Order Number 9207077

Estimates of translog cost functions and productivity in the shipping industry in Korea

Ha, Yeong-Seok, Ph.D.

City University of New York, 1991

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

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ESTIMATES OF TRANSLOG COST FUNCTIONS AND PRODUCTIVITY IN THE SHIPPING INDUSTRY IN KOREA

by

YEONG-SEOK HA

A dissertation submitted to the Graduate Faculty in Economics in partial fulfillmemt of the requirements for the degree of Doctor of Philosophy, The City University of New York.

1991

This manuscript has been read and accepted for the Graduate Faculty in Economics in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

7/10/91
Date

Michael Grossman
Chair of Examining Committee

7/10/91
Date

Michael Grossman
Executive Officer

Professor Michael Grossman

Professor Salih Neftci

Professor Ronald Anderson

Supervisory Committee

The City University of New York

ABSTRACT

Estimates of Translog Cost Functions and
Productivity in the Shipping Industry in Korea.

by

YEONG-SEOK HA

Adviser: Professor Michael Grossman

The purpose of this study is to analyze various economic phenomena of the shipping industry in Korea using the translog variable cost function which is treated as a second-order Taylor series approximation to an arbitrary underlying cost function. Since the variable cost model is considered in this study, the capital is treated as a quasi-fixed input throughout the study.

By adopting the methodology suggested by Caves et. al.(1981), productivity growth of the industry was estimated. The findings of productivity growth can partly answer questions on how responsive the industry is to changes in government policies(or regulations), to changes in input prices, and to why subsidy of the industry is necessary.

This study applies the seemingly unrelated regression analysis(SURE) for the cost function and the cost share equations, assuming that nonzero correlations for the equations of same year and zero correlation for the equations of different years. To verify proper function of the industry, the likelihood ratio test was made by calculating the determinants of the unrestricted and restricted estimates of the disturbance var-covariance matrix.

The main findings of this study are: the higher elasticity of substitution between labor and supply was found to be average and the own price elasticity of labor was relatively bigger compared to that of supply and fuel, implying that the wage rates are highly negotiable. Economies of densities of the industry are high in general but decreased over the period 1964-1983, were negative in 1983, and recovered thereafter.

The likelihood ratio test reveals that the assumptions of homotheticity and homogeneity cost stucture of the industry are inappropriate, ruling out the use of Cobb-Douglas functional form. Moreover, the results are fortified by the fact that the elasticities of substitution are significantly below unity.

The average productivity growth rates of the industry are generally low compared to the growth rates of the Korean economy. Substantial productivity growth was achieved during the early period(1964-76) and no substantial growth was discovered during the late seventies and the eighties.

Finally, we discussed the impact of government plans(or policies) and fuel price changes on productivity growth. The importance of subsidy was also explained.

Acknowledgments

I am deeply indebted to Professor Michael Grossman for his intellectual guidance and help on all aspects of this study. His rigorous training in economic theory and excellent supervision made it possible for me to complete this work. I would also like to thank Professor Salih Neftci who helped to accumulate knowledge on econometrics and logical thought. I am also grateful to Professor Ronald Anderson for his intellectual lectures and guidance.

I wish to thank Chi-Hyun Whang and Jong-Hai Hong who through their efforts provided me with various data for this work. Their warm friendship encouraged me when I had difficuties.

Heartfelt thanks go to my mother, father-in-law, mother-in-law, and my family. Because of their encouragement, support, and willingness to sacrifice, I was able to devote myself to this work.

This work is dedicated with love and gratitude to my wife Bosoon and my daughter Inhai.

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I. INTRODUCTION

The study of productivity growth in shipping industry is cumbersome and very sparse. The difficulties for the study of productivity growth in shipping industry stem from various reasons, such as hetero geneity of services, choice of appropriate methods to measure productivity, and the variability of the market structure. Moreover the basic data required for proper research is not readily available.

The fundamental reasons for the study of productivity are to evaluate the performance of economic regulations, industry structure, wage negotiations, and prevailing government policies, as well as to provide information for future institutional decisions. In addition, we can partly answer the question of why a certain level of subsidy for the industry is necessary in terms of productivity growth rate. Because of the important role of productivity changes to both public and private decision processes, the precise model specification is crucial.

The recently developed methodology by Caves, Christensen, and Swanson[1] will be applied to technological change in the shipping industry in Korea in consideration of the fact that the method is closely related to the total factor productivity, which

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1. Douglas W. Caves, Laurits R. Christensen, and Joseph A. Swanson, "Productivity Growth, Scale Economies, and Capacity Utilization in U.S. Railroads, 1955-74." The American Economic Review, Vol. 71, No. 5, (Dec., 1981), pp. 994-1002.

was applied to various transpotation productivity studies, such as Kendrick(1961), Meyer and Morton(1975), Caves et al.(1980), and Moshe Kim(1985) and it correctly accounts for factor substitution over time. Furthermore, their method takes account of the fixity of a large part of rail costs that is similar to the case of the shipping industry.

Since shipping has always been considered a risky business that confronts many uncertainties in its operations, management of shipping has always been based on short-term factors. Thus, I estimated a translog variable cost function that shows a short-run relationship.

The objective of this paper is to show how the change of input prices and how the various government plans -- the five year term economic development plans(1962-1976) and the 1984 rationalization plan for the shipping industry -- affect the productivity of the industry. In addition, the estimation of the parameters in the variable cost function will be another objective.

I-1. A Brief History of the Shipping Industry in Korea.

The Korea Shipping Corporation, which was the first private shipping company in Korea, was established in 1950. In 1952, the company opened the first liner service between the United States and Korea with five commercial vessels. When the Korean government started the first term five year economic development plan in 1962, there was only one company(Korea Shipping Corporation) engaged in ocean transportation with fourteen ships(64,046 GRT).

At the end of the third term economic development plan(1976), sixty six companies were engaged in ocean transportation with 478 ships (266 were owned by Koreans and the rest were long-term or short-term chartered), a total of 3,683,242 GRT (1,960,365 GRT were owned by Koreans). After the forth term(1982-1986) economic development plan, the fleet increased to 7,415,982 GRT(6,034,600 GRT was owned by Korean). The physical growth of the industry in terms of gross tonnage owned by Koreans was more than threefold during the ten years(1977-86).

Thus, the rapid increase in shipping capacity relied heavily on government supports of various kinds: indirect financial aids such as government guarantees of payment of international bank loans; operating loss compensation for major companies; and direct aid to shipbuilding done in Korean shipbuilding yards. Moreover, the government withdrew the restriction on the purchasing of vessels over fifteen years old, in order to promote physical growth.

Export-led government policy has helped the remarkable growth in shipping capacity, since the dramatic increase in trade volume moved by ships from 5.2 million M/T in 1964 to 55.8 million M/T in 1976 and 198.5 M/T in 1988 has required a rapid expansion of the industry. The shares of Korean flag vessels in the transportation of cargoes both imports and exports has continuously increased from an average of 23.5% (1967-71), to an average of 25.2% (1972-76), to 44.8% (1977-81), and to 46.5% (1982-86).

In 1984 the government announced a plan to rationalize the shipping industry to overcome a continuous downturn which resulted from successive oil shocks and over-capacity, and to increase competitiveness in the world shipping market by means of horizontal merger. Ten leading companies were chosen for international shipping services, aside from the companies which empolyed vessels in Japan and South East Asia routes. After the announcement of the plan, the number of shipping companies was decreased from sixty in 1983 to thirty seven in 1985.

As Park(1990)[2] pointed out, the Korean government has been collaborative and even coercive in relations with the private sector. The policy bureaucracy has also heavily intervened in the shipping industry. So, despite the rapid expansion of the industry, it is difficult to conclude that the entrepreneurship of each individual firm has played an important in this growth.

I-2. Sources of Productivity Change in the Industry

Productivity change can occur as an effect of a number of forces working in the external environment in addition to endogeneous factors taken by firms within the industry. The possible sources are depicted in figure 1. Besides exogeneous and endogeneous factors, the shipping industry often improves productivity efficiency through the combined effects of increasing scale of operation(merger).

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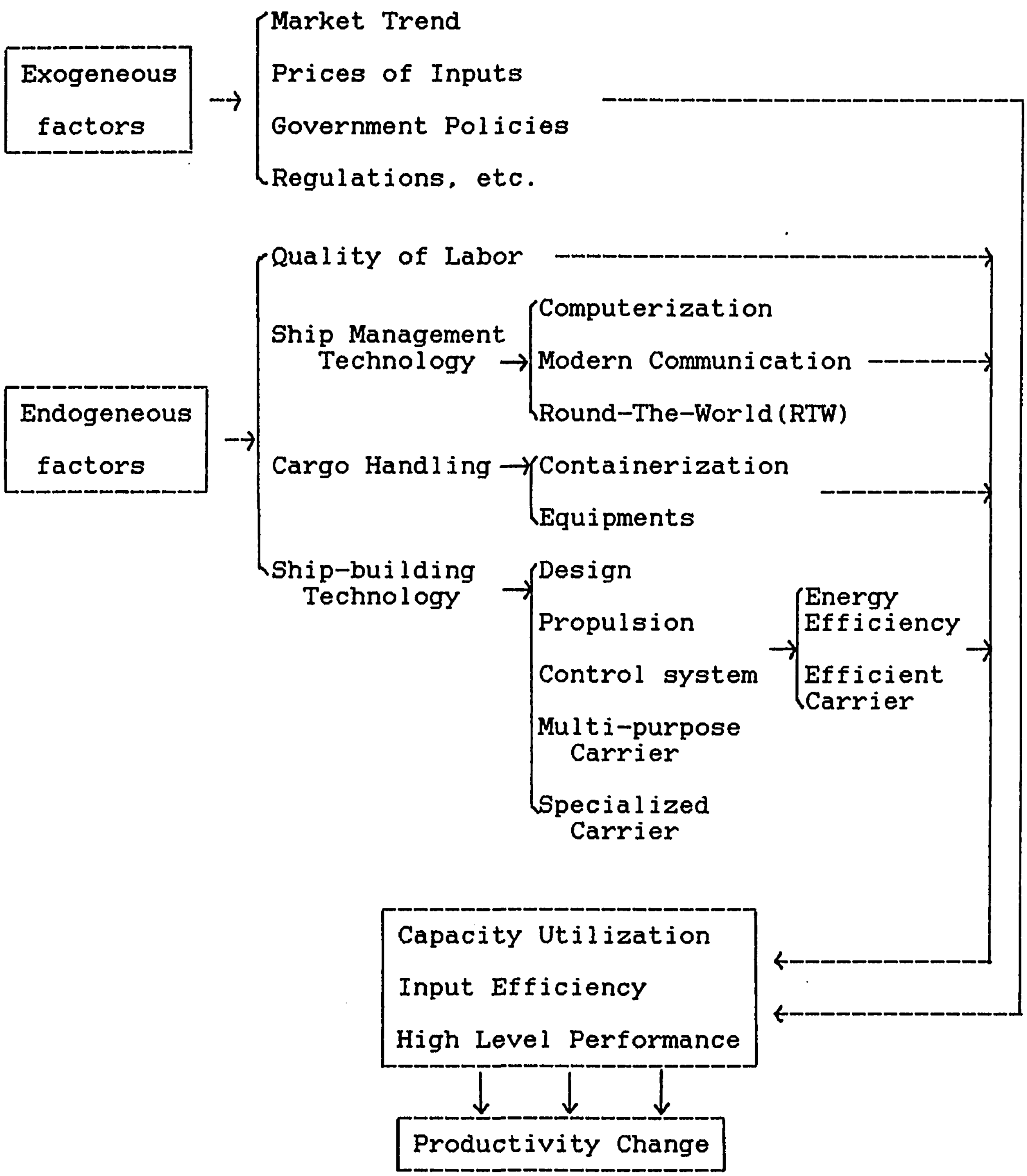
2. Yung Chul Park, "Development Lessons from Asia: The Role of Govenment in South Korea and Taiwan," American Economic Review, AEA Papers and Proceedings, vol.80, No.2 (May 1990), pp. 198-121.

Figure 1

Diagram for the Factors of Productivity Change



The highly competitive environment of the international shipping industry requires advanced ship management[3] technology, such as Round-The-World(RTW) service in liner shipping. The RTW concept is one of the global strategies which focuses on the horizontal connection of a few high volume trade routes with feeder sevices between load center and intermediate volume ports.

The increasing cost of fuel has undoubtedly contributed to technological changes in ship design, propulsion, and control systems that increase energy efficiency and other input efficiencies.

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3. Ship management was defined(Frankel, 1982) as the set of decisions required to assure effective operation and performance of ships, either as a unit, part of a fleet of ships, or part of a transportation system.

II. Theoretical Foundation

Productivity is defined as the relationship between an input or group of inputs and output from the production process. Productivity, which is often measured as a ratio of output(s) to inputs, is differentiated from productivity change or growth, that is represented as any kind of shift in the production function(Solow, 1957)[4]. For example, productivity measures the ratio of ouput per man-hour for a given period of time, while productivity growth is the perentage change in this ratio between two time periods.

The concept of productivity change is categorized under the five options: (1) Increased output, holding inputs at a constant level, (2) decreased inputs at a given level of output, (3) increased output while decreasing input, (4) increased output faster than input increasement, (5) decreased output less than input decreasement. The options (1) and (2) are dealt with in this study as a productivity growth in connection with cost function.

II-1. Productivity Indices

There are several kinds of productivity indices. The most commonly used and most important indices are the partial productivity indices of labor and capital, total factor productivity, and total productivity. The partial productivity indices

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4. Robert Solow's geometric index of productivity growth is called as the "residual" or the index of "technical progress."

are ratios of indices of output to a single input. These partial indices simply reveal the average product of a single input. The indices are of the forms:

$AP_L = Q/L$

$AP_K = Q/K$, where Q:ouput L:labor K:capital

The productivity changes according to the partial productivity simply reveal the intensity of use of that input over time, but do not measure changes in total productive efficiency over time. Put differently, labor productivity change measures not only changes in output resulting from the changes in labor input, but also changes in output implied by changes in capital input, and in intermediate input, plus those due to technological change.

Total factor productivity, often referred to as the "residual" that reflects the net saving of both inputs or the index of "technical progress," combines the two major inputs of capital and labor into a joint index of inputs and relates its movement to an index of output(s). Although this is undoubtedly a more reliable measure than the partial productivity measures, intermediate inputs are most often simply ignored in measuring total factor productivity. The general form of the index is:

$TFP = Q/(aL+bK)$

where Q, L, and K are, respectively, the aggregate level of output, labor, and capital inputs and a and b are appropriate weights. There are two well known indices of total factor productivity. One is the Kendrick's arithmetic measure[5] and the other

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5. By assuming homogeneous production function and the Euler condition, the productivity changes can be represented as

is the Solow's geometric index[6].

The conceptually more complete, efficient, and therefore the more reliable measure for the productivity changes, is the concept of total productivity. The difference between this measure and total factor productivity derives from the fact that

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$$\frac{dA}{A} = \frac{dTFP}{TFP} = \frac{Q_1/Q_0}{(wL_1+rK_1)/(wL_0+rK_0)} - 1$$

where w and r are the wage rate and the return on capital respectively, and subscript 1 refers to the current period and subscript 0 refers to base period. This measure allows the change of weights smoothly over time.

6. Solow's mesure is based on the production function with constant returns to scale and neutral technology change.

(a) $Q=F(K,L,t)$

The variable t for time appears in F to allow for technical change. In the case of neutral technical change, the production form has

(b) $Q=A(t)f(K,L)$

A(t) measures the cumulative effect of shifts over time. Differentiate (b) totally with respect to time and divide by Q,

$$\text{(c)}\quad \frac{\dot{Q}}{Q} = \frac{\dot{A}}{A} + A\frac{df}{dK}\frac{\dot{K}}{Q} + \frac{df}{dL}\frac{\dot{L}}{Q}$$

where dots indicate time derivatives. The equation (c) can be transformed as

$$\text{(d)}\quad \dot{Q}/Q = \dot{A}/A + S_K(\dot{K}/K) + S_L(\dot{L}/L)$$

where S_L and S_K are shares of capital and labor. Let $Q/L = q$, $K/L = k$, $S_L = 1-S_K$, (d) becomes

$$\text{(e)}\quad \dot{q}/q = \dot{A}/A + S_K(\dot{k}/k)$$

The technical change index A(t) is represented by the series for output per labor, capital per man-hour, and the share of capital. For empirical purposes, (e) can be rewritten as,

$$\text{(f)}\quad dA/A = dq/q - S_K\, dk/k$$

intermediate purchases are included among the input measures. The most reliable productivity changes in overall efficiency of operation are captured in the concept of total productivity, since all inputs are quantified, therefore, the measure of productivity reflects only those increases in output that are not accounted for by increase in any inputs.

Most previous productivity researches were made under the assumptions of specific production function, such as Cobb-Douglas or CES(Abramovitz(1956), Kendrick(1961), and Solow(1957,1962)). Although those forms are especially convenient for estimation, they, unfortunately, impose serious and perhaps unrealistic restrictions on production processes.[7] Because of the convenient duality principles of production, the productivity growth and technical change have been measured through the cost function. In addition, the use of flexible functional forms to estimate productivity growth is widely applied, since it provides a lot of flexibility and still allows fairly simple estimations(Diwert, 1976 and Caves et al, 1980, 1981). The general derivation of quadratic function developed by Diwert(1976) is

$$\text{(A)} \qquad h(Z) = a_o + \sum a_i Z_i + 1/2 \sum \sum a_{ij} Z_i Z_j$$

$$= a_o + aZ + 1/2\, Z'AZ$$

where $a_{ij}=a_{ji}$, $a = (a_1,\ldots,a_n)$, $A = \{a_{ij}\}$. It follows that

$$\text{(B)} \qquad h(Z^1)-h(Z^o) = 1/2\left[\frac{d\ln h(Z^1)}{d\ln Z_i} + \frac{d\ln h(Z^o)}{din Z_i}\right] (Z^1-Z^o)$$

---

7. Cobb-Douglas assumes seperability, unitary elasticity of substitution, homogeneity, and limited ability to approximate other functions.

If production function exhibits Hicks-neutral technical change,

(C) $$Q = A(t)f(x)$$

By assuming f(x) is translog, the f(x) can be written

(D) $$\ln f(x) = b_0 + \Sigma_i b_i \ln x_i + 1/2 \Sigma_i \Sigma_j b_{ij} \ln x_i \ln x_j$$

Using (B),

(E) $$\ln f(x_t) - \ln f(x_o) = \frac{1}{2} \Sigma_i \left(\frac{d\ln f(x_t)}{d\ln x_i} + \frac{d\ln f(x_o)}{d\ln x_i} \right) (\ln x_{ti} - \ln x_{oi})$$

By taking antilog,

(F) $$\frac{f(x_t)}{f(x_o)} = \exp \frac{1}{2} \Sigma_i \left(\frac{d\ln f(x_t)}{d\ln x_i} + \frac{d\ln f(x_o)}{d\ln x_i} \right) (\ln x_{ti} - \ln x_{oi})$$

If it is possible to represent the right-hand side of (F) with observable data, the equation (F) reveals an observable technical change index consistent with the translog. Since elasticity of output equals the cost share under constant returns to scale and cost minimization[8], (F) can be written as

(G) $$\frac{A(t)}{A(0)} = \frac{Q_t}{Q_o} \exp \frac{1}{2} \Sigma (S_{it} + S_{io})(\ln x_{io} - \ln x_{it})$$

Thus, expression (G) corresponds exactly to the Tornqvist index, which is an exact measure of technical change if the original production function exhibits Hicks-neutral technical change and can be closely approximated by a translog. Diewert has called

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8.
$$Ei = \frac{d\ln Q}{d\ln xi} = \frac{dQ}{dxi}\frac{xi}{Q} = \frac{w}{p}\frac{xi}{Q} = \frac{wxi}{C} = S_i$$

since R=C in constant returns to scale, and $MC = p = \dfrac{w}{mpx_i}$.

equation (G) a superlative index of technical change because it is an exact measure of technical change for a functional form that is flexible.

Caves et al. have developed a flexible cost function to estimate productivity growth(1981), and flexible cost function with Divisia index method(1980) in the U.S. railroad. Since the methodology suggested by Caves et al. was applied in this study, the method can be discussed in full length later on.

II-2. Technical Change, Hicks Neutral and Factor-Augmenting Technical Change

In this section, the characteristics of technical change are briefly discussed by means of production function and one of the indirect objective functions such as the cost function. Also the most widely used concepts of neutral technical change in the empirical study are considered as well as technical bias.

II-2-1. Production Function

If a stable relationship between output, inputs, and time(t) is presumed to exist:

(H) $$Q = F(X,t)$$

Expression (H), however, assumes that the technical change does not require new inputs and further that the production function maintains the same basic form as time elapses. Therefore, the technical change caused by the production function (H) is referred to as "disembodied" technical change[9]. Analytically,

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9. Robert G. Chambers, Applied Production Analysis (New York: Cambridge University Press, 1988), pp. 203-205.

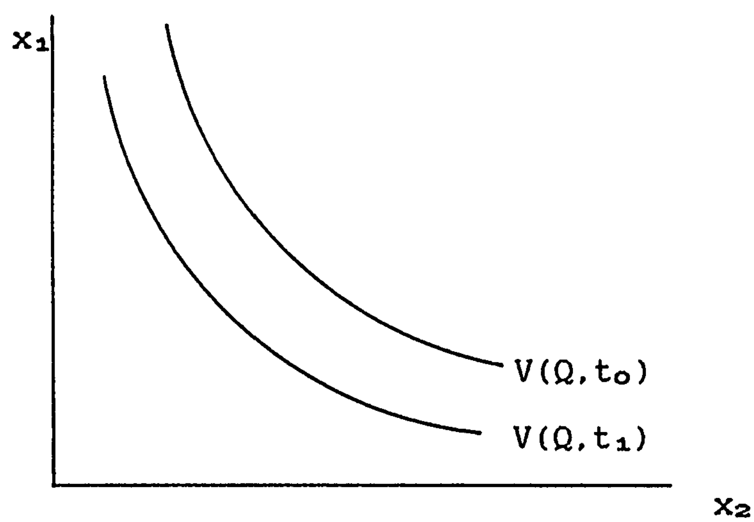
embodied technical change requires differentiating the production function itself as well as input bundle over time. Conceptually, "embodiment" is defined as the new inputs are more efficient than the old inputs in technology advance[10]. Hereafter any technical change is categorized as disembodied.

The technical change is said to be progressive(regressive), if input requirement set defined (I) reveals $V(Q,t_o) \geq V(Q,t_1)$ (reverse of equality considered as regressive), where $t_1 > t_o$.

(I) $V(Q,t) = \{X: F(X,t) \geq Q\}$

This is presented in Figure 2.

Figure 2



Progressive Technical Change

Hicks(1963) considered the case where production function is composed by labor(L) and capital(K) inputs with time variable(t) for technical change

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10. M. Ishaq Nadiri, "Measurement of Total Factor Productivity: A Survey," Journal of Economic Literature. No.8 (Dec, 1970) pp.1137-1170.

(J) $Q = F(K,L,t)$

Technical change is defined as neutral if at the points on the expansion path the marginal rate of substitution is independent of the time variable. Put another way, the isoquant may be shifted through time. However, the marginal rate of substitution is not affected by time. That is, the time variable(t) is separable from K and L in production.

(K) $Q = F[\phi(K,L),t] = A(t)f(K,L)$[11]

---

11. If production function is both Hicks neutral and homothetic in x, then $Q=F(x,t)=H[G(x,t)]$, where $G(x,t)$ is linearly homogeneous in x and $H'(.) \neq 0$. $G(x,t)$ must be consistent with Hicks neutrality since

(a) $$\frac{dF(x,t)}{dxi} = \frac{dH}{dG}\frac{dG}{dxi}$$

(b) $$\frac{d}{dt}\frac{dF(x,t)/dxi}{dF(x,t)/dxj} = \frac{d}{dt}\frac{dG(x,t)/dxi}{dG(x,t)/dxj} = 0,$$ since maginal rate of substitution does not change as t varies.

From the second equality of (b) under the assumption of $dG/dxi>0$,

(c) $$\frac{d\ln(dG/dxi)}{dt} = \frac{d\ln(dG/dxj)}{dt} \quad \text{all } i,j$$

Because the derivative of the logarithm of each marginal productivity with respect to time is the same for all i,j, this derivative is independent of x. Therefore

(d) $$\frac{d\ln(dG/dxi)}{dt} = g(t)$$

Integrating and taking antilog gives

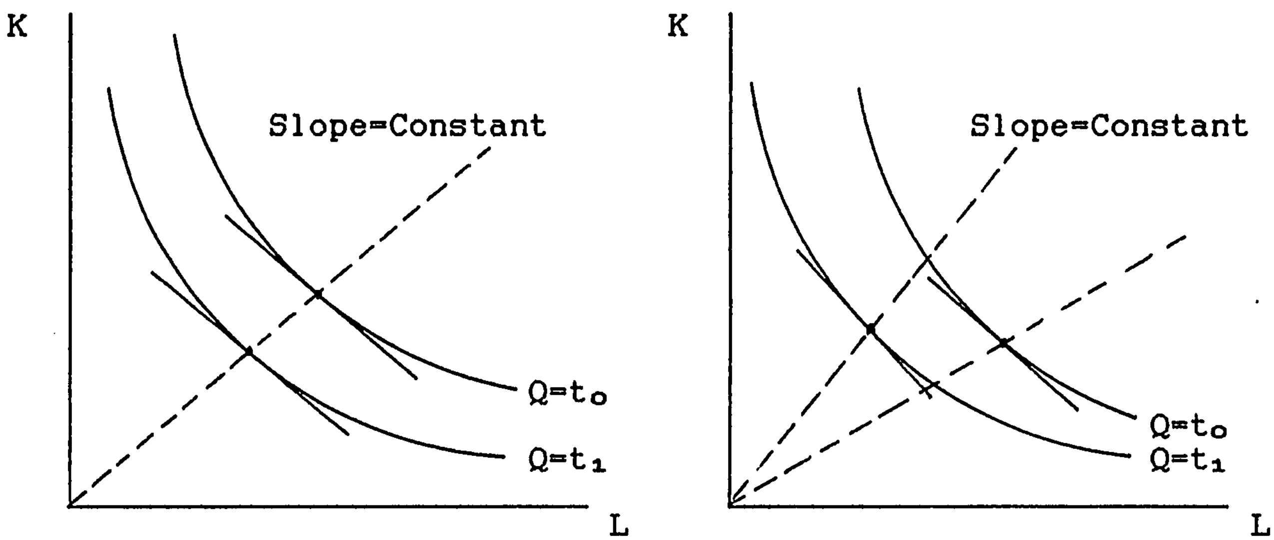
$$dG(x,t)/dxi = \exp[g(t)]\exp[mi(x)]$$

Linear homogeneity of $G(x,t)$ implies

$$G(x,t) = \sum(dG/dxi)xi = \exp[g(t)] \sum\exp[mi(x)]xi$$
$$= A(t)f(x)$$

This case of neutral shift is depicted in Figure 3-a, where technical change moves the isoquant for given output level Q. Moreover, technical change can be Hicks neutral if and only if it is either progressive or regressive. Alternative assumptions of labor saving technical change and capital saving technical change can be defined as biased Hicks technical progress[12], which is

<u>Figure 3</u>



(a) Neutral (b) Labor Saving

expressed graphically in Figure 3-b.

One view of techncal change is that it improves input

Therefore

$$h(Q) = A(t)f(x), \text{ where } h(Q) = H^{-1}(Q)$$

12. The Hicksian measures the bias along a constant capital-labor ratio. Symbolically,

$$\left.\frac{d\ (MP_K\ K)/(MP_L\ L)}{dt}\right|_{K/L\ \text{constant}} \gtreqless \quad \text{Hicks} \begin{cases} \text{Labor saving} \\ \text{Neutral} \\ \text{Capital saving} \end{cases}$$

That is labor-saving technical progress raises the relative marginal product of capital, and vice versa.

efficiency. This is called factor-augmenting or input-augmenting technical change which generalizes the concept of Harrod neutrality that is central to many growth models. In the Harrodian sense, technical progress is neutral if the capital-output ratio(K/Q) and marginal product of capital are constant as capital-efficient input ratio($K/\tilde{L}$) is constant, since both the capital-output ratio and the marginal product of capital depend on the ratio of capital-efficent input ratio. The Harrod-neutral production function postulates that only if labor effectiveness changes over time, it is of the form

(L) $$Q = F[K, \tilde{L}(L,t), t]$$

(M) $$Q = F[K, a(t)L], \text{ where } a(t)L = \tilde{L}$$

The function (M) is an implemented form for empirical analysis from the generalized expression of labor-augmenting technical change, which is (L). The intuition behind factor-augmenting technical change is that the quality of input varies with time. That is, the passage of time makes a quality difference in input(s) that affects production. For example, one unit of labor input used in the first year does not necessarily yield the same effectiveness in the second year for the same production process. Nevertheless, this is differentiated from embodied technical change because a stable relationship between output, input, and time still exists. By taking derivatives of (L) with respect to time, we can obtain a more complete understanding of factor-augmenting technical change.

$$\frac{dQ}{dt} = \frac{dF}{dK}\frac{dK}{dt} + \frac{dF}{d\tilde{L}}\frac{d\tilde{L}}{dt} + \frac{dF}{dt}$$

Diving by Q,

$$\frac{d\ln Q}{dt} = \frac{d\ln F}{d\ln K}\frac{d\ln K}{dt} + \frac{d\ln F}{d\ln \tilde{L}}\frac{d\ln \tilde{L}}{dt} + \frac{d\ln F}{dt}$$

Thus, the augmenting technical change has two components. The first one is effective effect of inputs with certain weights (elasticities with respect to input). The second is a pure shift of production function that can not be attributed to any particular inputs.

The case of cost minimization associated with Hicks-neutral is

$$\frac{MP_L}{MP_K} = \frac{w}{r}$$

where w is the wage per unit of labor and r is rental price of unit of capital. In this case, an increase of A(t) has no effect on the capital-labor ratio under the assumption of w/r being fixed. The cost minimization condition associated with equation (M) is writtem as

$$\frac{MP_{\tilde{L}}}{MP_K} = \frac{\tilde{w}}{r}$$

where $\tilde{w}$ is the wage of one efficiency unit of labor. Since $\tilde{L} = a(t)L$, $a(t)MP_{\tilde{L}} = MP_L$

$$\frac{MP_{\tilde{L}}}{MP_K} = \frac{\tilde{w}}{r} = \frac{MP_L/a(t)}{MP_K}\text{, or } \frac{MP_L}{MP_K} = \frac{a(t)\tilde{w}}{r} = \frac{w}{r}$$

Under the assumption of w/r fixed, the $\hat{w}$ falls as a(t) is rising so that the ratio of K/L would vary as a(t) varies if the elasticity of substitution is not equal to unity[13]. If the type of production function is Cobb-Douglas, the amout of technical progress is the same for both Hicks-neutral and Harrod-neutral.

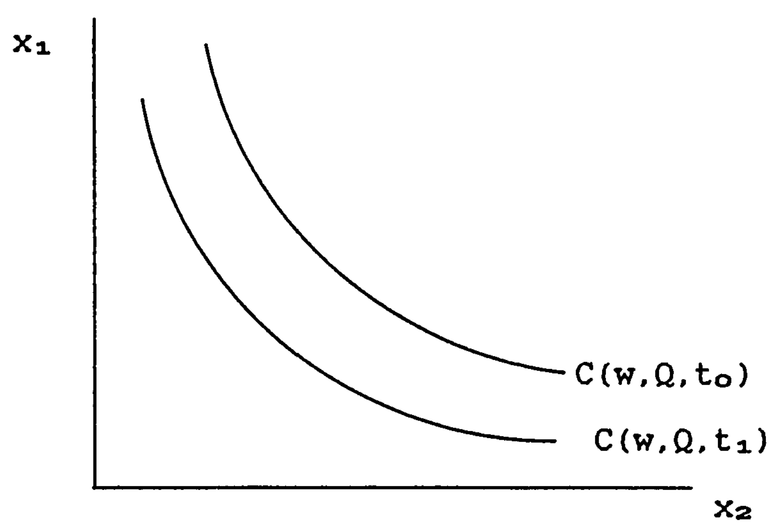
II-2-2. Cost Function

Even though there are some arguments against simply adding the time variable in cost(production) fuction to measure technical change, it has workable advantages for econometric analysis. If input requirement set V(Q,t) satisfies certain conditions(regular,convex, monotonic technology) to generate a cost function,

$$c(w,Q,t) = \min\{wx: x \in V(Q,t)\}$$

then there exists the implicit input reqirement set.[14]

Fiqure 4



Progressive Technical Change

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13. See appendix for proof.

14. Hal R. Varian, Microeconomic Analysis 2nd Ed. (W. W. Norton & Company: New York, 1984), pp. 62-63 for proof.

$V^*(Q,t)=\{x: wx \geq c(w,Q.t), w>0\}$

The cost function will satisfy the following properties: non-negative, nondecreasing, concave, continuous, and homogeneous degree 1 in w and nondecreasing in Q.

If the cost function is non-increasing(non-decreasing) in t, the technical change is progressive(regressive). The technical change is depicted in Figure 4. There exists a unique relationship between the rate of technical change and cost elasticity with respect to output. Consider the Lagrangian,

$$\mathcal{L} = wx + \hat{\lambda}[Q-f(x,t)]$$

By means of the envelope theorem and the optimal value of Lagrangian multiplier for the cost minimization problem[15], we can derive the result.

$$\frac{dC(w,Q,t)}{dt} = -\hat{\lambda}\frac{df(x,t)}{dt} = -\frac{dC}{df}\frac{df(x,t)}{dt}$$

---

15. (1) Under the consideration of two inputs case(K and L) at fixed w,r, first order condition of Lagrangian gives

$$\hat{\lambda} = \frac{w}{MP_L} = \frac{r}{MP_K}$$

(2) C = wL + rK. By taking derivative with respect to output

$$\frac{dC}{dQ} = MC = w\frac{dL}{dQ} + r\frac{dK}{dQ} = \hat{\lambda}(MP_L\frac{dL}{dQ} + MP_K\frac{dK}{dQ})$$

(3) Taking total derivative of production function, and divide by dQ, we can get

$$\frac{dQ}{dQ} = \frac{MP_L\, dL}{dQ} + \frac{MP_K\, dK}{dQ} = 1$$

Therfore MC = $\hat{\lambda}$, since right-hand side formulations of equation (2) and (3) are same.

Dividing both sides by C

$$\frac{d\ln C(w,Q,t)}{dt} = -\frac{d\ln C}{d\ln f}\frac{d\ln f(x,t)}{dt} = \theta(w,Q,t)$$

(N) $T[x(w,Q,t),t] = -e^{*}(w,Q,t)\ \theta(w,Q,t)$

where e^{*}=dlnf/dlnC is associated elasticity of size and θ is rate of cost diminution. If $T[x,t]$ and $\theta(w,Q,t)$ are both constant, the associated elasticity of size must be constant and is always homogeneous of degree e^{*}.

Cost-neutrality and Hicks-neutrality are analogous, but not identical concepts. Cost neutrality implies that cost-minimizing input ratios are independent of the technical change. Meanwhile, Hicks-neutral change has a constant slope of isoquant which is independent of the state of technology. By the homogeneity property of cost function, the general form of the cost-neutral technical change can be written as[16]

(O) $C(w,Q,t) = g(t)h(w,Q)$

If the technical change is not neutral, that is, if there is a

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16. $C(w,Q,t) = G[C(w,Q),t]$, then G(.) is linearly homogeneous in C and C to be linearly homogeneous in w. The ratios of partial derivative yields

$$\frac{dC(w,Q,t)/dwi}{dC(w,Q,t)/dwj} = \frac{(dG/dC)(dC/dwi)}{(dG/dC)(dC/dwj)}$$

Since c(w,Q,t) is linearly homogeneous in w, both sides of the equality must be homogeneous of degree zero in w. Furthermore, Lau's lemma(Ref. Robert G Chambers, <u>Applied Production Analysis</u>, pp 316-17) on homothetic functions implies that C(w,Q) must be at least homothetic in w. By the defintion of the homothetic function,

$$C(w,Q,t) = g(t)h(w,Q)$$

greater pecentage adjustment in one input than in another, the cost-minimizing input ratios vary. Moreover, the biased technical change can be represented in terms of effects on cost shares. The unbiased technical change leaves relative cost shares unchanged.

$$\text{(P)} \qquad \frac{d}{dt}\,\frac{Si(w,Q,t)}{Sj(w,Q,t)} = 0$$

Since patial derivative of (O) with respect to wi shows

$$\frac{d\ln C(w,Q,t)}{d\ln wi} = Si = \frac{dC}{dwi}\,\frac{wi}{C} = g'(t)h'(wj,Q)\,\frac{wi}{C} = \frac{H(w,Q)}{h(w,Q)}$$

Therefore, cost shares for all possible i are independent of the state of technology if technical change exhibits cost neutral. By using the results,

$$S_i(w,Q,t) = m_i(w,Q)$$

Integrating this expression over wi and exponentiating both sides

$$\ln C(w,Q,t) = n(w,Q) + m(t)$$

$$C(w,Q,t) = \exp[n(w,Q)]\exp[m(t)]$$

$$= g(t)h(w,Q)$$

Consequently, the share-neutral technical change is equivalent to the cost-neutral technical change.

The biased technical changes are easily verified in terms of biased cost shares. That is, technical change shows input i using (input j-saving), if

$$\frac{d\ln Si(w,Q,t)}{dt} > 0$$

Cost-neutral means that the curvature of the factor price frontier shifts in a parallel manner, implying that for any given factor prices cost-neutral technical changes leave optimal input ratios unaltered. On the other hand, Hicks-neutrality requires that the marginal rate of substitution be independent of technology on the expansion path. Both concepts coincide when the expansion path is linear, suggesting that the necessary condition for the equivalence is the presence of homotheticity.

Since factor augmentation and cost neutrality are closely related, a similar phenomenon might be expected. Let us recall the early version of factor augmenting technology. The effective input is discribed as $x_i \cong a_i(t)x_i$, then $F(x,t) = F(a_1x_1,\ldots)$. The cost function associated with efficient input vector can be expressed as

$$C(w,Q,t) = C(w_i/a_i(t),Q,t)$$
$$= C(\hat{W},Q)$$

Thus, the cost function expressed in terms of factor-augmenting technology is always represented by effective input prices or input prices divided by efficient units.

II-3. Transcendental Logarithmic(Translog) Functional Form

In the pioneering paper written by Christensen et al.(1973), the translog production functional form is described as functions that are quadratic in the logarithmic of the quantities of inputs and outputs and that provide a local second-order approximation to any production frontier. This function can be applied to the theory of production or of indirect objective functions without employing additivity and homogeneity as part of the maintained hypothesis.

The employment of translog functional form for production analysis is advantageous in finding estimable relationships because the function places relatively few prior restrictions on the technology. Estimability typically implies a choice of form, and once the form is parameterized in accordance with received economic theory, duality guarantees the existance of a unique dual function. By assuming the twice differentiable primal or indirect objective functions, the gradient and the Hessian of the function represent various important economic effects. For example, the gradient of the cost function reveals the derived demand of inputs and the Hessian is the matrix of derived-demand elasticities.

Considering an n-input and 1 output case, Fuss et al.(1978) have shown (n+1)(n+2)/2 relevant economic effects expressed in terms of economies of scale(1), share of inputs(n-1), own price elasticities(n), elasticities of substitution(n(n-1)/2), and cost(or output) level(1)[17]. Thus, a necessary and sufficient condition for a functional form to account for all these effects without imposing restrictions on any of them is to have at least

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17. If time variabe t is included, then n+2 economic effects would be added: the rate of technical change(1), the acceleration of technical change(twice differential with respect to t, 1), and the rates of change of marginal products(n). There would be a total of (n+2)(n+3)/2 effects.

This is consistent with the present study of four inputs with time variable in cost function, since (4+2)(4+3)/2 = 21. The current study has 20 parameters because I ignored the effect of the acceleration of technical change.

Alternatively, Chambers(1988) has calculated in the following manner: n marginal productivity, n diagonal Hessian elements and n(n-1)/2 off-diagonal elements, and 1 term for function value

$(n+1)(n+2)/2$ parameters in the cost function.

A common method of producing flexible forms which contain all the effects is to use second-order Taylor's series expansion to a cost function at a point $\bar{p}$. Let the function C_v be a second-order numerical approximation to an arbitrary function C_v^* at a point $\bar{p}$, then it can be written as

$$Cv^*(\bar{p}) = Cv(\bar{p})$$

$$Cv_i^*(\bar{p}) = Cv_i(\bar{p})$$

$$Cv_{ij}^*(\bar{p}) = Cv_{ij}(\bar{p})$$

where subscripts indicate first and second partial derivatives. The Cv is an approximation to Cv^* at $\bar{p}$ if Cv accurately reproduces the value, gradient, and Hessian matrix of Cv^*.

In econometric analysis, the most popular transformation method of economic variables is the natural logarithm. By assuming the vetor *of* $\bar{p}$ *is the mean vector of each* p_i, that is $\bar{p}=(p_1^o, p_2^o, \ldots\ldots, p_n^o)$, the second order numerical approximation of the natural logarithm of the arbitrary cost function Cv^*

$$(\Omega) \qquad \ln Cv^*(p) \cong \ln Cv(\bar{p}) + \Sigma_i^n \frac{d\ln Cv(\bar{p})}{d\ln p_i} (\ln p_i - \ln p_i^o)$$

$$+ \frac{1}{2} \Sigma_i \Sigma_j \frac{d^2 \ln Cv(\bar{p})}{d\ln p_i \, d\ln p_j} (\ln p_i - \ln p_i^o)(\ln p_j - \ln p_j^o)$$

Letting

$$\ln Cv(\bar{p}) = a_o$$

$$\frac{d\ln Cv(\bar{p})}{d\ln p_i} = a_i$$

$$\frac{d^2 \ln Cv(\bar{p})}{d\ln p_i \, d\ln p_j} = r_{ij}$$

Then the equation (Q) is rewritten as

(R) $$\ln Cv^*(p) \cong a_o + \sum_i^n a_i (\ln p_i - \ln p_i^o) + \sum_i \sum_j r_{ij} (\ln p_i - \ln p_i^o)(\ln p_j - \ln_j^o)$$

The right-hand side of (R) is the translog cost function and is considered as a second-order numerical approximation to an arbitrary Cv^* in the neighberhood of $\bar{p}=(p_1^o, \ldots, p_n^o)$. According to Diewert(1974), the economic interest of this approximation lies in the fact that there exists a linear approximation to an arbitrary well-behaved cost function. Moerover, since it involves at least (n+1)(n+2)/2 independent parameters, it should not impose any restrictive assumptions on the underlying cost(or dual production) structure.

By examining the second derivative of Taylor's expansion with time variable, one can decompose the productivity effects into their relevant components and determine whether technical change comes about through input effects or output effects, viewing the time as a proxy for the level of technical change. In particular, as Friedlaender and Bruce(1985) pointed out the parameters on the non time second-order terms are assumed to be fixed in the common second order translog approximation. This implies, for example, that the effects of state variables which affect the structure of costs and production(e.g. regulatory policy) on the factor shares or upon the use of inputs are invariant over time. Since regulatory policy in the transportation industry is one of the important characteristics which affects the shipping cost, this is obviously a constraining assumption. Furthermore, the use of a second-order approximation constrains changes in the elasticity of substitution to come about through shifts over time in the factor shares of inputs rather than through technically induced shifts in the second-order relations among input prices.

The general approach was suggested by Stevenson(1980), who used a truncated third-order approximation of a cost function that includes output, input prices, and time and adds state variables which affect the structure of cost function. Symbolically, the function can be written as

$$C = C(w, Q, t, S)$$

where w represents a vector of factor prices, t represents time, and S represents a vector of state variables or operating characteristics. By estimating a general third-order cost function under the assumption of Hicks-netral technical change, Stevenson was able to decompose technological growth into three components: output effect, input effects, and state effects.

Although the traslog functions are widely used in a variety of contexts, they do not represent a panacea for applied production analysis. First, they limit the range of technology since fundamental duality results imply that any specification of a cost or a profit function places some restrictions on the technology. Secondly, the generalized quadratic forms, such as the generalized Leontief, and the translog, are very inflexible in representing seperable technology[18]. Imposing separability on the generalized quadratic function involves parametric restrictions that result in more restrictions than originally desired. It is no longer flexible since there are not enough free parameters left to depict the remaining distinct effects. Therefore, it is worthwhile to stress a point: the flexible functional forms are quite unrestrictive, but their ability to approximate arbitrary technologies is limited. The notions of approximation relied upon are local in nature. The nature of globalness and approximation based on Taylor's expansion can not be very exact for a wide range of observations.

For the sake of concreteness of this fact, consider translog cost function which can be represented as

$$(S) \qquad \ln C(w,Q) = a_0 + \sum_i^n a_i \ln w_i + a_Q \ln Q + 1/2 \sum_i^n \sum_j^n a_{ij} \ln w_i \ln w_j + 1/2\, a_{QQ} (\ln Q)^2 + \sum_i^n a_{Qi} \ln w_i \ln Q$$

where $a_{ij} = a_{ji}$. This is interpreted as a second-order Taylor series expansion around $\bar{W} = (1,1,\ldots,1)$, and $\bar{Q} = 1$. To be a well behaved cost function, (S) must be consistent with both linear homogeneity and concavity in w. The theory requires the following parametric restrictions.

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18. Seperability of cost function is defined in terms of the solpe of the price frontier. Prices wi and wj are seperable from w_k in C(w,Q) if

$$\frac{d}{dwk}\ \frac{dC(w,Q)/dwi}{dC(w,Q)/dwj} = 0 \qquad \frac{dXi(w,Q)/dwk}{Xi(w,Q)} = \frac{dXj(w,Q)/dwk}{Xj(w,Q)}$$

Hence, wi and wj are seperable from wk if and only if eik=ejk.

$$\sum_i^n a_i = 1 \text{ and } \sum_i a_{Qi} = \sum_j^n a_{ij} = 0$$

Under the consideration of concavity, the right-hand side of (S) does not admit parametric restrictions that make it globally concave in w. Concavity requires that the second derivative of the function, for demonstration we use function $a_{ii}(\ln wi)^2$, be non-positive. The result of second-order derivative is

$$\frac{2a_{ii}}{w_i^2}(1-\ln w_i)$$

If $a_{ii} \geq 0$, this function could be negative if and only if $\ln w_i \geq 1$. Therefore, no parameteric restriction on a_{ii} ensures that the function is globally concave.

III. Model Specification

III-1. Studies on Translog Function in the Transportation Industry

The translog cost function developed by Christensen, Jorgenson, and Lau[19], and further elaborately organized by Fuss et. al.[20] has been adopted for this study on account of several distinguiished characteristics. First, it does not place a priori restrictions on substitution possibilities among the factors of production and separability between inputs and outputs. Secondly, it allows scale economies to change as output varies. Thirdly, it can be used to derive productivity indices both from the variable and the total cost function. Furthermore, Guilkey et. al.(1983)[21] found that the translog system estimator which contains cost equation and share equations, turned out to be more reliable than other flexible functional forms in almost all comparisons by using the Monte Carlo experiments.

After the pioneering work of Christensen et. al., the translog flexible function has been applied to many transportation studies accompanied with the formal duality relationships between

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19. L.R. Christensen, D.W. Jorgenson and L.J. Lau, "Transcendental Logarithmic Production Frontiers," Rev. Econ. and Statis. vol. 55(Feb. 1973), pp. 28-45.

20. Melvyn Fuss, Daniel McFadden and Yair Mundlak, "A Survey of Funtional Forms in the Economic Analysis of Production," in Production Economics, M. Fuss and D. McFadden eds. (Amsterdam, Holland: Noth-Holland, 1978), pp. 219-68.

21. David K. Guilkey, C.A. Knox Lovell and Robin C. Sickles, "A Comparison of the Performance of Three Flexible Functional Forms." International Economic Review, Vol.24, No. 3 (Oct. 1983), pp. 591-616.

cost functions and production functions. Spady and Friedlaender (1978), and Friedlaender and Spady(1981) have used the translog hedonic production function[22] in the trucking industry with single output and in the railroad industry with multiple outputs. Viton(1981), Berechman(1983), Borger(1984), and Moshe Kim(1985) applied translog cost fuction to estimate parameters, economies of scales, and productivity of the bus industry in various countries. By using the cross-section and time series data, Caves et. al.(1980,1981) analyzed the productivity and scale economies of the U.S. railroad industry. Braeutigam, Daughety and Tornqvist (1984) estimated long-run cost function for a large railroad firm, disaggregating outputs of total carloads moved and average speed as a proxy of quality-of-service by using time series data and concluded that the firms in the industry have strong economies of density[23] and that the omission of a quality variable leads to an underestimation of the extent of economies of density in the system.

Recently the translog cost function has been applied to the shipping industry by Tally et. al.(1986) and Tolofari et. al. (1986,1987). Tally et. al.[24] examined the operating costs

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22. This function can be written as $C=c[g(y,q),w,t]$, where $g(.)$ represents hedonic output that is composed of the firm's physical output y(ton-miles or passenger-miles) and the quality of output q(service time or safety), w refers to a vector of factor prices, and t represents a vector of given technological conditions.

23. It was defined as economies of scale resulting from increased traffic volume when the size of firm is held fixed.

24. Wayne K. Tally, Vinod B. Agarwal and James W. Breakfield, "Economies of Density of Ocean Tanker Ships," Journal of Transport Economics and Policy, Vol. 20 (Jan. 1986), pp. 91-99.

incurred by various ship sizes of a given type of ship and developed size elasticities that measure how responsive short-run variable cost is to change as size(measured in deadweight tons) varies by using manipulated cross-section data. They found that the economies of density generally increse until the size of the tanker reaches 40,000 deadweight tons, and decline thereafter. This is a significant improvement in contrast to the previous literature which focused on elasticities only for a certain type of ship regardless of size differences. However they did not consider factor substitution.

In the paper of Tolofari et. al.,[25] they showed that elasticities of total cost with respect to factor prices, which were equivalent to the mean factor shares, were to 0.47 with respect to capital, 0.32 with respect to labor, 0.14 with respect to repairs and 0.07 with respect to stores for bulk carriers (0.4119, 0.3678, 0.1436 and 0.0767 respectively for tankers[26]). The Allen partial elascities of substitution are generally small and almost zero(in the case of tankers, elasticities between labor and store, and repair and store are higher than those of bulk carriers), implying that the possibilities of substitution

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25. S.R. Tolofari, K.J. Button and D.E. Pitfield, "Shipping Costs and the Contraversy over Open Registry," The Journal of Industrial Economics, Vol.34. No.4 (June 1986), pp. 409-427. "A Translog Cost Model of Bulk Shipping Industry," Transportation Planning and Technology, Vol.11 (1987), pp. 311-321.

26. In the case of Tally et. al., elasticities of short-run variable cost with respect to the labor and the supply price are 1.437 and -0.473 respectively, assuming fuel is fixed input.

are severely limited and the own price elasticities are generally inelastic in both type of ships.

In the shipping industry, there has been excess capacity in the world fleet after 1974 and the world seaborn trade volume did not increase between 1974 and 1985 in tonnage terms and declined by about 20 per cent in ton-mile terms(16,387 and 13,160 billions ton-miles in 1974 and 1985 respectively).[27] For these reasons, output levels can not be chosen to maximize profit by the operator's will. They are determined by the pattern of demand over which operators have no control, implying that the output level as an exogeneous variable is plausible. Furthermore, the Korean government is involved in determining those companies which are to serve specific routes in order to reduce destructive competition among Korean companies, and is also involved in deciding the cargo reservation of each company, which is also likely to affirm the exogeneity of output. In addition, all prices of production factors are exogeneously determined by the market, while variable input levels are endogeneous variables.

As pointed out by Christensen and Greene,[28] estimation of cost function is more attractive since the level of output is considered as an exogeneous variable.

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27. Ernst G. Frankel, The World Shipping Industry (Croom Helm, Australia: Croom Helm Publishers Ltd., 1987), pp. 1-14.

28. Laurits R. Christensen and William H. Greene, "Economies of Scale in U.S Electric Power Generation," Journal of Political Economy, Vol.84 (1976), pp. 655-678.

III-2. Specification of Variable Cost Model

The variable cost in this study can be defined as short-run and mid-run costs, which include aggregate labor(L), supplies(S), and fuel(F) costs.[29] The reason that the costs for repair and maintenance, insurance, and administration were not considered as variable costs in this model is because those costs are regarded as somewhat fixed in terms of the characteristic which is invariant to changes in output and accrued when output is zero, even though it varies slightly. Here I assumed that almost all repair and maintenace takes place at the dock yard during periodic surveys and that companies are long-lived for justification of the fixed administration cost.

The efficient way of disaggregating outputs is to use ton-miles for non-liner cargoes moved and cubic ton-miles for liner cargoes moved, since in all liner trades volume rather than weight determines the constraint to the carring capacity.[30] The additional rationale for the disaggregation is the fact that barely 10% of the total seaborne ton-miles produced by liners earns about 50% of the total freight revenue of in the U.S. shipping industry. Unfortunately, the data for the shipping industry in Korea was not readily available as was other countries' data.

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29. Generally accepted breakdown of costs represented by T.D Heaver(1985) are capital cost, operating costs which are divided into five categories(1. Manning 2. Supplies 3. Repair and Maintenance 4. Insurance 5. Administration), and voyage costs(1. Fuel 2. Port charge 3. Canal fees)

30. J.O. Jansson and D. Shneerson, Liner Shipping Economics New York: Chapman and Hall,1987), pp. 1-5.

However this problem of heterogeneity can be partly overcome by weighing the different tonnages of each commodity by their freight rates. Needless to say, the gross revenue is the sum of multiplying the individual tonnages of each class, commodity and so on by their freight rates as Goss(1982) suggested. However the use of revenue as output raises the problem of inclusion or omission of variables in econometric analysis[31]. For this reason, we have chosen to employ tons-carried as output, since the data for ton-miles, which is the most prevalent output in the transportation studies, does not exist. The aggregate data are provided for the industry by the Bureau of Statistics, Economic Planning Board in Korea.

The shipping industry is assumed to produce a single output(Q), tons-carried, by means of four distinctive inputs: labor(L), supplies(S), fuel(F), and capital(K). In addition, the

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31. Since dual cost function is homogeneous degree one in w, total cost will double if input prices double and so will the average cost of a given output if production function is linearly homogeneous(that is, cost function is homogeneous degree one in output(X)). If price equals average cost, price also will double. In this case, C = R, if R is used as the output measure.

In addition, if cost function is not homogeneous degree one in X, another problem will be created. To concrete this statement, consider the following simple model, where X is output, L is labor input, w is the wage rate, R is revenue, and P is the price of output.

$$X = L^{a}$$

$$C = wL = wX^{1/a}$$

$$C = wR^{1/a}P^{-1/a}$$

If a = 1, P = w and both variables drop out of the cost fuction. If we regress lnC on lnw and lnR, there could be existed an specification error or omitted variable bias.

time variable(t) is included to account for technological shifts in the production function. The transformation can be written as

(1) $G(Q, L, S, F, K, t) = 0$

Since the behavior of each firm in the industry is assumed to minimize variable cost, the objective the industry as a whole is assumed to minimize variable cost. The duality theory states that, if G(.)is strictly convex with respect to inputs, there exists a unique cost funtion which is dual to equation (1). By assuming that the capital stock is fixed in the short and mid-run, the function can be written as

(2) $Cv = Z(Q, P_L, P_S, P_F, K, t)$

where the P_i are prices of inputs. The assumption that capital is fixed input is, in general, plausible. First, the supply of capital tends to be highly inelastic in the short-run. Second, ship deliveries usually lag behind ship orders by 2 to 4 years (recently 1 to 2 years). Third, vessels live longer compared to other transportation modes, so short-run specification is more likely to reflect the true possibility open to the industry(inclusion of capital price on the cost function would lead to a long-run specification). Finally, specifying a fixed factor which is really variable involves no mis-specification.

The translog cost fuction can be interpreted as a second-order Taylor's series expansion to arbitrary, twice differenciable underlying function. Although the function may be treated as a representation of the true cost function, specification of a translog approximation is inevitable. The point of approximation is made at the sample mean of each variable. Then the translog variable cost function may be written as

$$(3)\quad \ln Cv = a_0 + a_Q \ln Q^* + a_K \ln K^* + a_t t^*$$
$$+ 1/2\, a_{QQ} (\ln Q^*)^2 + 1/2\, a_{KK} (\ln K^*)^2$$
$$+ b_L \ln P_L^* + b_S \ln P_S^* + b_F \ln P_F^*$$
$$+ r_{LS} \ln P_L^* \ln P_S^* + r_{LF} \ln P_L^* \ln P_F^*$$
$$+ r_{SF} \ln P_S^* \ln P_F^* + 1/2\, r_{LL} (\ln P_L^*)^2$$
$$+ 1/2\, r_{SS} (\ln P_S^*)^2 + 1/2\, r_{FF} (\ln P_F^*)^2$$
$$+ d_{QL} \ln Q^* \ln P_L^* + d_{QS} \ln Q^* \ln P_S^* + d_{QF} \ln Q^* \ln P_F^*$$
$$+ d_{KL} \ln K^* \ln P_L^* + d_{KS} \ln K^* \ln P_S^* + d_{KF} \ln K^* \ln P_F^*$$
$$+ d_{tL} t^* \ln P_L^* + d_{tS} t^* \ln P_S^* + d_{tF} t^* \ln P_F^*$$
$$+ f_{QK} \ln Q^* \ln K^* + f_{Qt} \ln Q^* t^* + f_{Kt} \ln K^* t^*$$

where $\ln Q^* = \ln Q - \ln \bar{Q}$ for notational economy, and $\ln \bar{Q}$ is a natural logarithm of the sample mean of Q. Economic theory says that the cost funtion must be homogeneous of degree one in prices to have a well defined production function. This implies that the following restrictions must be imposed:

$$(4)\quad b_S = 1 - b_L - b_F$$
$$r_{LS} = - r_{LF} - r_{LL}$$
$$r_{SF} = - r_{LF} - r_{FF}$$
$$r_{SS} = r_{LL} + r_{FF} + 2r_{LF}$$
$$d_{QS} = - d_{QL} - d_{QF}$$
$$d_{KS} = - d_{KL} - d_{KF}$$
$$d_{St} = - d_{Lt} - d_{Kt}$$

By applying these restrictons, the translog variable cost function can be transformed as

(5) $\ln C_v - \ln P_S^* = a_0 + a_Q \ln Q^* + a_K \ln K^* + a_t t^*$

$+ 1/2\ a_{QQ} (\ln Q^*)^2 + 1/2\ a_{KK} (\ln K^*)^2 + b_L (\ln P_L^* - \ln P_S^*)$

$+ b_F (\ln P_F^* - \ln P_S^*) + r_{LF} (\ln P_L^* - \ln P_S^*)(\ln P_F^* - \ln P_S^*)$

$+ 1/2\ r_{LL} (\ln P_L^* - \ln P_S^*)^2 + 1/2\ r_{FF} (\ln P_F^* - \ln P_S^*)^2$

$+ d_{QL} \ln Q^*(\ln P_L^* - \ln P_S^*) + d_{QF} \ln Q^*(\ln P_F^* - \ln P_S^*)$

$+ d_{KL} \ln K^*(\ln P_L^* - \ln P_S^*) + d_{KF} \ln K^*(\ln p_F^* - \ln P_S^*)$

$+ d_{tL} t^*(\ln P_L^* - \ln P_S^*) + d_{tF} t^*(\ln P_F^* - \ln P_S^*)$

$+ f_{QK} \ln Q^* \ln K^* + f_{Qt} \ln Q^* t^* + f_{Kt} \ln K^* t^* + U_c$

Derived factor demand functions are easily obtained by Shephard's Lemma. Differentiate the cost function partially with respect to factor prices

(6) $dC_v/dP_i^* = X_i \quad i = L, F, S$

In translog cost function, the logarithmic form for the derived demand of each input yields cost share equations that are linear function in the unknown parameters

(7) $$S_L = \frac{d\ln C_v}{din P_L^*} = \frac{dC_v}{dP_L^*}\ \frac{P_L^*}{C_v} = X_L\ \frac{P_L^*}{C_v}$$

$$= b_L + r_{LF}(\ln P_F^* - \ln P_S^*) + r_{LL}(\ln P_L^* - \ln P_S^*) + d_{QL} \ln Q^* + d_{KL} \ln K^* + d_{tL} t^* + u_L$$

$$S_F = b_F + r_{LF} (\ln P_L^* - \ln P_S) + r_{FF}(\ln P_F^* - \ln P_S^*) + d_{QF} \ln Q^* + d_{KF} \ln K^* + d_{tF} t^* + u_F$$

$$S_S = (1 - b_L - b_F) + r_{LF}(2\ln P_S^* - \ln P_L^* - \ln P_F^*) - r_{LL}(\ln P_L^* - \ln P_S^*) - r_{FF}(\ln P_F^* - \ln P_S^*) - d_{QL} \ln Q^* - d_{QF} \ln Q^* - d_{KL} \ln K^* - d_{KF} \ln K^* - d_{tF} t^* - d_{tL} t^* + u_S$$

where u_i is an additive disturbances term. By adding the cost share equations in the estimation of the cost function, problems of multicollinearity can be reduced. For the additional information helps to increase accuracy and degrees of freedom are increased without adding new parameters. However the estimation of all factor share equations would introduce linear dependency in the data, resulting that the variance-covariance matrix of error terms would be singular, since the shares must sum to unity. In this paper, therefore, estimations for the variable cost equation, labor share, and fuel share equations are made.[32]

Uzawa(1962) has derived Allen partial elasticity of substitution from the cost function by the formula

(8a) $$\sigma_{ij} = \frac{C\ C_{ij}}{C_i\ C_j}, \text{ where } C_i = \frac{dC}{dP_i}\ ;\ C_{ij} = \frac{d^2C}{dP_i\ dP_j}$$

By slight modification, the variable cost function can be used to derive patterns of factor substitution in the shipping industry.

(8b) $$\sigma_{ij} = \frac{Cv\ Cv_{ij}}{Cv_i\ Cv_j}\ ;\ \sigma_{ij} = \sigma_{ji}$$

In the case of variable translog cost function, this formula can be shown

(9) $$\sigma_{ij} = (r_{ij} + S_iS_j)/S_iS_j\text{[33]}, \quad i = L, F, S \text{ and } i \neq j$$

$$\sigma_{ii} = [r_{ii} + S_i(S_i - 1)]/S_i^2$$

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32. Viton(1981) argued that the estimates obtained are sensitive to which share equation deleted, if share equations are more than two. However Christensen and Greene(1976) have used the iteration of the Zellner estimation procedure to get maximum-likelihood estimates in order to avoid sensitiveness for the equation deleted as suggested by Barten(1969).

33. $$\sigma_{ij} = \frac{Cv\ Cv_{ij}\ (P_i^2/Cv^2)}{Cv_iCv_j(P_i^2/Cv^2)} = \frac{d(d\ln Cv\ Cv)/Cv\ d\ln P_i d\ln P_j}{S_i\ S_j}$$

$$= \frac{(Cv\ d^2\ln Cv + d\ln Cv\ dCv)/\ Cv\ d\ln P_i\ d\ln P_j}{S_i\ S_j} = \frac{r_{ij} + S_iS_j}{S_iS_j}$$

The output-constant factor price elasticities of demand are related to the partial elasticities of substitution

(10) $$E_{ij} = S_j \sigma_{ij} \quad , \quad E_{ii} = S_i \sigma_{ii}$$

with $\sigma_{ij} = \sigma_{ji}$ and $E_{ij} \neq E_{ji}$.

The economies of densities[34] of the shipping sector for each year of a sample period can be expressed as

(11) $$ED = 1 - \frac{d\ln C_v}{d\ln Q}$$

The positive numbers of this measure represent density economies and the negative numbers indicate density diseconomies.

Furthermore, the translog variable cost model allows us to test certain economic properties on the underlying cost function. A cost function has a homothetic production structure if and only if the cost function is separable in output and factor prices. In our case, $d_{QL} = d_{QF} = 0$ represent a homothetic production structure. A homogeneous technology requires further restriction on the elasticity of cost with respect to output to be constant. To satisfy the homogeneous production condition, $a_{QQ} = d_{QL} = f_{QK} = f_{Qt}$ must be zero. The constant elasticities of substitution can also be restricted to the unitary elasticity, which implies $r_{LF} = r_{LL} = r_{FF} = 0$ in our case.

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34. Braeutigam R.R. et. al. (1984) distinguished the concepts between economies of density and economies of size. They defined economies of density as economies of scale resulting from increased traffic volume, holding network configuration (fleet size) is fixed. Therefore economies of density measure short-run economies associated with increased output at the given level of capital stock(fixed input) in our study.

III-3 Measurement of Productivity

As indicated in early papers of Solow(1957) and Jorgenson and Griliches(1967), the productivity growth was more formally defined as a shift in the production function over time that distinguished it from the movement along a production function. It correctly represents efficiency improvement over time when an industry transforms its factors of production into outputs.

Many significant improvements were made in the index number methods by Jorgenson and Griliches(1967), Meyer and Morton(1975), and Caves, Christensen and Swanson(1980).[35] By adopting Diewert's (1976) logarithmic quadratic cost function, Moshe Kim[36] measured

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35. (a) Dual cost function, $C = g(Q_i, W_i, t)$
(b) Total cost function, $C = \sum W_i X_i$
Time derivative of the dual cost function is

(c) $$d\ln C/dt = \sum (d\ln g/d\ln Q_i)(d\ln Q_i/dt) + \sum (d\ln g/d\ln W_i)(d\ln W_i/dt) + d\ln g/dt$$

$$d\ln g/d\ln W_i = S_i$$

Time derivative of total cost function gives

(d) $$d\ln C/dt = \sum (W_i X_i/C)(d\ln W_i/dt + d\ln X_i/dt)$$

Therefore, if we substitute (d) into (c)

$$- d\ln g/dt = \sum (d\ln g/d\ln Q_i)(d\ln Q_i/dt) - \sum S_i \, d\ln X_i/dt,$$

where $d\ln g/d\ln Q_i$ represents cost elasticities of the output. Jorgenson and Griliches(1967) have used cost elasticities as the shares of the outputs in total revenue, assuming that the industry prevails constant returns to scale and outputs prices equal to marginal costs since $dC/dQ_i = MC_i = P_i$. On the other hand, Caves et. al.(1980) have used cost elasticities with respect to outputs, rather than revenue shares, to weigh the output growth rates. Meyer and Morton(1975) used input cost shares as weights to determine an aggregate input index under the assumptions of constant returns to scale, fixed proportions of outputs, and unitary elasticities of substitution.

intertemporal efficiency differential that is the dual problem of total factor productivity with aggregated industry data. In his paper, the implementation was made by using translog cost function to get cost elasticity of output and factor shares in total cost as weights on the Tornqvist approximation[37].

Bruno L. DE Borger(1984)[38] applied the methodology proposed by Caves et. al.(1981), which employed the translog variable cost function rather than the index number procedure, to study firm level technological change in the regional bus transport sector in Belgium.

Present research follows the methodology suggested by Caves et. al.(1981) and applies it to the shipping industry in Korea. In the transformation function at equation (1), each variable can be expressed as logarithmic form

(12) $G(\ln Q, \ln L, \ln S, \ln F, \ln K, t) = 1$

Total differential of (12) yields,

(13) $G_Q d\ln Q + G_L d\ln L + G_S d\ln S + G_F d\ln F + G_K d\ln K + G_t dt = 0$

where the G_i are partial derivatives of G with respect to the

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36. Moshe Kim, "Total factor Productivity in Bus Transport," Journal of Transport Economics and Policy, 19 (May 1985), 173-82.

37. Productivity growth can be calculated without estimation if changes of input prices, outputs, and costs are observed continuously. However, since most economic data comes in discrete observations, the approximation is necessary. The mentioned form is,in general, described as $1/2 \sum (S_{it} + S_{it-1})(\ln W_{it} - \ln W_{it-1})$, where S_{it} and S_{it-1} are certain weights at time t and t-1 respectively and W_i is the price of input i.

38. Bruno L. De Borger, "Cost and Productivity in Regional Bus Transportation: The Belgian Case", The Journal of Industrial Economics, 33, No. 1 (Sep. 1984), pp. 37-54.

logarithmic variable of i.

The productivity growth defined by Caves et. al., can be expressed in two ways. The first one is the rate at which output can rise over time, holding all inputs at a constant level. In terms of equation (13), the rate can be written as

$$(14) \qquad PG_1 = \frac{d\ln Q}{dt} = - \frac{G_t}{G_Q}$$

The second expression of productivity growth will be the common rate at which all inputs can be decreased over time at the level of output held constant. Under the condition that dlnL/dt = dlnS/dt = dlnF/dt, the rate can be shown in terms of equation (13) as

$$(15) \qquad PG_2 = - \frac{d\ln X_i}{dt} = \frac{G_t}{G_L + G_S + G_F + G_K} \qquad i = L, S, F, K$$

If returns to scale(RTS) are defined as a proportional increase in output as a result of a proportional increase in all inputs, holding time fixed in order to distinguish between returns to scale and productivity growth, PG_1 and PG_2 are related to the expression of RTS. That is,

$$RTS = PG_1/PG_2 = - (G_L+G_S+G_F)/G_Q$$

PG_1 is eqivalent to PG_2 if and only if the production process exhibits constant returns to scale in the sample period.

By assuming that each firm in the industry minimizes the cost of variable inputs subject to the certain level of quasi-fixed inputs, it can be said that there exists an industry level variable cost function (2), which provides all the information required to infer the structure of production. Rewriting the equation (2) to logarithmic form

(16) $$\ln Cv = Z(\ln Q, \ln P_L, \ln P_S, \ln P_F, \ln K, t)$$

In equations (12) and (16), the following relations can be derived by using the envelope theorem

(17) $$\frac{d\ln Cv}{d\ln Q} = -\frac{G_Q}{G_L + G_S + G_F}$$

$$\frac{d\ln Cv}{d\ln K} = -\frac{G_K}{G_L + G_S + G_F}$$

$$\frac{d\ln Cv}{dt} = -\frac{G_t}{G_L + G_S + G_F}$$

These equations are combined with equations (14) and (15) to get PG_1 and PG_2, which are calculated from estimated translog variable cost function.

(18) $$PG_1 = -\frac{d\ln Cv/dt}{d\ln Cv/d\ln Q}$$

$$PG_2 = -\frac{d\ln Cv/dt}{1-(d\ln Cv/d\ln K)}$$

The ratios from the variable cost function and from the total cost function coincide when the firm actually minimizes total cost as shown in the paper of Caves et. al.(1981)[39]

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39. Minimization of total cost requires

$$d\ln Cv/d\ln K = -P_K K/Cv$$

$$PG_2 = \frac{-(d\ln Cv/dt)}{1-(d\ln Cv/d\ln K)} = \frac{-(d\ln Cv/dt)}{(Cv+PK)/Cv} = -\frac{d\ln C}{dt}$$

IV. Data and Estimation Procedure

IV-1. Data

The data used for the analysis in this study come from three different sources that describe the shipping industry sector in Korea. The aggregated cost and revenue data were acquired from the "Report on Transportation Survey," published by the Industrial Bank of Korea for year 1964 and Bureau of Statistics of Economic Planning Board for 1976 to 1988. The reports between 1965 and 1975 do not exist(except output and GRT) since the Industrial Bank of Korea had stopped publishing the report after first issue. From 1976, Bureau of Statistics of Economic Planning Board took over the role and republished the report with more precision. Though all the figures entered in the report were calculated in terms of the vessels controlled by the Korean shipping companies, whether time charter-in or voyage charter-in for foreign vessels, rather than the vessels owned by Koreans, the disaggregated cost accounts, except for accounts of miscellaneous and charterage, were used for vessels owned by Korean shiping companies since the expenses born by the charter-in vessel were entered in the accounts of miscellaneous expenses and of charterage.

Second, the output data(1964-1988) of ocean(tons-carried) freight industry were extracted from the Statistical Yearbook of Transportation, published by the Ministry of Transportation.

The third source of this study was acquired from the

Statistical Year Book of Shipping and Port, published by the Korea Maritime and Port Administration. The total gross tonnage(GRT) of registered vessels in Korea except passenger vessels, tug boats, fishing boats and bareboat-chartered vessel was considered as GRT of freight vessels. In the early data before 1976, the GRT involved in coastal and ocean freight was reported separately. Data for the GRT of ocean freight vessel between 1976 and 1988 was calculated by subtracting the GRT involved in costal freight(showed at the Report on Transportation Survey) from the total GRT involved in freight transportation.

To increase data point, the omitted variables of labor, fuel, and supply cost, estimated value of capital, and number of employees were manipulated with certain fashion. For example, specific increasing factor(r) of i variable was calculated as follows:

$$\frac{X_{i64}}{GRT_{64}}(1+r)^{12} = \frac{X_{i76}}{GRT_{76}}$$

After obtaining the increasing factor, the next year variables(Xj) were manipulated:

$$\text{(a)} \qquad X_{i64}(1+ri)^{k*}\frac{GRT_j}{GRT_{64}} = X_j$$

i = labor, supply, capital, and number of employees.
j = 1965, 66,.............,75
k = 1,2,3, ...,12

However, because the supply costs fluctuated between 1976-1980, the average ratio of four increasing fators(between 1964-76, 1964-77, 1964-78, and 1964-79) was used for manipulation.[40]

In the manipulation of fuel cost, the bunker price index was considered in addition to the GRT in order to absorb the oil shock around 1974. For this reason, manipulations are divided into two stages: at first, calculated $R_{73} = (X_{F73}/GRT_{73})$ by[41]

$$(R_{73}-R_{64}) : (R_{76}-R_{64}) = (PI_{73}-PI_{64}) : (PI_{76}-PI_{64}),$$

where R is the ratio of input cost per thousand GRT for a certain year and PIs' are bunker price indicies which were selected from the <u>Journal of Commerce(1964-1969, 1985-1988)</u> and <u>International Marine Bunker Oil Market(1970-1984)</u> published by Drewry and Cockett(Mar.,1986).

At second stage, r_1, r_2, and r_3 calculated by

$$R_{64}(1+r_1)^9 = R_{73},\ R_{73}(1+r_2) = R_{74},\ R_{74}(1+r_3)^2 = R_{76}$$

then take same step (a) to get X_{Fj}.

This method is more plausible compared to the method that assumes a constant rate of growth of each factors in several points. First, since almost all the factor growths are highly correlated with the growth of GRT, including GRT in the factor calculation is reasonable. Secondly, the oil price impact on the industry was considered. Thirdly, the multicollinearity between the inputs and the time factor can be removed in the estimation.

The average yearly price of labor input was calculated by dividing the labor cost(remuneration and benefit) by the total number of employees per each year, that is, expenditure per

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40. Average incresing factor $(1+r) = 1.16598$, it comes from $[(1.2379 + 1.138 + 1.177 + 1.1105)/4]$

41. $r_1 = 0.0418$, $r_2 = 0.779$, and $r_3 = 0.2066$

employee per year. The average yearly supply price was obtained by dividing the yearly supply cost(that consists of the expenditures on stores, supplies and equipment) by the thousand gross tonnage, that is, expenditure per thousand GRT per year.

The price of fuel was calculated by dividing the fuel cost by the thousand tons carried per year, that is, expenditure on thousand tons-carried per year. By doing this, multicollinearity problem can be raised. Fortunately, the results of estimation revealed that those approaches did not make the estimation worse. Probably there are other alternatives, such as fuel cost per GRT, or actual bunker price. The first alternative is unreasonable, since bunker consumption, in general, takes place with demamd rather than supply. In the second alternative, it is not possible to assign a certain bunker price to a paticular industry, since fuel cost was borne by either charterer or owner depending on charter contract. Therefore, the dealing of fuel cost is problematic. For example, when a vessel is operating under time charter contract, the fuel cost, in general, is borne by the charterer. For this reason, translog estimation done by Tolofari et. al.(1986,1987) with cross-sectional data did not consider fuel as a variable or fixed input. And Talley et al.(1986) dealt fuel as a fixed input.

However fuel, one of the dominant intermediate inputs(22-40% of total cost[42], 22-66% variable cost in the model of study) in transportation industry, can not be ignored in the productivity

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42. Frankel p. 172

study of the shipping industry. If all the vessels owned by Koreans were chartered out, the direct impact of fuel price on the productivity could be removed. However liner sevice of Korean vessels, apart from voyage charters made, is continuously increasing from 17.3 % of the registered tonnage in 1984 to 20.7% in 1989, the price impact of fuel must be considered. In addition, fuel consumption is associated with actual transporting activities rather than ready-to-serve activities.

Under this context, the best way to describe fuel price is to allow time chartering-out activities, which are not measurerable, as an implicit function of fuel price. In other words, fuel price will be set at a lower level than actual market price, if many vessels are time chartered-out at a given market bunker price. This equally states that the effect of fuel price decreases as time chartering-out activities go up.

IV-2. Estimation Procedures

The usual econometric specification is that $E(U'U) = \sigma^2 I$, where I is the identity matrix, assuming that the covariance among the disturbance terms corresponding to any three equations in this study is zero. The specification of zero covariance in the error terms among the different year's equations is reasonable. However the specification of zero covariance is not reasonable among the contemporaneous disturbances of different equations, since the cost share equations are derived by differentiation of variable cost function. That is, the errors in the cost equation are correlated with those of the share equations, because those equations contain much of the same data. The relationship can be specified

(22) $E(U_{it}U'_{it+j}) = 0$

$E(U_{it}U'_{it}) = \Sigma$ i= cost equation and share equations
t= Time
j= 1, 2,.........

where Σ is a 3 by 3 covariance matrix. Here I assume that the elements of variance-covariance matrix are the same for each year's observations. Under this assumption the variance-covariance matrix of the errors, V, is a block-diagonal matrix with element Σ. I adopt an estimation procedure which yields coefficient estimators at least asymptotically more efficient than single-equation least square estimators. The procedure is to jointly estimate the variable cost function and the cost share equations as a multivariate regression system that is given by the Zellner method for handling seemingly unrelated equations(SURE). This procedure has the effect of adding many additional degrees of freedom without introducing new parameters. In addition to the effect, the variance of each regression coefficients was decreased noticeably by adopting the procedures. Therefore, the problem of multicollinerity among the equations estimated can be ignored.

In order to make the Zellner method operational, the variance covarimatrix matrix one of factor share equations(share of supply in this study) is deleted from the system, since the disturbances on the factor share equations must sum to zero that leads the variance covariance matrix of the error terms would be singular. It has been proven that the resulting regression coefficient has the same asymptotic properties as maximum likelihood estimates.[43] Once the maximum likelihood estimates has been obtained, the results of the estimation are invariant to which equation is dropped.

The elements of Σ estimated by the residuals of equation (5) and share of labor and fuel in equation (8), applying ordinary least square(OLS) estimation to each equation separately.

$$E(UU') = V = \frac{1}{n}\begin{pmatrix} U_c'U_c & U_c'U_L & U_c'U_F \\ U_c'U_L & U_L'U_L & U_L'U_F \\ U_c'U_F & U_L'U_F & U_F'U_F \end{pmatrix} = \Sigma \otimes I$$

where $\otimes$ denotes the Kronecker product, Σ is a 75 by 75 symmetric and positive definite matrix, and the dimension of I is 25 by 25. After getting the $\Sigma \otimes I$, the best linear unbiased estimator of true parameters is given by two approaches[44]. The first one is to get parameters applying generalized least square(GLS) estimation, then impose restrictions and reestimates the system. The X matrix and b_* matrix have the following structures in this case.

$$X = \begin{pmatrix} X1 & 0 & 0 \\ 0 & X2 & 0 \\ 0 & 0 & X3 \end{pmatrix} \qquad b_* = \begin{pmatrix} b_1 \\ b_2 \\ b_3 \end{pmatrix}$$

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43. Jan Kementa and R.F. Gilbert, "Small Sample Properties of Alternative Estimators of Seemingly Unrelated Regressions," Journal of the American Statistical Association, 63 (1968), pp. 1180-1200. In this paper, they stated that the asymptotic properties of maximum likelihood estimator are the same as those of Zellner's two stage Aitken Estimator(ZEF), Telser's iterative estimator(TIE), and Zellner's iterative Aitken estimator(IZEF).

44. The first approach has 17 degrees of freedom and the second approach has 55 degrees of freedom for the estimation of variable cost function.

where X1 and X2 are 25 by 6, and X3 is a 25 by 20 matrx.

$$b_* = [X'(\Sigma^{-1} \otimes I)X]^{-1} \; [X'(\Sigma^{-1} \otimes I)y]$$

By imposing restriction $Rb_* = r$, where R is 12 by 32 matrix and r is 12 by 1 column dummies, the reestimated SURE b_{**}

$$b_{**} = b_* + [X'(\Sigma^{-1} \otimes I)X]^{-1} \; R'\{R[X'(\Sigma^{-1} \otimes I)X]R'\}^{-1}(r-Rb_*)$$

An alternative approach is to arrange the columns of the data matrix obeying the constraints, then estimate the system by a direct application of GLS. In this case the X matrix can be written as:

$$X = \begin{bmatrix} 1 & x1 & x2 & x3 & x4 & x5 & x6 & x7 & x8 & x9 & x0 & z1 & z2 & z3 & z4 & z5 & z6 & z7 & z8 & z9 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & x_L8 & x_L0 & 0 & z_L2 & 0 & z_L4 & 0 & z_L6 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & x_F8 & 0 & x_F0 & 0 & z_F2 & 0 & z_F4 & 0 & z_F6 & 0 & 0 & 0 \end{bmatrix}$$

$$Y = \begin{bmatrix} \ln Cv - \text{in}Ps^* \\ S_L \\ S_F \end{bmatrix}$$

All the variables(x1 x2 ... 0,1) are 25 by 1 column vector and X is 75 by 20 matrix, and Y is 75 by 1 column matrix. The value of estimated parameters is almost the same in both approaches except that the first approach reveals a higher t-value(most of them are significant at the 95% level or more) than those of the second approach.

To test the hypotheses such as homotheticity($d_{QL}=d_{QF}=0$), and homogeneity($d_{QL}=d_{QF}=f_{QK}=f_{Qt}=0$ and $a_{QQ}=0$), and homogeneity with unitary elasticity of substitution($r_{LF}=r_{LL}=r_{FF}=0$), the likelihood ratio test was used, since the maximum likelihood estimates were obtained by the previouly mentioned procedures. The disturbance covariance matrix of the restricted model was obtained by just dropping the relevant variables from the model. Representing the determinants of the unconstrained and constrained estimates of the disturbance covariance matrix as Σ_r and Σ_u, respectively, the likelihood ratio can be written as

$$\lambda = (\Sigma_r / \Sigma_u)^{-N/2}$$

where N is the number of years in the data. The null hypotheses can be tested by using $-2\ln \lambda$, which has an asymptotic distribution of chi-square with degrees of freedom equal to the number of restrictions being imposed.

V. Empirical Results

Each variable in the translog variable cost function (5) and (7) are written as the natural logarithm of the variable minus the natural logarithm of the sample mean of the variable. On the basis of the time series data for twenty five years(1964-1988), estimates of parameters of equation (5) were obtained by means of multivariate regression system. The results are represented in Table 1. Denote output obtained from procedure 1 and 2 by estimate 1 and estimate 2 respectively. The reason that the different t-value between estimate 1 and estimate 2 comes out can be conjectured from the fact that the estimates which did not use many dummies in estimation have high t-values. For this reason, it is possible to conclude that large number of dummy variables used to estimate the parameters reduce the reliability of the estimates in set 2.

The results in Table 1 represent that 15 coefficients out of 20 are significant at the 0.005 level and f_{Qt} is significant at the 0.025 level. Among the three insignificant estimates, two involve capital(K). Of the remaining coefficients, a_{KK} is significant at the 0.10 level. The facts that the adjusted R^2s of the three estimated equations and that the 17 estimated coefficients out of 20 are significant give a confidence to the accuracy of the productivity growth obtained from the estimated translog variable cost function.[45]

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45. The first order serial correlation coefficent of the residuals of equations are $o_{CL}=0.18$, $o_{LF}=0.29$, $o_{CF}=0.03$, $o_{CC}=$

The estimates of parameters of different models--model 1 estimates the variable cost function without imposing restrictions, model 2 with homotheticity restriction, model 3 with homogeneity, and model 4 with homogeneity and unitary elasticity of substitution(Cobb-Doglas)--are presented in Table 2. According to the t-ratios for nonhomotheticity parameters(d_{QL} and d_{QF}), nonhomogeneity parameters(d_{QL}, d_{QF}, f_{Qt},and a_{QQ}), and non-Cobb Douglas parameters(r_{LF}, r_{LL}, and r_{FF}) are significant, suggesting that neither homotheticity and homogeneity nor homogeneity with constant elasticity of substitution is consistent with the shipping industry cost function. This proposition is confirmed through the likelihood ratio test. The test results presented in Table III. From the above results, we can infer several interesting behaviors of the industry. First of all, the variable cost elasticity with respect to output varies with not only changes in output, but also variations in factor prices without a general relationship between cost and output, since cost function is not a separable function between factor prices and output.[46] Secondly, The use of Cobb-Douglas cost function to describe cost

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-0.46, σ_{LL}=0.20, and σ_{FF}=0.42. Under the considerations of Ljung-Box Q-statistics and the first order autocorrelation coefficient, the first order serial correaltion did not seem to be a major problem.

46. The cost function $Cv(p_i, Q)$ is a homothetic function if the function can be written as the product of function of output and function of factor prices, that is, $Cv(p_i, Q) = J(Q)*A(p_i)$. $Cv(p_i,Q)$ is said to be multiplicately separable in Q and the factor prices.

TABLE 1

Estimated Parameters of the Variable Cost Function

parameters	Estmates 1	t-value	Estimate 2	t-value
a_O	11.8677	401.4566	11.8666	120.7159
a_Q	1.0709	5.1491	1.0754	1.5585
a_K	0.0003	0.0022**	0.0005	0.0012
a_t	-0.9803	-28.5163	-0.9815	-8.6132
a_{QQ}	0.4385	4.8856	0.4480	1.5119
a_{KK}	-0.1295	-1.6974*	-0.1259	-0.4984
b_L	0.3258	6.4257	0.3236	1.9044
b_F	0.3738	12.1188	0.3716	3.6117
r_{LF}	-0.0812	-8.7080	-0.0841	-2.6990
r_{LL}	0.0881	4.7326	0.0901	1.4530
r_{FF}	0.1953	25.7587	0.1990	7.8618
d_{QL}	-0.1258	-5.5175	-0.1265	-1.6597
d_{QF}	0.2385	13.2105	0.2398	3.9915
d_{KL}	0.0553	3.3007	0.0548	0.9765
d_{KF}	-0.1578	-12.6543	-0.1590	-3.8273
d_{tL}	-0.0064	-0.1257**	-0.0044	-0.0262
d_{tF}	0.0911	2.9600	0.0935	0.9104
f_{QK}	-0.0664	-0.8368**	-0.0708	-0.2696
f_{Qt}	-0.4881	-2.2039	-0.4956	-0.6748
f_{Kt}	0.4280	3.1848	0.4304	0.9676

R^2	DW	Q-Statistics(12)
cost eq. = 0.999	cost eq. = 3.102	cost eq. = 21.117
Labor share = 0.858	Labor share = 1.394	Labor share = 28.181
Fuel share = 0.976	Fuel share = 1.003	Fuel share = 50.21

*:significant at 10% level **:insignificant

Table II

Parameter Estimates with various restrictions.
(t-Ratios in Parentheses)

Parameter	Model 1 Translog	Model 2 Homotheticity	Model 3 Homogeneity	Model 4 Cobb-Douglas
a_O	11.86766	11.7607	11.7866	11.6789
	(401.467)	(330.542)	(293.557)	(186.484)
a_Q	1.0709	0.2931	0.5682	0.6403
	(5.1491)	(1.3976)	(41.2044)	(29.0334)
a_K	-0.0003	0.4499	0.2272	0.3125
	(-0.0022)	(3.4974)	(7.9715)	(9.7535)
a_t	-0.9803	-0.8399	-0.8681	-0.6938
	(-28.516)	(3.5644)	(-18.703)	(-9.540)
a_{QQ}	0.4385	0.3627		
	(4.8856)	(3.5644)		
a_{KK}	-0.1295	0.1671	-0.0858	
	(-1.6974)	(2.0471)	(-6.763)	
b_L	0.3258	0.3267	0.5053	0.2396
	(6.4257)	(5.5683)	(8.5430)	(3.6843)
b_F	0.3738	0.4364	0.3170	0.2497
	(12.119)	(10.1386)	(6.6228)	(3.5204)
r_{LF}	-0.0812	-0.0433	-0.0618	
	(-8.8079)	(-3.5236)	(-4.8163)	
r_{LL}	0.0881	0.0676	0.1061	
	(4.7326)	(3.3038)	(5.0560)	
r_{FF}	0.1953	0.1561	0.1615	
	(25.7587)	(12.266)	(11.740)	
d_{QL}	-0.1258			
	(-5.5175)			
d_{QF}	0.2385			
	(13.2105)			
d_{KL}	0.0553	0.0004	0.0311	-0.0067
	(3.3007)	(0.0275)	(2.4557)	(-0.3456)
d_{KF}	-0.1578	-0.0294	-0.044	-0.07315
	(-12.654)	(-2.5156)	(-3.3825)	(-3.2443)
d_{tL}	-0.0064	-0.0328	-0.2028	0.0569
	(-0.1257)	(-0.5602)	(-3.4454)	(0.0053)
d_{tF}	0.0911	0.0610	0.1675	0.2551
	(2.9600)	(1.4112)	(3.5083)	(3.6013)
f_{QK}	-0.0664	-0.2964		
	(-0.8368)	(-3.4648)		
f_{Qt}	-0.4881	0.3692		
	(-2.2039)	(1.6339)		
f_{Kt}	0.4280	-0.1078	0.1837	-0.0044
	(3.1848)	(-0.7678)	(6.6076)	(-0.134)
Log det $\hat{\Sigma}$	1.245	2.887	3.612	7.793

TABLE III

Likelihood Ratio Test

Hypotheses	Number of Restrictions	$-2\ln\lambda$	Chi-Sq. 1% level
Homotheticity	2	41.05	9.21
Homogeneity	5	59.175	15.086
Cobb-Douglas	8	163.70	20.09

structure of the industry is ruled out, as well as homotheticity. This finding is consistent with the results of the paper written by Tolofari et al.(1986, 1987). Furthermore, it reveals that the variable cost function is sensitive to factor substitution possibilities and factor shares.

In general, positive signs of the first order linear coefficients with respect to the factor prices are required to satisfy the regularity conditions for a well-behaved cost function. This condition was satisfied by the estimates. Moreover, the importance of estimating the gradients and the Hessian of the true underlying cost function lies in facilitating the estimation of the annual evaluation of the Allen-Uzawa partial elasticities of substitution and the price elasticities of factor demand, and the degree of ecomomies of density that describes how variable cost increases as output goes up. For example, if variable cost increases less proportionately than increases in output at a given level of capital stock, the density has positive values. The higher the value of density, the more possible it is to increase output without incurring additional costs. In this sense, economies of density are analogous to short-run economies of scale.[47]

Table IV summarizes various ecomomic phenomena of the industry. The substitution possibilities are, in general, higher than that of the cost model of Tolofari et al.(1986,1987), which developed under the consideration of four inputs(labor(M), repair and maintenace(R), supplies(S), and capital(K)) with cross-sectional data of various vessels. Even though the models and data set are quite different, it is possible to suggest why the substitution possibilities are quite different. The significant substitution possibilities may exist among the firms in a certain industry compared to those of the plant(each ship) level. The theory of cost and production requires that the own-partial price elasticites of the variable factors be negative and the Hessian matrix(d^2Cv/dP_idP_j) be negative semidefinite. It should be noted that the strict rules for the global negative semi-definiteness of the Hessian matrix are satisfied. However, the own price elasticities of inputs are violated because of the positive values of E_{FF}(1972-1973, and 1977), and of E_{SS} (1980, and 1983-1987) during certain periods. The positive values are slightly perverse but it is not too high(on average it is negative E_{SS} = -0.082) and there is no guarantee with the

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47. The degree of returns to scale(RTS) has been defined in this study as the proportional growth in output due to a proportional increase in all inputs, holding time fixed. From equation (13), $RTS(T) = -(G_L+G_S+G_F+G_K)/G_Q$. This notation is eqivalent to $RTS = \{1-(d\ln Cv/d\ln K)\}/(d\ln Cv/d\ln Q) = \{1+[(G_K)/(G_L+G_S+G_F)]\}/[(G_Q)/(G_L+G_S+G_F)] = (1-d\ln Cv/d\ln K)/(1-ED)$. The higher the ED is, the larger RTS is.

Table IV

Year	σ_{LS}	σ_{LF}	σ_{SF}	E_{LL}	E_{SS}	E_{FF}	ED
1964	0.8971	0.3754	0.0470	-0.4035	-0.2635	-0.1123	0.8484
1965	0.9081	0.3756	0.0320	-0.4061	-0.2744	-0.1158	0.8109
1966	0.9173	0.3709	0.0102	-0.4064	-0.2830	-0.1154	0.7539
1967	0.9250	0.3617	-0.0194	-0.4046	-0.2896	-0.1108	0.6369
1968	0.9315	0.3478	-0.0573	-0.4013	-0.2947	-0.1010	0.5970
1969	0.9370	0.3290	-0.1041	-0.3966	-0.2983	-0.0855	0.5353
1970	0.9416	0.3075	-0.1629	-0.3907	-0.3006	-0.0640	0.5808
1971	0.9457	0.2758	-0.2277	-0.3845	-0.3027	-0.0340	0.6196
1972	0.9492	0.2407	-0.3066	-0.3774	-0.3038	0.0038	0.6395
1973	0.9521	0.1993	-0.3986	-0.3700	-0.3044	0.0510	0.7159
1974	0.9394	0.3360	-0.1772	-0.3895	-0.2965	-0.0737	0.6393
1975	0.9383	0.3462	-0.1766	-0.3897	-0.2946	-0.0784	0.5966
1976	0.9479	-0.0942	0.0259	-0.4062	-0.2797	0.0154	0.5566
1977	0.9156	0.4927	-0.4436	-0.3778	-0.1947	-0.1108	0.3539
1978	0.9405	0.2283	-0.0063	-0.4039	-0.3046	-0.0722	0.3485
1979	0.8705	0.5248	-0.4444	-0.4016	-0.0686	-0.1078	0.1345
1980	0.7583	0.5039	-0.6581	-0.4010	0.2195	-0.0589	0.0354
1981	0.8310	0.3866	-0.0536	-0.3814	-0.1525	-0.0761	0.0728
1982	0.8499	0.3824	-0.0079	-0.3870	-0.1907	-0.0863	0.0675
1983	0.7253	0.5139	-0.8459	-0.4010	0.3579	-0.0521	-0.0089
1984	0.6964	0.5436	-1.1973	-0.4052	0.5752	-0.0539	0.0245
1985	0.6344	0.5422	-1.4742	-0.4034	0.8070	-0.0426	0.0542
1986	0.7653	0.5513	-0.9563	-0.4065	0.3468	-0.0731	0.1669
1987	0.7979	0.5617	-0.9180	-0.4042	0.2664	-0.0866	0.2465
1988	0.8942	0.5287	-0.5236	-0.3862	-0.1100	-0.1160	0.4007

Priod	Average		
	σ_{LS}	σ_{LF}	σ_{SF}
1964-1978	0.9324	0.2995	-0.1310
1979-1985	0.7665	0.4853	-0.6688
1986-1988	0.8191	0.5472	-0.7993
1964-1988	0.8714	0.3815	-0.3788

	E_{LL}	E_{SS}	E_{FF}	ED
1964-1978	-0.3939	-0.2857	-0.0669	0.6155
1979-1985	-0.3972	0.2211	-0.0682	0.0543
1986-1988	-0.3990	0.1677	-0.0919	0.2714
1964-1988	-0.3951	-0.0821	-0.0685	0.3991

σ_{ij} = Partial Elasticity of Substitution
E_{ii} = Own Price Elasticitiy of Input i
ED = Economies of Density

translog function that negative elasticities will automatically emerge as Frienlaender and Spady(1981) have pointed out.

As we expected, elasticity of substitution between labor and supply is generally high(average σ_{LS}=0.871) in contrast to the elasticity of substitution between labor and fuel(average σ_{LF} = 0.382). The result is plausible, since labor price, in general, is lower compared to the price of other inputs in developing countries. That means developing countries have a greater flexibility in shipping operation than those operating in developed maritime nations. This finding is supported by the results of Tolofari et al.(They found the elasticity of sub-stitutuion between labor and supply when vessels are registered in developed maritime nation is 0.0337 and are open registered in less developed countries is 0.1318 by using variable cost model). One interesting result is a complemantarity between fuel and supply (average σ_{SF} = -0.379). One way to justify the result is the fact that the supplies are generally required for the purposes of prevention and security, so that the amounts to be stored could be reduced as the price of fuel goes up. The elasticities of substitution which appeared in table III are substantially below unity in all data years, confiming the inappropriateness of Cobb-Douglas specification.

The demand elasticities of all inputs are very inelastic, especially supplies, and fuel. The higher price elasticity of labor demand with respect to those of fuel and supply reflects the greater flexibility in negotiating wage contracts. On the other hand, the prices of fuel and supply are extremely difficult to negotiate, since those inputs are purchased all around the world and have lesser substitution possibilities.

The economies of ship size have been studied by Heaver(1968) for tankers, by Jansson and Shneerson(1982) for dry bulk carriers and by Tally et al.(1986) for various sizes of tankers. These works provide evidence of the relationship between cost and ship size. The translog cost model measures appropriate scale effects through the economies of density(ED) for each year. All the years in data set exhibit economies of density(ED>0) except 1983. The result shows a consistent trend of economies of density. Even though there exists slight fluctuations between 1964 and 1983, economies of density initially decrease until 1982, then exhibit diseconomies of density in 1983, and continuously recover thereafter. The relatively low economies of density between 1979 and 1987 reveal that the economies of density were exhausted by the higher price of fuel that resulted in a higher share of fuel cost on the variable cost(50-66%). However, the shipping industry enjoyed higher economies of density before 1979, accompanied by government policies to expand the domestic merchant fleet and shipbuliding sectors.[48] With the efforts of

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48. Direct subsidies were made to the companies which has contributed considerably to the earning of foreign exchange. Also credit assistance schemes are available for vessels' operating cost up to 80% as export credits, and for shipbuilding costs up to 90-92%. In addition, a cargo preference system was established, that reserves an entire market or market segment for a particular carrier or set of carriers, thus offering the greatest degree of security to the preferred carriers on a trade route. Tax examption or reduction was applied on imported materials for shipbuilding, conversion, etc. which can not be

government to expand the shipping sector, the industry seemed to be able to increase output without incurring important additional costs, during the period 1964-1979. The expansion plan was revised in the early 80's, since Korea generally has suffered from the global recession, as well as the shipping industry. This resulted in low economies of density during the period 1980-1987.

To evaluate the effects of the price of fuel on the economic structures of the shipping industry, the data period was divided into three sub-periods, based on fuel price. The first period is set between 1964-1978, because the bunker prices are generally low in this period, though the first oil price shock was struck. The second is the high bunker price period between 1979-1985, that covers the period from the second oil shock to the time of retrogressive fuel prices. The third is the period in which fuel prices retured to their pre-1979 levels. Some interesting features were found. The substitutability of labor and supply decreases and the substituability between labor and fuel increases as fuel price goes up. On the other hand, the complementarity of fuel and supply is generally higher when fuel price is high. The stable price elasticities of inputs with respect to the change of fuel price show the rigidity of the demanding schedule for the inputs in the shipping industry. As mentioned before, the economies of density are highly sensitive to fuel price changes.

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produced domestically.

VI. Productivity Indices of the Shipping Industry

The productivity growth for the foreign freight shipping industry in Korea is presented according to both equations (14) and (15) for the purpose of comparison. The productivity growth rates for each year are presented in Table V.

As described earlier, the productivity growth rates calculated by equation (14) and (15) are the same only if the industry had exhibited constant returns to scale over the whole sample period. It is evident from our analysis that this was not the case in our study.

It is interesting to note the result that the series of PG1 and PG2 have quite a consistent pattern of productivity growth, even though large differences in absolute values in the early period(1964-1966) are revealed. The values of PG1 are shown to be larger than the value of PG2 before 1977, and higher values of PG2 are recorded thereafter.

For concretness of analysis, the average growth rates are caculated, based on specific events. The first comparison is made among the low fuel price period(1964-1978), the high price period(1979-1985), and the moderate price period(1986-1988). Even though the low fuel price period can be divided into two parts between 1964-1973 and 1974-1978(from the first oil shock to before the second oil shock), we chose the entire period for accuracy, since most of the data during the period(1964-1975) is manipulated.

Table V

Year	Index PG1	Index PG2
1964	10.52	3.12
1965	8.11	2.97
1966	5.71	2.54
1967	3.48	2.05
1968	2.87	1.81
1969	2.59	1.98
1970	3.07	2.43
1971	3.46	2.78
1972	3.46	2.72
1973	4.39	3.12
1974	2.18	1.32
1975	2.14	1.56
1976	1.95	1.66
1977	1.27	1.33
1978	1.55	1.99
1979	1.04	1.41
1980	0.78	1.03
1981	0.67	0.88
1982	0.83	1.23
1983	0.71	1.06
1984	0.67	0.97
1985	0.65	0.94
1986	0.77	1.13
1987	0.79	1.14
1988	1.08	1.61

The result is shown in Table V-I.

Table V-I

Period	PG1	PG2
1964-1978	3.78	2.23
1979-1985	0.76	1.07
1986-1988	0.88	1.29

According to Table V-1, modest productivity growth was obtained before the high price period and low growth rates were maintained during the high and moderate fuel price period in the series of PG1 and PG2. Moreover, the growth rates are seen to recover as the price of fuel declines.

Secondly, the data period was divided into four sub-periods, based on the government plans. The first period is 1964-1976. During the period, the third term of a five-year economic develpoment plan had been successfully completed, preparing for a take-off stage in all industries. Since the rationalization plan of the shipping industry had been started in 1984(actually ac complished in 1985), the remaining period after 1976 was just divided every four years. This was presented in Table V-II. This table contains the average growth rates for the complete period 1964-1988.

The both series PG1 and PG2 show the first period has a higher productivity growth rate than any other periods. From this fact, it could be argued that the higher productivity growth rates during the early period(1964-76) were highly dependent on the rapid improvement of the quality of labor skills and ship manegement skills due to the operation of large fleets. The shipping industry, as a whole, has spent little on research and development of technology with the exception of improved management skills and quality of labors.

During the second and the third periods, the improvement of the quality of labor and management skills was not an important source of productivity change, since the standardization of these skills had been achieved during the early period. Moreover, the sudden increases of fuel price might give a negative impact on the productivity growth.

After the reformation of the shipping industry(1984), the growth rates have recovered, though it is low, in the both series PG1 and PG2.

Table V-II

Period	PG1	PG2
1964-1976	4.15	2.31
1977-1980	1.16	1.44
1981-1984	0.72	1.03
1985-1988	0.82	1.20
1964-1988	2.26	1.74

However, it is hard to say that the increased growth rate has resulted from the reformation of the industry, since the fuel price has gone down during this period. As suggested in the early section, it is possible to decompose the effects of policies by adding state variable in the cost function, then utilizing a truncated third-order translog approximation, suggested by Stevenson(1980). However, this is not the case of our study.

The policy of government subsidy to the industry can be discussed based on our findings. The productivity growth rates of the industry are relatively low compared to the economic growth rates of the Korean economy in general. However, the shipping industry must be successfully managed in order to survive the fierce world-wide trade competition and to achieve national goals. Therefore, government support of the industry is necessary to a certain degree and investment in the industry must be made continuously so that the industry can compete in the world shipping markets.

As a consequence, we can derive some conclusions: first, major productivity increases of the sample period occured during the period 1964-1976. Second, no substantial productivity growth was exploited during the late seventies and eighties. Third, the two alternatives of the estimated productivity growth (PG1 and PG2) give us different values, but show approximately the same path of evolution over time. Fourth, in a matter with implications for policy, the government-lead reformation plan of the shipping industry did not have important effects on the productivity growth when decreasing fuel prices are considered. Fifth, the productivity growth of the industry is highly sensitive to the price of fuel, as is the case with almost all the transpotation industry.

Productivity growth indicates how efficiently the industry was operated. Furthermore, productivity growth is a major issue in wage negotiations and in the policy making process. Therefore, providing a reliable growth index is vital for successful guidance, since biased estimates of productivity growth invoke a serious negative impact on the system. One of the main contributions of this study is to provide a reliable growth index of the shipping industry in Korea on the basis of readily available statistical data, which has not been organized previously for empirical estimations.

VII. Conclusions

In this paper, two objectives are proposed: first the economic phenomena, such as elasticities of substitution of factors, own price elasticities of factor demand, and economies of densities that prevail in the shipping industry in Korea were estimated through the translog variable cost model. The second objective is to calculate two different indicators of productivity growth over the period 1964-1988 by using the estimated coefficients.

The translog variable cost function, which is one of the most widely used flexible functional forms in cost and production studies, was adopted for this study under the following considerations: first it does not place a priori restriction on substitution possibilities. It allows scale economies to change. It is convenient to estimate and easy to derive certain economic phenomena.

There are some possiblities that might lead to biased parameters. One of the posible sources of bias results from the assumption that the industry objective is to minimize the variable cost function. If this objective is not an appropriate goal of firms which are working in the industry, bias might be introduced in accordance with inefficient input mixture that resulted in the choice of inputs away from its minimized industry level cost curvature.

To increase data point, we constructed the missing variables with considerable care, but some errors, needless to say, might exist. Since the movements of the labor costs and the fuel costs exhibit certain patterns, the formulation of missing variables was quite credible. However, the movement of the supply costs does not exhibit a reliable pattern(frequently moving up and down), it could be a possible source of biased estimation.

Moreover, the use of tons-carried rather than ton-miles as a level of output is arguable, even though higher correlation exists between tons-carried and ton-miles in the shipping industry in Korea. The disparity between tons-carried and ton-miles in terms of distance-carried may result in incorrect parameter estimation.

The main findings of this study are: the higher elasticity of substitution between labor and supply was discovered to be average and the own price elasticities of labor was relatively bigger compared to those of supply and fuel, implying that the price of labor is highly negotiable. Economies of densities of the shipping industry are, in general, high but decreased over the period 1964-1983, and recovered thereafter. Our results further indicate that the elasticities of substitution are significantly below unity, ruling out the use of simpler first-order fuctional forms such as Cobb-Douglas to describe cost structure of the shipping industry.

The productivity growth rates, calculated based on the estimates of the variable cost model, reveal that the patterns of PG1 and PG2 are almost the same, even though large differences in absolute values are revealed in the early period. The average growth rates of the industry are generally low compared to the growth rates of the Korean economy in general. Substantial productivity growth was achieved during the early period(1964-1976) and no substantial productivity growth was obtained during the late seventies and eighties.

Finally we discussed certain impacts of government policies, such as the reformation plan, on productivity growth. The results showed that the government plan did not have noticeable effects on the industry in terms of productivity.

VIII. Appendix

VIII-1

Let us consider CES production function.

$$Q = [bK^{-g} + (1-b)\tilde{L}^{-g}]^{-1/g}, \text{ where } \tilde{L} = a(t)L$$

For the notational economy, define $[bK^{-g} + (1-b)\tilde{L}^{-g}]^{-1/g} = M$.

First order conditions are

$$MP_{\tilde{L}} = dQ/d\tilde{L} = (-1/g)M^{-1-1/g}(1-b)(-g)\tilde{L}^{-g-1}$$

$$= (1-b)M^{-(1+1/g)}\tilde{L}^{-(g+1)}$$

Same manner,

$$MP_K = dQ/dK = bM^{-(1+1/g)}K^{-(g+1)}$$

Since

$$\text{(a)} \qquad \frac{dK}{d\tilde{L}} = -\frac{MP_{\tilde{L}}}{MP_K} = -\frac{1-b}{b}\left(\frac{\tilde{L}}{K}\right)^{-(1+g)} = \frac{w}{r}$$

Because $\tilde{L} = a(t)L$, $\tilde{w} = w/a(t)$, and $\sigma = 1/(1+g)$, the equation (a) can be written as:

$$\frac{\tilde{L}}{K} = \left(-\frac{b}{1-b}\right)^{-\sigma} \left(\frac{w/a}{r}\right)^{-\sigma}$$

$$\ln\left(\frac{L}{K}\right) + \ln a(t) = -\sigma \ln\left(\frac{b}{b-1}\right) + \sigma \ln\left(\frac{r}{w}\right) + \sigma \ln a$$

Therefore,

$$\frac{d\ln(L/K)}{d\ln a(t)} = \sigma - 1$$

$$\frac{d\ln(L/K)}{d\ln a(t)} \gtreqless 0 \quad \text{as} \quad \sigma \gtreqless 1$$

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