ln G}{\partial \ln P_i} = \frac{\partial G}{\partial P_i} \cdot \frac{P_i}{G} = \alpha_i + \sum_j \beta_{ij} \ln P_j , \quad i,j = E,O,C. \tag{6}$$

According to Shephard's lemma,

$$\frac{\partial G}{\partial P_i} = \frac{X_i}{R} \qquad \left(\frac{\partial V}{\partial P_i} = \frac{\partial(R \cdot G)}{\partial P_i} = R \cdot \frac{\partial G}{\partial P_i} = X_i\right) , \tag{7}$$

where X_i represents the cost minimizing energy demand when aggregate energy input R is held constant. By substituting (7) into (6), we get

$$\frac{\partial \ln G}{\partial \ln P_i} = \frac{P_i X_i}{\sum_i P_i X_i} = M_i = \alpha_i + \sum_j \beta_{ij} \ln P_j , \qquad i,j = E,O,C, \tag{8}$$

where M_i is the cost share of energy input i.

The system of cost share equations is as follows:

$$\begin{aligned} M_E &= \alpha_E + \beta_{EE}\ln P_E + \beta_{EO}\ln P_O + \beta_{EC}\ln P_C + u_E, \\ M_O &= \alpha_O + \beta_{OE}\ln P_E + \beta_{OO}\ln P_O + \beta_{OC}\ln P_C + u_O, \\ M_C &= \alpha_C + \beta_{CE}\ln P_E + \beta_{CO}\ln P_O + \beta_{CC}\ln P_C + u_C, \end{aligned} \tag{9}$$

where the disturbance term is added for each cost share equation to allow for randomness in the cost minimizing behavior. As the cost shares sum to unity, the following restrictions are imposed on (9):

$$\begin{aligned} &\alpha_E + \alpha_O + \alpha_C = 1, \\ &\beta_{EE} + \beta_{OE} + \beta_{CE} = 0, \\ &\beta_{EO} + \beta_{OO} + \beta_{CO} = 0, \\ &\beta_{EC} + \beta_{OC} + \beta_{CC} = 0. \end{aligned} \tag{10}$$

Parameter estimates of any two cost share equations generate the parameter estimates of remaining one equation due to the restriction (10). Furthermore, the cross equation symmetry restriction leaves only five out of twelve parameters free of restriction. Imposition of the cross equation symmetry restrictions on the B_{ij} together with the adding up restrictions ensures that the unit cost function is linear homogeneous in its prices. Cost share equations to be estimated after adding up and symmetry restrictions being imposed are as follows:

$$\begin{aligned} M_O &= \alpha_O + \beta_{EO}(\ln P_E - \ln P_O) + \beta_{OC}(\ln P_C - \ln P_O) + u_O, \\ M_C &= \alpha_C + \beta_{EC}(\ln P_E - \ln P_C) + \beta_{CO}(\ln P_O - \ln P_C) + u_C. \end{aligned} \tag{11}$$

Estimates of $\alpha_E, \beta_{EE}, \beta_{OO}$, and β_{CC} are calculated from (10). But an arbitrary choice of two equations for estimation will result in varying parameter estimates. To avoid this problem, the iterative Zellner efficient (IZEF) method is used. Parameter estimates by this procedure converge to maximum likelihood estimates which are invariant to the equations chosen.[5]

Following Uzawa,[6] Allen partial elasticities of substitution between energy input i and j are

$$\sigma_{ij} = \frac{G \cdot G_{ij}}{G_i \cdot G_j}, \qquad i = E,O,C, \tag{12}$$

where G is a unit energy cost function and G_i and G_{ij} are first and second derivatives of the unit cost function with respect to energy prices. $\sigma_{ij} = \sigma_{ji}$ follows from (12). These Allen partial elasticities of substitution can be calculated from the estimated cost share equations of (11) as follows:

$$\sigma_{ii} = \frac{\beta_{ii} + M_i^2 - M_i}{M_i^2}, \quad i = E,O,C, \tag{13}$$

$$\sigma_{ij} = \frac{\beta_{ij} + M_i M_j}{M_i M_j}, \quad i,j = E,O,C, i\neq j. \tag{14}$$

Allen has shown that Allen partial elasticities of substitution are related to the price elasticities of demand for factors of production as follows:[7]

$$E_{ii} = \frac{\partial X_i}{\partial P_i} \cdot \frac{P_i}{X_i} = M_i(\sigma_{ii} - \eta), \quad i = E,O,C, \tag{15}$$

$$E_{ij} = \frac{\partial X_i}{\partial P_j} \cdot \frac{P_j}{X_i} = M_j(\sigma_{ij} - \eta), \quad i,j=E,O,C, \; i\neq j, \tag{16}$$

where $\eta = \frac{\partial R}{\partial P_R} \cdot \frac{P_R}{R}$ denotes price elasticity of demand for aggregate energy. If R is held constant, η becomes zero and this guarantees the following relations:

$$E_{ii} = M_i \sigma_{ii} = \frac{\beta_{ii} + M_i^2 - M_i}{M_i}, \; i,j = E,O,C, \tag{17}$$

$$E_{ij} = M_j \sigma_{ij} = \frac{\beta_{ij} + M_i M_j}{M_i}, \; i,j = E,O,C, \; i\neq j. \tag{18}$$

Since the elasticities of substitution and the price elasticities are

functions of cost shares, they will be different across the sample. If the price data are scaled at the means, the estimated constants $\alpha_i (i = E,O,C)$ become equal to the fitted cost shares at the means. In this paper, the price elasticities will be calculated at the means of the data by replacing M_i and M_j in (17), (18) by α_i and α_j.

A cost function is well behaved if cost increases monotonically with its input prices and if it is concave to input prices. As the translog cost function does not satisfy these conditions globally, we have to check the conditions separately. Monotonicity requires $\partial G/\partial P_i > 0$. Since $M_i = \partial G/\partial P_i \cdot P_i/G$, and P_i and G are always positive, the fitted unit cost function increases monotonically in its input prices if the fitted cost shares are positive. Concavity of the translog unit cost function can be checked by the Hessian matrix which is made of second partials of the unit cost function. If the Hessian matrix is negative semidefinite for each observation, the concavity condition is satisfied. This means that the principal minors alternate in sign starting from negative sign. As a measure of goodness of fit, ''pseudo-R^2'' is calculated. Pseudo-R^2 can be calculated as $1-\exp(2(L_1-L_2)/T)$, where L_1 is the logarithm of the maximum likelihood function when the coefficients of all the right hand variables are constrained to zero, L_2 is the logarithm of the maximum likelihood function when the coefficients are unconstrained, and T is the number of observations. The value of pseudo-R^2 is invariant to the choice of equation omitted from the system of cost shares.[8]

III. Data

The data used are national aggregate time-series data ranging from 1962 to 1975. To estimate the cost share equations which are derived from the translog unit cost function, prices and cost shares of three energy sources are constructed from the raw data. The prices for electricity (P_E) are weighted average prices of electricity, where the shares of electricity sale by kinds are used as weights. The prices of oil (P_O) are divisia price indexes of fuel oil. The types of fuel oil used to get the divisia price indexes of fuel oil are gasoline, kerosene, diesel, heavy fuel, bunker-c, propane, and jet fuel. For the prices of coal (P_C), the prices of anthracite coal from government-owned mines are used as an approximation. All the nominal price data are converted into 1970 constant prices using wholesale price indexes. Total cost for energy is the summation of price times quantity for three energy sources. Cost shares for each energy source are calculated by dividing the expenses for each energy source by total energy cost.

As this paper investigates inter-energy substitution at national aggregate level, national energy consumption data should be adjusted properly to avoid double counting. Oil and coal are the main sources of fuel in generating thermal electricity. So the amounts of heavy fuel oil, diesel oil, and coal which were sold to the electric utilities were subtracted from total consumptions of those respectively to get net consumption data.[9] In Table 1, total energy cost and cost shares of electricity, net fuel oil, and net coal are

Table 1

Total Energy Cost and Cost Shares of
Electricity, Fuel and Coal

Year	Total Energy Cost[a,b]	Cost Shares		
		Electricity	Fuel Oil	Coal
1962	.160	.266	.370	.364
1963	.151	.256	.354	.389
1964	.133	.291	.333	.375
1965	.178	.307	.360	.333
1966	.208	.335	.342	.323
1967	.391	.225	.590	.185
1968	.317	.347	.424	.230
1969	.397	.330	.451	.218
1970	.479	.330	.480	.190
1971	.578	.292	.541	.167
1972	.666	.287	.561	.152
1973	.804	.273	.572	.155
1974	1.210	.211	.682	.106
1975	1.464	.263	.642	.095

a Wood and charcoal are not included.

b In 1970 billion dollars.

reported. Column 1 of Table 1 shows that from 1962 to 1975, expenses for the three energy sources increased more than nine times from \$0.160 billion to \$1.464 billion. Annual cost share of oil shows continuous rise except in 1975. This trend in oil is sharply contrasted to the continuous fall in the cost share of coal. The cost share of electricity rose during the 1960s in general but fell continuously in the 1970s. In 1975, the combined cost shares of electricity and net fuel oil comprised more than 90 percent of the total energy cost.

IV. Empirical Results

Parameter estimates and asymptotic errors with and without the cross equation symmetry restrictions imposed are shown in Table 2. The calculated pseudo-R^2 was .754. The cost shares, M_i, are equal to $\partial \ln G/\partial \ln P_i$ which are the percentage changes in the unit cost of energy with respect to the percentage changes in the prices of energy sources. At the means of the data, α_i in Table 2 show the elasticities of unit energy cost with respect to the energy prices. Table 2 shows that the change in the price of fuel oil had the greatest effect in changing unit cost of aggregate energy.

The likelihood ratio test was performed to check the significance of the cross equation symmetry restrictions. Minus twice the logarithm of a likelihood ratio ($-2 \log\lambda$), where λ is the ratio of the maximum value of the likelihood function with the cross equation symmetry restrictions imposed to that without the restrictions

Table 2

Parameter Estimates of Translog Cost Function

Parameters	Symmetry Constrained	Symmetry Unconstrained
α_E	.287 (.009)	.287 (.008)
α_C	.234 (.022)	.234 (.017)
α_0	.479 (.027)	.479 (.020)
β_{EE}	- .038 (.038)	.039 (.066)
β_{EC}	.127 (.042)	.035 (.068)
β_{CE}	.127 (.042)	.371 (.141)
β_{EO}	- .087 (.027)	- .077 (.025)
β_{OE}	- .087 (.027)	- .409 (.167)
β_{CC}	- .108 (.071)	- .441 (.147)
β_{CO}	- .021 (.068)	- .016 (.053)
β_{OC}	- .021 (.068)	.406 (.174)
β_{00}	.108 (.083)	.094 (.063)
Pseudo-R^2	.754	

* Figures in parentheses are asymptotic standard errors.

Table 3

Test of Hypotheses

	Cross-Equation Symmetry of B_{ij}	Cobb-Douglas Functional Form
Test Statistic	8.30	19.62
Degrees of Freedom	3	6
χ^2 Critical Value [a]	11.34	16.81
Test Results	Not rejected	Rejected

a At the .01 significance level.

imposed, is distributed asymptotically as chi-squared with the degrees of freedom equal to the number of restrictions being tested.[10] The null hypothesis of cross equation symmetry is rejected if and only if the test statistic exceeds the critical value. As shown in Table 3, the cross equation symmetry restriction was not rejected at the .01 level. Monotonicity of the unit cost function was checked by the fitted values of the cost shares. Since all 42 fitted cost shares were positive, the monotonocity condition was satisfied. Concavity of the unit cost function was checked by examining the signs of the principal minors at each observation. First and second ordered principal minors had the correct signs in all but one observation. In addition to the tests of regularity conditions, the test to see if there is a significant difference in the estimation results of translog and Cobb-Douglas functions was performed and the result is shown in the right column of Table 3. The test result shows that the translog functional form gives significantly more information than the Cobb-Douglas functional form.

The estimates of the price elasticities at the means of the data are shown in Table 4 together with asymptotic standard errors. These estimates show the responses of energy consumption to the changes in the prices of energy sources when total energy is constant.[11] All the estimated own price elasticities have correct signs. The estimated price elasticity for coal is greater than one, and the estimated price elasticities for electricity and fuel oil are less than one. All the estimates of the cross price elasticities have

Table 4

Estimates of Price Elasticities (Total Energy Constant)

Elasticity	Estimates
E_{EE}	- .853 (.132)
E_{CC}	-1.221 (.311)
E_{OO}	- .297 (.175)
E_{EC}	.678 (.147)
E_{CE}	.829 (.184)
E_{EO}	.175 (.098)
E_{OE}	.105 (.058)
E_{CO}	.391 (.292)
E_{OC}	.192 (.144)

* Figures in parentheses are asymptotic standard errors.

positive signs, implying that all three energy sources are substitutable. According to Table 4, electricity and coal have been the best substitutes of all.

V. Concluding Remarks

The translog cost function was employed for the analysis of inter-energy substitution in Korea. The model performed well satisfying most of the conditions checked. Estimated cross price elasticities showed that electricity, coal, and oil are all substitutable. Among these energy sources, electricity and coal turned out to be the best substitutes. As most of the coal consumption in Korea was by residential and commercial sectors, this finding suggests that the increasing energy demand in the residential and commercial sectors can best be met by increasing the supply of electric energy. With limited hydro resources and poor coal reserves, and under the increasing burden of oil import, the construction of nuclear power plants is one of few choices available to Korea. Of course, the environmental effects of nuclear power plants should be considered carefully when planning future energy policy.

Three comments on the interpretation of the present study are in order. First, the data used for the analysis were highly aggregated national time-series data which could not allow for variations across different sectors and industries. If proper data were available, disaggregated studies in the manufacturing industry or at the individual industry level would produce more fruitful results.

Second, as the consumption data for coal and oil were net of the amounts sold to electric utilities, the estimated cross elasticities show substitution possibilities among secondary energy sources. The results should not be used to get an insight into the problem of substitution among primary energy sources. Third, the analysis is partial in that total energy consumption is kept constant. If unit energy cost changes, relative prices among labor, capital, and energy will change and substitutions among factors of production will take place.

FOOTNOTES

1. Estimated total exploitable coal reserve in Korea was 600.42 million tons in 1975. At the 1975 production rate of 13.57 million tons, the estimated reserve would last for 44 years.

2. The share of each energy source among total energy consumption is compared in converted kilo calorific values. (1 kilo calorie = 3.968 Btu.) See Table 2 of Shin (1980) for more information.

3. Wood and charcoal are excluded from the analysis. Besides the fact that they are not one of modern energy sources, the published data were not suitable to use for the present study.

4. See Christensen, Jorgenson, and Lau (1971, 1973) for the early development of the translog function.

5. See Zellner (1962), and Oberhofer and Kmenta (1974) for discussions on this subject.

6. Uzawa utilized a unit cost function to derive this condition. Berndt and Christensen (1973) extended the idea to the case of a homothetic production function.

7. See Allen (1938), p. 508.

8. See Berndt and Khaled (1977).

9. In 1975, 21.3 percent of oil and 4.6 percent of coal consumptions

were for the generation of electricity. In 1962, the composition of oil and coal used for the generation of electricity were 12.2 percent and 10.0 percent, respectively. For further information, see Table 15 of Shin (1980).

10. See Theil (1971) p. 98 and p. 396.

11. If total energy is allowed to vary, own price elasticities will be greater in absolute values and cross price elasticities will be smaller than the estimated results of Table 4. For further discussion on this topic refer to Shin (1981).

APPENDIX: SOURCES OF DATA

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