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Noboru Hamaguchi

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The task of filling the "empty boxes of economic theory" with relevant empirical content becomes everyday more urgent and challenging. (p. 15.)

--W.W. Leontief, "Input-Output Economics," _Scientific American_ Vol. 185, No. 4, October, 1951, pp. 15-21.

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TABLE OF CONTENT

CHAPTER I

INTRODUCTION

The main purpose of this study is to analyze the change in total factor productivity (TFP) in the Japanese and American economies during the period 1963-70. TFP is an index representing the productivity of <u>all</u> the inputs (capital, labor, and intermediate inputs) in a production process. <u>Partial</u> productivity, on the other hand, measures the productivity of a single input, such as labor. The growth rate of TFP is defined as the difference between the growth rate of real output and the weighted average of the growth rates of real inputs. In other words, a TFP change shows how inputs are saved in a production process.

While previous TFP studies have considered only direct inputs, my study incorporates indirect inputs as well. To produce its output an industry needs as <u>direct</u> inputs labor, capital, and intermediate inputs. The intermediate inputs, however, are produced by other industries, which also need for their production labor, capital, and intermediate inputs. In other words, through the purchase of intermediate inputs the industry concerned uses <u>indirectly</u> capital and labor inputs which other industries use directly when they produce these intermediate products. It is important to consider the indirect inputs when measuring TFP. If TFP of an industry increases and its output becomes cheaper, then other industries which use this output as an intermediate input can reduce their production costs. Thus, production costs of different industries are related to each other through interindustry flows of intermediate inputs. For TFP to reflect such relations, it should incorporate indirect inputs.

Moreover, since intermediate inputs are traded internationally, production costs of an industry depend partially on production efficiency in the industries of trading partners. For example, the high efficiency of Japanese steel production may contribute to cost reduction in the U.S. auto industry.

This study is proposing a new concept, direct and indirect TFP, which has different implications from ordinary, direct TFP used in previous studies. Direct TFP measures how the production function or cost function shifts, while direct and indirect TFP measures how the production costs of a certain industry are affected directly by the change in the direct TFP of the own industry and indirectly by the change in direct TFP of other industries which supply intermediate inputs to the industry concerned.

This study attempts to combine in a consistent analytical framework interindustry and international dependence of TFP, which have not been adequately investigated in previous studies. I will use as my data base international input-output (I-O) tables which connect I-O tables of Japan and the U.S. by trade flow matrices for 1963 and 1970.

Japan and the U.S. are particularly appropriate for such a study since trade between them affects the economies of not only those two countries but of other nations as well. The U.S. has been the most important trade partner of Japan since 1850, when Japan resumed foreign relations and trade after two centuries of national isolation.[1] Except for Canada, Japan has been the most important trading partner of the U.S.

During the period of this study, 1963-70, the Japanese economy grew at an extremely rapid rate, which substantially exceeded the U.S. growth rate. Since TFP study is an examination of sources of economic growth, this period is also appropriate for an empirical study. More precisely, the study focuses on the role of TFP in economic growth and expansion of production in various industries. The focus is warranted because, since the seminal paper by Solow [1957], the importance of TFP changes in economic growth has become widely accepted, and many empirical studies and theoretical developments have been realized. Moreover, one of the distinguishing features of Japanese growth is that it has been accompanied by rapid technical change.[2] As a "late

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[1]The only exception was during 1931-45, when Japan traded particularly heavily with its occupied territories--Korea, Taiwan, and Manchuria.

[2]The terms "technical change" and "change in TFP" are

comer," Japan has been catching up with the Western standard of technology, taking advantage of the situation in which it can borrow the latest technology from other developed countries without worrying about scrapping obsolete machinery. This tendency was strengthened in the postwar period by the temporary isolation of the Japanese economy due to the war.

This period was also marked by growing symptoms of many economic conflicts between Japan and the U.S. concerning the former's exports of textiles, steel, plate glass, and televisions, to the latter and the latter's exports of agricultural products to the former.[3]

These facts may reflect changes in comparative advantage in the two countries. Another focus of the thesis is the effects of changes in TFP on the changes in comparative advantage. This is reasonable because the discovery of the Leontief Paradox in 1953 and the development of technology theories of trade such as the technological gap and product cycle hypotheses have drawn much attention to the role of technical change as a determinant of comparative advantage.

The organization of the study will be as follows: Chapter II will investigate the theoretical foundations of the TFP measurement. Chapter III will examine how the

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synonymous throughout.

[3]For example, the Sato-Nixon talk in 1970 was a turning point for the lengthy confrontation between Japan and the U.S. concerning textiles.

foundations can be applied to empirical studies. Chapter IV will present empirical results and discuss their economic implications. Conclusions will be presented in Chapter V. Statistical Appendix A describes industries investigated in Chapter IV. Explanations of data sources and data processing procedures will be described in Statistical Appendix B.

CHAPTER II

THEORETICAL BACKGROUND

Review of Literature

Total factor productivity (TFP) is an index representing the productivity of all the inputs in a production process. Partial productivity, on the other hand, measures the productivity of a single input, such as labor. The growth rate of TFP is defined as the difference between the growth rate of real output and the weighted average of the growth rates of real inputs. In other words, a TFP change shows how inputs are saved in a production process.

While TFP has been often investigated since Solow's seminal paper in 1957, most studies, whether theoretical or empirical, rely on aggregate production functions. In contrast, my approach will be to investigate TFP at the disaggregated level.[4] The disaggregation will make possible the analysis of the role of intermediate inputs in TFP measurement.

An incorporation of intermediate inputs into the

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[4]A disaggregation will always mean a breakdown by industry.

production function is not particularly new. Agricultural economists have estimated production functions which often included intermediate inputs such as fertilizer.[5] Engineering production functions have also involved materials and energy inputs.[6] However, these studies have used partial equilibrium analysis, examining a production process as an activity separate from other part of the economy. General equilibrium and interindustry dependence are not considered as their background.

On the other hand, more conventional neoclassical production functions have usually excluded intermediate inputs and focused on the value-added generating process. Empirical studies on TFP followed this tradition.[7]

As Griliches and Ringstadt [1971,pp. 108-09] suggested:

> This procedure [to exclude intermediate inputs from production functions] has received a variety of justifications in the past: (1) It facilitates the comparison of results for different industries with different material use intensities and it improves the comparability of data for individual establishments even within the same industry as long as they differ in their "tickness" (the amount of vertical integration). (2) It facilitates the aggregation of output measures across industries through the reduction of "double counting".[8] When output is

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[5]See, e.g., Heady and Dillon [1961].

[6]See, e.g., Chenery [1949].

[7]TFP analysis was pioneered by Tinbergen in 1942, although his work has not been well known because it was written in Germany. Solow [1957] is the most often cited as an early work on TFP.

[8]However, an aggregation over industries will not eliminate all intermediate inputs from the production

measured by value added only, the materials that are embedded in a particular product are not counted each time as the product crosses industry lines on its way toward final consumption. (3) It reduces the problems of estimation and interpretation by the elimination of a variable (M) [intermediate inputs] from both sides of the production relation. (4) "Materials" are an asymmetric input. Often their use is very closely associated with the level of gross output and hence their inclusion as an "independent" variable in a regression analysis would obscure the relationships of interest. Thus, one could presumably explain very well the output of the "cloth" industry if one used "yarn" as an input, since there is an almost one to one relationship between yards of cloth and pounds of yarn for a particular quality of cloth, and leave no role for the more interesting capital and labor variables. (5) Finally, any short run fluctuation in demand may be met without much change in the work force or machinery in place, but will usually induce a similar fluctuation in the use of raw materials or energy input. In this sense, M is more endogenous than L [labor] and K [capital] and its use as an independent variable is more likely to lead to simultaneous equation biases if standard least squares estimation procedures are followed.

However, Fabricant [1940] had already recognized the important role of intermediate inputs in productivity studies. Domer [1961] was the first formal analysis of effects of incorporating intermediate inputs into TFP studies in his purely theoretical model. Watanabe [1971] conducted the first empirical investigation of TFP incorporating intermediate inputs, in his study of the Japanese economy. He was followed by Star [1974], who analyzed the U.S. economy.

Three reasons exist for a TFP study to emphasize the

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function if the economy is open to international trade since imported intermediate inputs have to be treated as primary inputs, and hence should be included in the production function. See Gollop and Roberts [1981] and Gollop [1983] for more thorough discussion of this issue.

role of intermediate inputs:

1. Several authors have examined the relationship between sectoral and aggregate TFP. They have drawn attention to the existence of intermediate inputs since those are the major difference between these two kinds of TFP. Works by Domer, Watanabe, and Star were all related to this issue.[9]

2. Many researchers began to realize that economic theories may not justify the elimination of intermediate inputs because the concept of real value added (real gross output minus real intermediate inputs) is diffucult to interprete. This issue will be discussed more throughly at the end of the Chapter III (pp. 61-66).

3. The oil crisis stimulated studies on the role of energy and raw materials in economic growth.[10]

Total Factor Productivity and Intermediate Inputs

TFP measurement incorporating intermediate inputs can be given as follows.[11] For each industry of an economy the following accounting identity always holds:

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[9]See also Gollop [1979] and Bigman [1980] for more thorough discussions.

[10]For example, see Gander [1977].

[11]Nishimizu [1974] provides an excellent exposition of the issues. See also Baird [1977], Sato and Ramachandran [1980], Sudit and Finger [1981], and Nelson [1981] for conceptual and methodological problems of estimating TFP, which will not be discussed extensively.

$$(2.1)\ P_jX_j = \sum_{i=1}^{n} P_iX_{ij} + \sum_{h=1}^{m} q_hV_{hj}\ \ (j=1,\ldots,n),$$

where X_j is the quantity of gross output of the jth industry; X_{ij} is the quantity of the intermediate input produced in the ith industry and used in the jth industry;[12] V_{hj} is the quantity of the hth primary input used in the jth industry; and P_j, P_i, and q_h are prices of X_j, X_{ij} and V_{hj} respectively.

The growth rate of the TFP index ($\hat{E}_j$), which is defined as the difference between the growth rate of real outputs and of real inputs, can be derived from total differentiation of (2.1) with respect to time:

$$(2.2)\ \hat{E}_j = \hat{X}_j - \sum_{i=1}^{n} \frac{P_iX_{ij}}{P_jX_j}\hat{X}_{ij} - \sum_{h=1}^{m} \frac{q_hV_{hj}}{P_jX_j}\hat{V}_{hj}\quad (j=1,\ldots n),$$

where a circumflex indicates the relative growth rate of a variable (e.g., $\hat{X}_j = (\partial X_j/\partial t)/X_j$).

A change in TFP can be interpreted as a shift of a production function. Consider a disaggregate production function by industry with constant returns to scale:[13]

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[12]Throughout the thesis "gross" means "including intermediate inputs," not "including depreciation of capital stock".

[13]It is not self-evident that single-output, multi-

$$(2.3)\quad X_j = f^j(X_{1j},\ldots,X_{nj};\ V_{1j},\ldots,V_{mj};\ t_j) \qquad (j=1,\ldots,n),$$

where t_j represents a shift parameter of the function of the jth industry. By totally differentiating (2.3) with respect to time, we get

$$(2.4)\quad \hat{f}^j = \hat{X}_j - \sum_{i=1}^{n} \frac{f_i^j X_{ij}}{X_j} \hat{X}_{ij} - \sum_{h=1}^{m} \frac{f_h^j V_{hj}}{X_j} \hat{V}_{hj} \qquad (j=1,\ldots n),$$

where $\hat{f}^j = (\partial f^j/\partial t)/\ f^j$, $f_i^j = \partial f^j/\partial X_{ij}$ and $f_h^j = \partial f^j/\partial V_{hj}$. If we assume competitive pricing in all goods and primary input markets, $\hat{f}^j = \hat{E}_j$, since $f_i^j = P_i/P_j$ and $f_h^j = q_h/q_j$. Thus, equation (2.4) representing a shift of a production function, is equivalent to equation (2.2) defining a TFP change.[14]

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input production functions like equation (2.3) represent an arbitrary production process. The most general expression of a production process is F(X,V)=0, where X and V are a vector of real outputs and inputs, respectively. Hall [1973] and Bruno [1978] discuss the assumptions required for reducing a multi-output, multi-input production function to a single-output, multi-input production function.

[14]Necessary and sufficient conditions for a change in TFP to be identified as a shift of a production function are: (1) the production function is subject to constant returns to scale; (2) the technical progress is Hicks neutral; and (3) the factors of production and outputs are competitively priced. See Diewert [1980] for rigorous proof.

Equation (2.2) shows how the saving in intermediate and primary inputs affects the TFP of an industry. However, it does not reveal adequately the interindustry dependence of production costs. More precisely, this approach obscures the fact that the growth rate of intermediate inputs embodies the TFP growth created in the industries which produce these inputs. It cannot measure such "indirect" TFP. A different approach is necessary to explicitly analyse the effects of other industries' TFP on the production cost of a single industry.

Total Factor Productivity and Interindustry Dependence

In order to examine the effect on TFP of interindustry dependence of production costs. TFP, consider the following simple model. Suppose an economy has only two industries, the production functions of which are given by the following:[15]

(2.5) $X_1 = f_1(L_1, K_1, X_2, t_1)$,

(2.6) $X_2 = f_2(L_2, K_2, t_2)$,

where X_i is the output of the ith industry, and L_i (K_i) is the labor (capital) input of the ith industry.

[15]This model was first proposed by Domar [1961], and also used by Star [1974] in different contexts.

By totally differentiating equations (2.5) and (2.6) and arranging terms,

$$(2.7)\quad \hat{E}_1 = \hat{X}_1 - \psi_{L1}\hat{L}_1 - \psi_{K1}\hat{K}_1 - \psi_{X_{21}}\hat{X}_2,$$

$$(2.8)\quad \hat{E}_2 = \hat{X}_2 - \psi_{L2}\hat{L}_2 - \psi_{K2}\hat{K}_2,$$

where ψ_{hj} is the output elasticity of the hth input in the jth industry, i.e., $\psi_{Kj} = (\partial X_j/\partial K_j)(K_j/X_j)$ and $\psi_{Lj} = (\partial X_j/\partial L_j)(L_j/X_j)$. If perfect competition prevails, each elasticity gives the factor share in total output of each input, i.e., $\psi_{Kj} = q_K K_j/P_j X_j$ and $\psi_{Lj} = q_L L_j/P_j X_j$.

By substituting equation (2.8) into equation (2.7),

$$(2.9)\quad \hat{E}_1 + \psi_{X_{21}}\hat{E}_2 = \hat{X}_1 - \psi_{L1}\hat{L}_1 - \psi_{K1}\hat{K}_1 - \psi_{X_{21}}[\psi_{L2}\hat{L}_2 + \psi_{K2}\hat{K}_2].$$

Equation (2.9) represents the TFP of the economy as a whole. The two industries are now vertically integrated. Note that the model is recursive in the sense that the output of the second industry is used by the first industry, while the second industry does not use the output of the first. The second industry produces only an intermediate good which is exclusively used by the first industry, while the first industry produces only a final commodity. Note also that equation (2.9) shows that the growth rate of the gross output of the first industry, when the indirect input requirement is also taken into account, depends on the second industry's TFP. If the growth rate of primary inputs are all zero, output growth rate of the first industry, $\hat{X}_1$, is entirely explained by the TFP growth rate of two industries. The TFP of the first industry considering only direct inputs (i.e., direct TFP) is $\hat{E}_1$, while the TFP incorporating both direct and indirect inputs is $\hat{E}_1 + \psi_{X_{21}}\hat{E}_2$, which may be called direct and indirect TFP.

I will now consider a more general case:

$$(2.10)\quad X_1 = f_1(L_1, K_1, X_1, X_2, t_1),$$

$$(2.11)\quad X_2 = f_2(L_2, K_2, X_1, X_{22}, t_2).$$

By totally differentiating equations (2.10) and (2.11) and arranging terms,

$$(2.12)\quad \hat{E}_1 = \hat{X}_1 - \psi_{L1}\hat{L}_1 - \psi_{K1}\hat{K}_K - \psi_{X_{11}}\hat{X}_1 - \psi_{X_{21}}\hat{X}_2,$$

$$(2.13)\quad \hat{E}_2 = \hat{X}_2 - \psi_{L2}\hat{L}_L - \psi_{K2}\hat{K}_K - \psi_{X_{12}}\hat{X}_1 - \psi_{X_{22}}\hat{X}_2.$$

Note that what equation (2.9) really does is to eliminate all intermediate inputs from the system such that the growth rate of each intermediate input is replaced by the growth rate of the primary inputs and the TFP of the industry producing it. To perform the same type of operation as in equation (2.9) is difficult since the system is completely simultaneous, not recursive.

A dual system may be easier to understand. A change in TFP can be interpreted as shift of a unit cost function as well as a production function.[16] For simplicity I consider two industry economy.[17]

A. <u>The case in which no intermediate input exists.</u>

If perfect competition prevails, the prices of products are equal to their production cost, i.e.,

$$(2.14)\quad P_1 = v_{L1}q_L + v_{K1}q_K,$$

$$(2.15)\quad P_2 = v_{L2}q_L + v_{K2}q_K.$$

Totally differentiating equations (2.14) and (2.15) with respect to time, we get

[16] TFP derived from production functions and cost functions should be theoretically identical. However, a discrete approximation of Divisia index create some discrepancy between these two kinds of TFP. Moreover, the discrepancy also reflects the performance of price mechanism since the theoretical identity is based on the duality between production functions and cost functions, which in turn, requires the assumption of cost minimization and perfect competition. Kuroda and Imamura [1981] demonstrate that the discrepancy was the smallest during 1966-69 and relatively large after the oil crisis. The discrete approximation of Divisia index will be discussed later (see p. 35).

[17] This model is based on Jones [1965].

$$(2.16)\quad \hat{P}_1 = \psi_{L1}\hat{q}_L + \psi_{K1}\hat{q}_K + [\psi_{L1}\hat{v}_{L1} + \psi_{K1}\hat{v}_{K1}],$$

$$(2.17)\quad \hat{P}_2 = \psi_{L2}\hat{q}_L + \psi_{K2}\hat{q}_K + [\psi_{L2}\hat{v}_{L1} + \psi_{K2}\hat{v}_{K2}],$$

where $\hat{v}_{hj} = \dfrac{\partial v_{hj}/\partial t}{v_{hj}}$ is the rate of change in input coefficient of the hth primary input in the jth industry caused by technical change. Note that

$$\psi_{Lj}\frac{\partial v_{Lj}/\partial(q_L/q_K)}{v_{Lj}} + \psi_{Kj}\frac{\partial v_{Kj}/\partial(q_L/q_K)}{v_{Kj}} = 0 \quad (j=1,2)$$

at the equilibrium.[18] The expressions in the brackets represent the technical change.

B. <u>The case in which interindustry flows of intermediate inputs exist</u>

Equations (2.14) and (2.15) become

$$(2.18)\quad P_1 = v_{L1}q_L + v_{K1}q_K + a_{11}P_1 + a_{21}P_2,$$

$$(2.19)\quad P_2 = v_{L2}q_L + v_{K2}q_K + a_{12}P_1 + a_{22}P_2.$$

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[18] This is an example of the envelope theorem. See Varian [1978], pp.267-69.

The solution for P_1 and P_2 is

(2.20) $P_1 = R_{L1}q_L + R_{K1}q_K$,

(2.21) $P_2 = R_{L2}q_L + R_{K2}q_K$,

where

(2.22) $$R_{h1} = \frac{v_{h1}(1-a_{22}) + v_{h2}a_{21}}{(1 - a_{11})(1 -a_{22}) - a_{12}a_{21}},$$

(h=L,K),

(2.23) $$R_{h2} = \frac{v_{h2}(1-a_{11}) + v_{h1}a_{12}}{(1 - a_{11})(1 -a_{22}) - a_{12}a_{21}},$$

Totally differentiating equations (2.20) and (2.21) we get

(2.24) $\hat{P}_1 = \theta_{L1}\hat{q}_L + \theta_{K1}\hat{q}_K + [\theta_{L1}\hat{R}_{L1} + \theta_{K1}\hat{R}_{K1}]$,

(2.25) $\hat{P}_2 = \theta_{L2}\hat{q}_L + \theta_{K2}\hat{q}_K + [\theta_{L2}\hat{R}_{L2} + \theta_{K2}\hat{R}_{K2}]$.

where $\theta_{hj} = R_{hj}/P_j$ is the distributive share of direct and indirect inputs of the hth input in the jth industry. Equations (2.22) through (2.25) show that a change in the unit cost in an industry depends on the technical changes in other industries. Direct TFP can be derived by totally differentiating equations (2.18) and (2.19) without solving them for P_1 and P_2.

Notice the analogy between direct TFP and direct and indirect TFP. As shown in equations (2.16) and (2.17) direct TFP is a weighted average of the rate of decrease in direct factor requirement per unit of output (or the rate of increase in factor productivity), where the weights are the distributive share of direct inputs. On the other hand, as equations (2.24) and (2.25) indicate direct and indirect TFP is a weighted average of the rate of decrease in direct and indirect factor requirement per unit of output, where the weights are the distributive share of direct and indirect factor inputs.

The rest of the dissertation will often use linear price equations such as equation (2.18) instead of general cost functions. There are several ways to interpret these linear equations. (i) These are accounting identities defining unit production costs and the calculated TFP is an accounting concept independent of economic theories. (ii) These are precise expressions of the Leontief type cost functions, which is the dual of the Leontief type production function with fixed input-output coefficients:

$$(2.26)\quad X_j = \mathrm{Min}\,(K_j,\ L_j,\ X_{1j},\ X_{2j},\ldots,\ X_{nj},\ t_j) \qquad (j=1,\ldots,n),$$

where X_j is the jth gross output; K_j and L_j are capital and labor input in the jth industry; X_{ij} is the intermediate input produced in the ith industry and used in the jth industry. The calculated TFP measures a shift of the

Leontief production function. However, it is difficult to apply to the Leontief functions the neoclassical framework of measuring TFP, which is presented at the beginning of this chapter, since it is not clear whether or not the marginal productivity theory of production factors is possible.[19] (iii) These equations are a first order linear approximation of an arbitrary cost function.

A more rigorous procedure is to totally differentiate arbitrary cost functions and derive a local linear approximation around the equilibrium. Then by solving the system of these approximated cost functions for the prices of gross outputs, direct and indirect TFP can be derived. This rigorous procedure, nonetheless, yields exactly the same TFP index as the procedure described here. For formal proof of this assertion see the appendix to this chapter. Therefore, direct and indirect TFP derived here can be interpreted as an economic variable although it is defined as an accounting measure. This is analogous to the interpretation of ordinary, direct TFP that the TFP is defined as an accounting measure of productivity of inputs although it can be interpreted from an economic viewpoint as a shift in cost functions.

Consider a general model of an economy in order to examine more closely the derivation of direct and indirect TFP. Let us represent the supply side of an economy by cost

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[19] See Ferguson [1969], Chapter 2 and 3, and Georgescu-Roegen [1935] for a thorough analysis of this issue.

functions:

$$(2.27)\quad \begin{aligned} P_1 &= g_1(q_K,\ q_L,\ P_1,\ P_2, \ldots,\ P_n,\ t_1), \\ P_2 &= g_2(q_K,\ q_L,\ P_1,\ P_2, \ldots,\ P_n,\ t_2), \\ &\cdots \\ P_n &= g_n(q_K,\ q_L,\ P_1,\ P_2, \ldots,\ P_n,\ t_n), \end{aligned}$$

where P_j is the price of the jth gross output; q_K and q_L are the rental prices of capital and the wage rate of labor, respectively; and t_j is the direct TFP of the jth industry.

A measurement of direct and indirect TFP regarded as a comparative static experiment. In this model P_j is a endogenous variable; q_K, q_L and t_j are exogenous variables. Direct and indirect TFP measures indicate how endogenous variables change when t alone changes, holding q_K and q_L constant.

However, since the endogenous variables (P_j's) also appear on the RHS as well as the LHS the following reduced form can be derived by solving the system for P_j's:

$$(2.27')\quad \begin{aligned} P_1 &= h_1(q_K,\ q_L,\ t_1,\ t_2, \ldots, t_n) \\ P_2 &= h_2(q_K,\ q_L,\ t_1,\ t_2, \ldots, t_n) \\ &\cdots \\ P_n &= h_n(q_K,\ q_1,\ t_1,\ t_2, \ldots, t_n) \end{aligned}$$

Then, by totally differentiating each equation, direct and indirect TFP can be derived. On the other hand, ordinary, direct TFP is derived by totally differentiating each equation of the system (2.27) without solving for its endogenous variables. However, since t_j's are not directly observable, TFP, whether direct or direct and indirect, is calculated from observable P_j's, q_K, and q_L.

The price equations in a general case are

$$(2.28)\quad P_j = \sum_{h=1}^{m} v_{hj} q_h + \sum_{i=1}^{n} a_{ij} P_i \quad (j=1,\ldots,n),$$

where P_j is the price of the jth output, and q_h is the rental price of the hth primary input. The solution of this n equation simultaneous equation system for P_j is

$$(2.29)\quad P_j = \sum_{h=1}^{m} R_{hj} q_h \quad (j=1,\ldots,n).$$

The next step is to calculate the direct and indirect primary input requirements per one unit of final demand in each sector and see how the requirements change over time. The calculation is given as follows:[20]

[20]Parikh [1975] discussed different formulae for direct and indirect input requirements. The present study will use the formula proposed by Carter [1970].

$$(2.30)\ [R] = [v][I - A]^{-1},$$

where

$$[R] = \begin{bmatrix} R_{11},\ldots,R_{1n} \\ \vdots \qquad \vdots \\ R_{m1},\ldots,R_{mn} \end{bmatrix} \qquad [v] = \begin{bmatrix} v_{11},\ldots,v_{1n} \\ \vdots \qquad \vdots \\ v_{m1},\ldots,v_{mn} \end{bmatrix};$$

R_{hj} is the direct and indirect requirement of the hth primary input needed to satisfy one unit of final demand for the jth industry's output; $v_{hj} = V_{hj}/X_j$, where V_{hj} is the hth primary input used in the jth industry; and $[I - A]^{-1}$ is the Leontief inverse matrix.

Totally differentiating equation (2.29), direct and indirect TFP of the jth industry can be derived as follows:

$$(2.31)\ \hat{\Pi}_j = - \sum_{h=1}^{m} \theta_{hj}\hat{R}_{hj}\ (j=1,\ldots,n),$$

where θ_{hj} is the direct and indirect distributive share of the hth primary input in the jth industry, i.e.,

$$(2.32)\ \theta_{hj} = R_{hj}q_h/P_j\ (j=1,\ldots,n).$$

Four related works should be mentioned here:

First, I-O analysis often calculates the direct and indirect labor requirement per unit of final demand. Gupta and Steedman [1977] examined a change in this requirement over time. They called the requirement the "system" measurement of productivity as opposed to the ordinary "industry" measurement of productivity. The former corresponds to direct and indirect productivity, and the latter corresponds to direct productivity in this study. However, these I-O analyses have never been applied to the study of TFP, but rather to labor productivity. Erdilek [1977], Sato and Ramachandran [1980], and Moon [1981] survey these studies.

Second, one of the important extensions of the pure theory of international trade is the introduction of intermediate inputs and technical change. For instance, Casas [1972] demonstrated that Hicks-neutral technical change occurred in one industry increases the output in the own industry and decreased the output in the other industry. See also Batra and Pattanaik [1971] and Kemp and Uekawa [1972].

Third, Hulten [1978] proposed "the effective rate of productivity change," which is derived from the solution of a general equilibrium model of growth accounting. The model consists of TFP of each industry and total supply of each primary input as exogenous variables, and prices and quantities of gross output, final demand, intermediate inputs and primary inputs of each industry as endogenous variables. The model that I proposed may be interpreted as a special case of the Hulten model, which is so general that its application to an empirical analysis is virtually impossible.

Fourth, Griliches and Lichtenberg [1982, 1984], Scherer [1982, 1984], and Terleckyj [1980] analyzed the interindustry flows of R&D inputs, although their investigations are limited to these particular inputs. On the other hand, their studies treat R&D inputs as process as well as products. As a product R&D is an intermediate input, while as a process it is primary input. Thus, they endogenized a part of primary inputs. This study was not able to accomplish this endogenization.

So far I have examined TFP in a domestic economy. The next section will expand the model to incorporate the international dependence of TFP. For that purpose, I will use an international I-O table.

Total Factor Productivity and International Dependence

An international I-O table entails comparable I-O tables of different countries connected by matrices of trade flows. This is an application of interregional I-O tables, where a region and a country correspond to a country and the world in international I-O tables.

Several regional I-O models exist.[21] This study is

[21]See Richardson [1972] for a survey of regional I-O models.

based on the inter-regional models first developed by Isard [1951] and modified by Moses [1955] and Chenery [1956].[22] These models all assume that different regions have different I-O coefficients. However, the Isard model distinguishes trade flows of a good to different industries, while the Chenery-Moses model assumes that these flows share the same proportion of the total supply (domestic supply plus imports). Details will be discussed below.

There have been many studies of either trade structure (international dependence) or domestic industrial structure (interindustry dependence).[23] However, studies which combine both in one consistent analytical framework are rare. International I-O analysis is one, and perhaps the only example of such an integrated approach. It is obvious that such an approach is desirable, since trade and industrial structure are different sides of the same coin. International I-O analysis is particularly interesting, because international trade involves mainly the exchange of intermediate inputs rather than final outputs.[24]

The first international I-O table was compiled and analyzed by Wonnacott [1961]. The first joint Japanese-U.S.

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[22]Hartwick [1971] examined the relationship among models developed by these three authors.

[23]Examples of empirical analysis of changes in industrial structure using Input-Output analysis are Ozaki [1976] for the Japanese economy and Carter [1970] for the U.S. economy. Chenery and Watanabe [1958] is an example of international comparison of industrial structure using I-O tables.

[24]See Yates [1959], pp. 159-99.

table was compiled by Watanabe [1966]. Ishida [1978] analyzed Japanese-American dependence using a more detailed Japanese-U.S. table compiled by the Institute of Developing Economies [1977]. Yorozu [1978] conducted the first intertemporal comparison of international I-O tables. However, these analyses have not dealt with TFP.

The model to be used is basically a static, open Leontief system which consists of three regions--Japan, the U.S. and the rest of the world (ROW). Mathematically, the balance equations for the Japanese economy are

$$(2.33) \quad \sum_{j=1}^{n} X_{ij}^{JJ} + \sum_{j=1}^{n} X_{ij}^{JU} + F_i^{JJ} + F_i^{JU} + X_i^{JR} = X_i^{J}. \qquad (i=1,\ldots,n).$$

Similarly for the U.S. economy,

$$(2.34) \quad \sum_{j=1}^{n} X_{ij}^{UJ} + \sum_{j=1}^{n} X_{ij}^{UU} + F_i^{UJ} + F_i^{UU} + X_i^{UR} = X_i^{U} \qquad (i=1,\ldots,n),$$

and for the ROW

$$(2.35) \quad \sum_{j=1}^{n} X_{ij}^{RJ} + \sum_{j=1}^{n} X_{ij}^{RU} + F_i^{RJ} + F_i^{RU} = M_i \qquad (i=1,\ldots,n),$$

where X_{ij}^{kl} is a good produced by the ith industry in the kth country and used in the jth industry in the lth country as an intermediate input; F_i^{kl} is a good produced by the ith industry in the kth country and used as a final good in the lth country; X_i^{kl} is a good produced by the ith industry in the kth country and exported to the lth country both as an intermediate input and as a final good; X_i^k is the total domestic production of the ith industry in the kth country; M_i is the total imports of the ith good of Japan and the U.S. from the ROW; and superscripts, J, U, and R, stand for Japan, the U.S. and the ROW, respectively.

Now, define an I-O coefficient,

$$(2.36)\ a_{ij}^{kl} = X_{ij}^{kl} \ /\ X_j^l \ (k,l=J,U;\ i,j=1,\ldots,n).$$

Let A^{kl} be a matrix containing a_{ij}^{kl}. Then equations (2.33) and (2.34) can be rewritten,

$$(2.37)\ A^{JJ}X^J + A^{JU}X^U + F^{JJ} + F^{JU} + X^{JR} = X^J,$$

$$(2.38)\ A^{UJ}X^J + A^{UU}X^U + F^{UJ} + F^{UU} + X^{UR} = X^U,$$

where F^{kl} is a vector of final demands of the lth country supplied by the kth county; X^{JR} (X^{UR}) is a vector of exports of Japan (the U.S.) to the ROW; and X^J (X^U) is a vector of total domestic production of Japan (the U.S.).

Then the system can be solved for total output of these two countries,

$$(2.39)\qquad \begin{bmatrix} X^J \\ X^U \end{bmatrix} = \begin{bmatrix} I - A^{JJ} & -A^{JU} \\ -A^{UJ} & I - A^{UU} \end{bmatrix}^{-1} \begin{bmatrix} F^{JJ} + F^{JU} + X^{JR} \\ F^{UJ} + F^{UU} + X^{UR} \end{bmatrix}.$$

I-O coefficients, a_{ij}^{kl}'s, involve intermediate inputs which are either produced domestically (if k=l) or imported (if k≠l).

Let us decompose a_{ij}^{kl} in the following way:

$$(2.40)\qquad a_{ij}^{kl} = \frac{X_{ij}^{kl}}{X_j^l} = \frac{X_{ij}^{kl}}{\sum_k X_{ij}^{kl}} \; \frac{\sum_k X_{ij}^{kl}}{X_j^l} = t_{ij}^{kl}\, a_{ij}^l$$

(k,l=J,U,R; i,j=1,...,n),

where t_{ij}^{kl} is a trade coefficient indicating the proportion of the imports of the ith good from the kth country by the jth industry in the lth country to the total supply of the ith good to the jth industry in the lth country; and a_{ij}^l is the technical I-O coefficient, i.e., the ratio of the total (domestically produced and imported) intermediate input of the ith good to the gross output of the jth industry in the lth country. The difference between a^{l}_{ij} and a^{ll}_{ij} is that the former includes imported inputs, while the latter does not.

The decomposition is desirable for my research purpose. Changes in t^{kl}_{ij} and a^{l}_{ij} have different economic implications. a^{l}_{ij} is a technical coefficient, which represents the engineering relationship between input and output. Thus, a change in a^{l}_{ij} reflects technical change. On the other hand, t^{kl}_{ij} does not represent a technological relationship. It reflects substitution between domestically produced and imported intermediate products. Changes in t^{kl}_{ij} occur because of import substitution or reverse import substitution, i.e., the replacement of domestic production by imports.

However, data concerning X^{kl}_{ij}, where $k \neq l$, are not published in most countries, including the U.S. To deal with this problem, I redefine the trade coefficient as follows:

$$(2.41)\quad t^{kl}_{i} = \left(\sum_{j=1}^{n} X^{kl}_{ij} + F^{kl}_{i}\right) \Big/ \sum_{k}\left(\sum_{j=1}^{n} X^{kl}_{ij} + F^{kl}_{i}\right)$$

$$(k,l=J,U,R;\ i=1,\ldots,n).$$

The numerator is the lth country's imports of the ith good from the kth country. The denominator is the total supply of the ith good to the lth country. Two additional assumptions are made, both of which are restrictive but necessary. One is that $t_{ij}^{kl} = t_i^{kl}$ for all j, which means that each industry uses domestically produced and imported intermediate inputs in the same proportion. The other assumption is that the same proportions apply to final demand. In other words, the ratio of domestically produced goods of an industry to imports which satisfy final demand is the same as the proportion of domestically produced goods of the industry to imports which are used as intermediate inputs in production.

Using the redefined trade coefficient, the new balance equations are derived as follows: let Q_i^k be the total supply of the ith good to the kth country. Then,

$$(2.42)\quad Q_i^J = \sum_{j=1}^{n} X_{ij}^{JJ} + F_i^{JJ} + \sum_{j=1}^{n} X_{ij}^{UJ} + F_i^{UJ} + \sum_{j=1}^{n} X_{ij}^{RJ} + F_i^{RJ},$$

$$(2.43)\quad Q_i^U = \sum_{j=1}^{n} X_{ij}^{JU} + F_i^{JU} + \sum_{j=1}^{n} X_{ij}^{UU} + F_i^{UU} + \sum_{j=1}^{n} X_{ij}^{RU} + F_i^{RU}$$

$$(i=1,\ldots,n).$$

From equation (2.41),

$$(2.44)\quad t_i^{kl} Q_i^l = \sum_{j=1}^{n} X_{ij}^{kl} + F_i^{kl} \quad (k,l=J,U,R;\ i=1,n).$$

Thus the new balance equations are

$$(2.45)\quad X_i^J = t_i^{JJ}Q_i^J + t_i^{JU}Q_i^U + X_i^{JR},$$

$$(2.46)\quad X_i^U = t_i^{UJ}Q_i^J + t_i^{UU}Q_i^U + X_i^{UR} \qquad (i=1,\ldots,n).$$

Since

$$X_{ij}^{JJ} + X_{ij}^{UJ} + X_{ij}^{RJ} = a_{ij}^J X_j^J,$$

and

$$X_{ij}^{JU} + X_{ij}^{UU} + X_{ij}^{RU} = a_{ij}^U X_j^U, \qquad (i,j=1,\ldots,n),$$

the equations (2.45) and (2.46) can be rewritten in a matrix form,

$$(2.47)\quad X^J = T^{JJ}A^J X^J + T^{JU}A^U X^U + T^{JJ}F^J + T^{JU}F^U + X^{JR},$$

$$(2.48)\quad X^U = T^{UJ}A^J X^J + T^{UU}A^U X^U + T^{UJ}F^J + T^{UU}F^U + X^{UR},$$

where

$$T^{kl} = \begin{bmatrix} t_1^{kl} & & 0 \\ & \ddots & \\ 0 & & t_n^{kl} \end{bmatrix} \qquad A^k = \begin{bmatrix} a_{11}^k & \cdots & a_{1n}^k \\ \vdots & & \vdots \\ a_{n1}^k & \cdots & a_{nn}^k \end{bmatrix}$$

$$X^k = \begin{bmatrix} X_1^k \\ \cdot \\ \cdot \\ \cdot \\ X_n^k \end{bmatrix} \quad F^k = \begin{bmatrix} F_1^{kk} + F_1^{lk} \\ \cdot \quad\quad \cdot \\ \cdot \quad\quad \cdot \\ \cdot \quad\quad \cdot \\ F_n^{kk} + F_n^{lk} \end{bmatrix} \quad X^{kR} = \begin{bmatrix} X_1^{kR} \\ \cdot \\ \cdot \\ \cdot \\ X_n^{kR} \end{bmatrix}$$

$$(k,l=J,U,R),$$

where T^{kl} is a diagonal matrix whose diagonal elements are trade coefficients representing the exports from the kth country to the lth country; A^k is a matrix of I-O coefficients of the kth country; X^k is the vector of the gross output of the kth country; and F^k is a vector of total final demand in the kth country. The solution of equations (2.47) and (2.48) is

$$(2.49) \quad \begin{bmatrix} X^J \\ X^U \end{bmatrix} = \begin{bmatrix} I - T^{JJ}A^J & - T^{JU}A^U \\ - T^{UJ}A^J & I - T^{UU}A^U \end{bmatrix}^{-1} \left\{ \begin{bmatrix} T^{JJ} & T^{JU} \\ T^{UJ} & T^{UU} \end{bmatrix} \begin{bmatrix} F^J \\ F^U \end{bmatrix} + \begin{bmatrix} X^{JR} \\ X^{UR} \end{bmatrix} \right\}.$$

The solution can be applied to the index of TFP incorporating direct and indirect input requirements.

Before the application, however, the model must introduce the imports of intermediate inputs from the ROW as primary inputs, in addition to "ordinary" primary inputs such as capital and labor. Note that the model cannot determine quantities and prices of goods produced in the ROW. Equation (2.30) is rewritten as follows:

$$(2.50)\quad [R] = [R^J;R^U] = [V^J;V^U][I - TA]^{-1},$$

$$(2.50')\quad [r] = [r^J;r^U] = [T^{RJ}A^J;T^{RU}A^U][I - TA]^{-1},$$

where

$$[R] = [R^J;R^U] = \begin{bmatrix} R^J_{11},\ldots,R^J_{1n} & R^U_{11},\ldots,R^U_{1n} \\ \vdots \quad\quad \vdots & \vdots \quad\quad \vdots \\ R^J_{m1},\ldots,R^J_{mn} & R^U_{m1},\ldots,R^U_{mn} \end{bmatrix},$$

$$[r] = [r^J;r^U] = \begin{bmatrix} r^J_{11},\ldots,r^J_{1n} & r^U_{11},\ldots,r^U_{1n} \\ \vdots \quad\quad \vdots & \vdots \quad\quad \vdots \\ r^J_{n1},\ldots,r^J_{nn} & r^U_{n1},\ldots,r^U_{nn} \end{bmatrix},$$

$$[v] = [v^J;v^U] = \begin{bmatrix} v^J_{11},\ldots,v^J_{1n} & v^U_{11},\ldots,v^U_{1n} \\ \vdots \quad\quad \vdots & \vdots \quad\quad \vdots \\ v^J_{m1},\ldots,v^J_{mn} & v^U_{m1},\ldots,v^U_{mn} \end{bmatrix},$$

$$[T^{RJ}A^J;T^{RU}A^U]$$

$$= \begin{bmatrix} t_1^{RJ}a_{11}^J, \ldots, t_1^{RJ}a_{1n}^J & t_1^{RU}a_{11}^U, \ldots, & t_1^{RU}a_{1n}^U \\ \vdots \quad\quad \vdots & \vdots & \vdots \\ t_n^{RJ}a_{n1}^J, \ldots, t_n^{RJ}a_{nn}^J & t_n^{RU}a_{n1}^U, \ldots, & t_n^{RU}a_{nn}^U \end{bmatrix},$$

$$[I - TA]^{-1} = \begin{bmatrix} I - T^{JJ}A^J & - T^{JU}A^U \\ - T^{UJ}A^J & I - T^{UU}A^U \end{bmatrix}^{-1},$$

Production costs in each country are defined as follows:

Japan

$$(2.51) \quad P_j^J = \sum_{i=1}^{n} t_i^{JJ}a_{ij}^J P_i^J + \sum_{i=1}^{n} t_i^{UJ}a_{ij}^J P_i^U + [\sum_{i=1}^{n} t_i^{RJ}a_{ij}^J P_i^R + \sum_{h=1}^{m} v_{hj}^J q_h^J] \quad (j=1,\ldots,n),$$

U.S.

$$(2.52) \quad P_j^U = \sum_{i=1}^{n} t_i^{JU}a_{ij}^U P_i^J + \sum_{i=1}^{n} t_i^{UU}a_{ij}^U P_i^U + [\sum_{i=1}^{n} t_i^{RU}a_{ij}^U P_i^R + \sum_{h=1}^{m} v_{hj}^U q_h^U] \quad (j=1,\ldots,n).$$

The arguments in the brackets contain primary inputs. The solution of this 2n equation system for P_j^J and P_j^U is

$$(2.53)\ P_j^k = \sum_{h=1}^{m} R_{hj}^k q_h^k + \sum_{i=1}^{n} r_{ij}^k P_i^R \quad (k=J,U;\ j=1,\ldots,n).$$

Let θ_{hj} be the direct and indirect distributive share of the hth primary factor in the jth industry in the kth country and ϕ_{ij} be the direct and indirect distributive share of the ith intermediate input imported from the rest of the world in the jth industry in the kth country. Totally differentiating equation (2.53), direct and indirect TFP can be derived as follows:

$$(2.54)\ \hat{\Pi}_j^k = -\sum_{h=1}^{m} \theta_{hj}^k \hat{R}_{hj}^k - \sum_{i=1}^{n} \phi_{ij}^k \hat{r}_{ij}^k \quad (k=J,U;\ j=1,\ldots,n).$$

This is a Divisia index number whose weights are supposed to change continuously. In reality, data are discrete, not continuous. Many empirical studies use data on annual growth rates, and change weights annually.[25] Because annual data for I-O tables are difficult to obtain, my study will use only the growth rate of the beginning and end years, and the arithmetic mean of the distributive share of these two periods as the weight.[26]

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[25]Tonqvist [1936] first proposed a discrete approximation of a Divisia index number.

[26]See Star and Hall [1976] for the justification for such approximation. See Richter [1966] for properties of the Divisia index numbers. Diewert [1980] discussed the relationship between TFP and Divisia index number.

$$(2.54')\quad \hat{\Pi}_j^k = -\sum_{h=1}^{m} \bar{\theta}_{hj}^k \; [\text{Log } R_{hj}^k(t) - \text{Log } R_{hj}^k(t-1)]$$

$$-\sum_{i=1}^{n} \bar{\phi}_{ij}^k \; [\text{Log } r_{ij}^k(t) - \text{Log } r_{ij}^k(t-1)],$$

where

$$\bar{\theta}_{hj}^k = [\theta_{hj}^k(t) + \theta_{hj}^k(t-1)]/2,$$

and

$$\bar{\phi}_{ij}^k = [\phi_{ij}^k(t) + \phi_{ij}^k(t-1)]/2$$

$$(k=J,U;\ i,j=1,\ldots,n;\ h=1,\ldots m)$$

where the t-1 indicates the base period, and t is the period to compare.

Appendix to Chapter II:
The Equivalence of Two Procedures to Devive TFP

This appendix will prove that two procedures to derive TFP mentioned in this chapter (pp. 18-19) are equivalent. The first procedure begins with linear price equations:

$$(2.55)\quad P_1 = a_{11}P_1 + a_{21}P_2 + v_{K1}q_K + v_{L1}q_L,$$

$$(2.56)\quad P_2 = a_{12}P_1 + a_{22}P_2 + v_{K2}q_K + v_{L2}q_L.$$

where P_j, q_K, q_L are the prices of the gross output, capital input, and labor input in the jth industry, respectively; a_{ij} is the I-O coefficient; v_{Kj} and v_{Lj} are the input coefficient of capital and labor in the jth industry, respectively.

In matrix notation,

$$\text{(2.57)} \quad \begin{bmatrix} P_1 \\ P_2 \end{bmatrix} = \begin{bmatrix} 1 - a_{11} & - a_{21} \\ - a_{12} & 1 - a_{22} \end{bmatrix}^{-1} \begin{bmatrix} v_{K1} & v_{L1} \\ v_{K2} & v_{L2} \end{bmatrix} \begin{bmatrix} q_K \\ q_L \end{bmatrix}$$

$$= \begin{bmatrix} b_{11}v_{K1} + b_{12}v_{K2} & b_{11}v_{L1} + b_{12}v_{L2} \\ b_{21}v_{K1} + b_{22}v_{K2} & b_{21}v_{L1} + b_{22}v_{L2} \end{bmatrix} \begin{bmatrix} q_K \\ q_L \end{bmatrix}$$

$$= \begin{bmatrix} R_{K1} & R_{L1} \\ R_{K2} & R_{L2} \end{bmatrix} \begin{bmatrix} q_K \\ q_L \end{bmatrix},$$

where b_{ij} is the ijth element of the (transposed) Leontief inverse; R_{hj} is the direct and indirect requirement of hth input in the jth industry. Totally differentiating and arranging terms, direct and indirect TFP of each industry is

$$(2.58)\quad \hat{\Pi}_j = \frac{R_{Kj}q_K}{P_j}\,\hat{q}_K + \frac{R_{Lj}q_L}{P_j}\,\hat{q}_L - \hat{P}_j$$

$$= -\,\frac{R_{Kj}q_K}{P_j}\,\hat{R}_{Kj} - \frac{R_{Lj}q_L}{P_j}\,\hat{R}_{Lj}$$

where $j = 1, 2$; Π_j is the direct and indirect TFP of the jth industry.

The second procedure starts with a general form of cost functions:

$$(2.59)\quad P_1 = g_1(P_1, P_2, q_K, q_L, t_1),$$

$$(2.60)\quad P_2 = g_2(P_1, P_2, q_K, q_L, t_2),$$

where t_j is a shift parameter representing a change in TFP. Totally differentiating them,

$$(2.61)\quad \hat{P}_1 = \theta_{11}\hat{P}_1 + \theta_{21}\hat{P}_2 + \theta_{K1}\hat{q}_K + \theta_{L1}\hat{q}_L - \hat{E}_1,$$

$$(2.62)\quad \hat{P}_2 = \theta_{12}\hat{P}_1 + \theta_{22}\hat{P}_2 + \theta_{K2}\hat{q}_K + \theta_{L2}\hat{q}_L - \hat{E}_2,$$

where θ_{ij} (i,j=1,2) is the distributive share of the ith intermediate input in the jth industry; θ_{hj} (h=K,L; j=1,2) is the distributive share of hth primary input in the jth industry ; and E_j is the direct TFP in the jth industry.

Solving the system for $\hat{P}_1$ and $\hat{P}_2$,

$$(2.63)\quad \begin{bmatrix} \hat{P}_1 \\ \hat{P}_2 \end{bmatrix} = \begin{bmatrix} 1 - \theta_{11} & -\theta_{21} \\ -\theta_{12} & 1 - \theta_{22} \end{bmatrix}^{-1} \left\{ \begin{bmatrix} \theta_{K1} & \theta_{L1} \\ \theta_{K2} & \theta_{L2} \end{bmatrix} \begin{bmatrix} \hat{q}_K \\ \hat{q}_K \end{bmatrix} - \begin{bmatrix} \hat{E}_1 \\ \hat{E}_2 \end{bmatrix} \right\}.$$

In terms of physical input-output coefficients,

$$(2.64)\quad \begin{bmatrix} \hat{P}_1 \\ \hat{P}_2 \end{bmatrix} = \begin{bmatrix} 1 - a_{11} & -a_{21}P_2/P_1 \\ -a_{12}P_1/P_2 & 1 - a_{22} \end{bmatrix}^{-1}$$

$$\times \left\{ \begin{bmatrix} v_{K1}q_K/P_1 & v_{L1}q_L/P_1 \\ v_{K2}q_K/P_2 & v_{L2}q_L/P_2 \end{bmatrix} \begin{bmatrix} \hat{q}_K \\ \hat{q}_L \end{bmatrix} - \begin{bmatrix} \hat{E}_1 \\ \hat{E}_2 \end{bmatrix} \right\}$$

$$= \begin{bmatrix} b_{11}v_{K1}q_K/P_1 & b_{11}v_{L1}q_L/P_1 \\ \quad +b_{12}(P_2/P_1)v_{K2}q_K/P_2 & \quad +b_{12}(P_2/P_1)v_{L2}q_L/P_2 \\ b_{22}v_{K2}q_K/P_2 & b_{22}v_{L2}q_L/P_2 \\ \quad +b_{21}(P_1/P_2)v_{K1}q_K/P_1 & \quad +b_{21}(P_1/P_2)v_{L1}q_L/P_1 \end{bmatrix}$$

$$\times \left\{ \begin{bmatrix} \hat{q}_K \\ \hat{q}_L \end{bmatrix} - \begin{bmatrix} b_{11} & b_{12}P_2/P_1 \\ b_{21}P_1/P_2 & b_{22} \end{bmatrix} \begin{bmatrix} \hat{E}_1 \\ \hat{E}_2 \end{bmatrix} \right\}$$

$$= \begin{bmatrix} R_{K1}q_K/P_1 & R_{L1}q_L/P_1 \\ R_{K2}q_K/P_2 & R_{L2}q_L/P_2 \end{bmatrix} \begin{bmatrix} \hat{q}_K \\ \hat{q}_L \end{bmatrix} + \begin{bmatrix} b_{11} & b_{12}P_2/P_1 \\ b_{21}P_2/P_1 & b_{22} \end{bmatrix} - \begin{bmatrix} \hat{E}_1 \\ \hat{E}_2 \end{bmatrix}.$$

Direct and indirect TFP of the first and second industries are

$$(2.65)\quad \hat{\Pi}_1 = b_{11}\hat{E}_1 + b_{12}\frac{P_2}{P_1}\hat{E}_2 = \frac{R_{K1}q_K}{P_1}\hat{q}_K + \frac{R_{L1}q_L}{P_1}\hat{q}_L - \hat{P}_1,$$

$$(2.65')\quad \hat{\Pi}_2 = b_{22}\hat{E}_2 + b_{21}\frac{P_1}{P_2}\hat{E}_1 = \frac{R_{K2}q_K}{P_2}\hat{q}_K + \frac{R_{L2}q_L}{P_2}\hat{q}_L - \hat{P}_2.$$

A comparison of the equations (2.58) and (2.65) clearly shows that above two procedures yield exactly the same direct and indirect TFP.

CHAPTER III

EMPIRICAL MODELS

This chapter will examine how the basic methodology developed in the previous chapter can be applied to an empirical investigation of Total Factor Productivity (TFP) of Japanese and U.S. industries during the period 1963-70. The major focus of the empirical study is to quantitatively demonstrate the differences between the new and conventional measures of TFP. The differences will show how interindustry and international dependence of production costs affect TFP. For this purpose the empirical investigation will calculate six kinds of TFP indices whose differences will be employed to clarify and quantify the difference between the new and conventional measurements. A two letter title identifies each index. The first letter indicates the kind of TFP: T, I, H, M, N, and V, while the last letter identifies the country: U for the U.S. and J for Japan.

T Index

This is direct and indirect TFP incorporating U.S.-

Japanese interdependence of production costs. The index can quantify the effect of direct TFP of a Japanese (U.S.) industry on the production costs of U.S. (Japanese) industries.

The basic price equations underlying the index TJ and TU are

$$(3.1)\quad P_j^J = \sum_{i=1}^{n} P_i^J t_i^{JJ} a_{ij}^J + \sum_{i=1}^{n} P_i^U t_i^{UJ} a_{ij}^J + \sum_{i=1}^{n} P_i^R t_i^{RJ} a_{ij}^J + q_{Kj}^J k_j^J + q_{Lj}^J l_j^J,$$

and

$$(3.1')\quad P_j^U = \sum_{i=1}^{n} P_i^J t_i^{JU} a_{ij}^U + \sum_{i=1}^{n} P_i^U t_i^{UU} a_{ij}^U + \sum_{i=1}^{n} P_i^R t_i^{RU} a_{ij}^U + q_{Kj}^U k_j^U + q_{Lj}^U l_j^U \quad (j=1,\ldots,n),$$

where P_j^h = the price of the gross output of the jth industry;

t_i^{mh} = the trade coefficient of the ith industry in the hth which represent the imports from the mth country to the hth country;

a_{ij}^h = the input-output coefficient, which represents the flow of an intermediate input from ith industry to jth industry in the hth country;

k_j^h (l_j^h) = the capital (labor) input coefficient of the jth industry in the hth country.

The solution of the system in terms of endogenous prices is

$$(3.2) \quad \begin{bmatrix} P^J \\ P^U \end{bmatrix} = \begin{bmatrix} I - A'^J T^{JJ} & - A'^J T^{UJ} \\ - A'^U T^{JU} & I - A'^U T^{UU} \end{bmatrix}^{-1}$$

$$x\left\{ \begin{bmatrix} \tilde{k} \end{bmatrix} \begin{bmatrix} q_K \end{bmatrix} + \begin{bmatrix} \tilde{l} \end{bmatrix} \begin{bmatrix} q_L \end{bmatrix} + \begin{bmatrix} A'^J T^{RJ} & 0 \\ 0 & A'^U T^{RU} \end{bmatrix} \begin{bmatrix} P^R \\ P^R \end{bmatrix} \right\},$$

where P^h = a nx1 vector of price of the gross outputs in the hth country.

A'^h = a nxn matrix of a^h_{ij};

T^{mh} = a nxn diagonal matrix, in which the ith diagonal element is t^{mh}_i, a trade coefficient;

$[\tilde{k}]$ ($[\tilde{l}]$) = a 2nx2n diagonal matrix in which the first n diagonal elements are k^J_j (l^J_j), capital (labor) input coefficients in Japan and next n diagonal elements are k^U_j (l^U_j), capital (labor) input coefficients in the U.S.;

$[q_K]$ ($[q_L]$) = a 2nx1 vector, in which the first n elements are the prices of k^J_j's and next elements are the prices of k_j^U's;[27]

The growth rate of prices for Japan or the U.S. is

$$(3.3)\quad \hat{P}_j^h = \sum_{i=1}^{2n} \frac{b_{ji}^{Th} k_i^h q_{Ki}^h}{P_j^h} (\hat{b}_{ji}^{Th} + \hat{k}_i^h + \hat{q}_{Ki}^h)$$

$$+ \sum_{i=1}^{2n} \frac{b_{ji}^{Th} l_i^h q_{Li}^h}{P_j^h} (\hat{b}_{ji}^{Th} + \hat{l}_i^h + \hat{q}_{Li}^h)$$

$$+ \sum_{i=1}^{2n} \frac{b_{ji}^{Th} t_i^{Rh} P_i^h}{P_j^h} (\hat{b}_{ji}^{Th} + \hat{t}_i^{Rh} + \hat{a}_{ij}^h + \hat{P}_i^h),$$

where $h = J$ if $j = 1,\ldots,n$, and $h = U$ if $j = n+1,\ldots,2n$, where b_{ji}^{Th} is the jith element of the inverse matrix in equation (4.2). The circumflex indicate a growth rate (e.g., $\hat{k} = \frac{\partial k/\partial t}{k}$).

The TFP index TJ or TU is

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[27]Prices of capital and labor are different from one industry to another. This is because the "capital" and "labor" are composites of heterogeneous factor services, and the compositions of subcategories of these factors differ in different industries, not because the factor market is imperfect or factors are specific to industries. Each subcategory of factors has the same price in every industry, although these subcategories do not explicitly appear in the models.

$$(3.4)\quad \hat{\Pi}_j^{Th} = -\sum_{i=1}^{n} \frac{b_{ji}^{Th} k_i^h q_{Ki}^h}{P_j^h} (\hat{b}_{ji}^{Th} + \hat{k}_i^h)$$

$$-\sum_{i=1}^{n} \frac{b_{ji}^{Th} l_i^h q_{Li}^h}{P_j^h} (\hat{b}_{ji}^{Th} + \hat{l}_i^h) - \sum_{i=1}^{n} \frac{b_{ji}^{Th} a_{ij}^h t_i^{Rh} P_i^h}{P_j^h} (\hat{b}_{ji}^{Th} - \hat{t}_i^{Rh} + \hat{a}_{ij}^h),$$

where $h = J, U$; $j=1,\ldots,n$.

Imported intermediate inputs are treated as if they are primary inputs. This is because the model does not have production functions for "the rest of the world". Another important contribution of this study is to include two countries and explicitly incorporate international dependence between these countries so that a part of imported intermediate inputs are also endogenized. That is, production costs in a country is affected by TFP in other countries through international trade in intermediate inputs.

I Index

This is also direct and indirect TFP. However, it ignores U.S.-Japanese interdependence of production costs. It does not distinguish intermediate inputs imported from the partner country and the rest of the world. The derivation of T index needs a simultaneous solution of 56 equations (28 for the U.S. and Japan, respectively), while I index is derived by separately solving Japanese and American system of 28 equations. By setting $T^{JU} = T^{UJ} = 0$ in equation (3.2), T index becomes equivalent with I index, which is derived as follows:

The basic price equations underlying the index IJ and IU are

$$(3.5)\quad P_j^J = \sum_{i=1}^{n} P_i^J t_i^{JJ} a_{ij}^J + \sum_{i=1}^{n} P_i^{MJ}(1-t_i^{JJ}) a_{ij}^J + q_{Kj}^J k_j^J + q_{Lj}^J l_j^J,$$

and

$$(3.5')\quad P_j^U = \sum_{i=1}^{n} P_i^U t_i^{UU} a_{ij}^U + \sum_{i=1}^{n} P_i^{MU}(1-t_i^{UU}) a_{ij}^U + q_{Kj}^U k_j^U + q_{Lj}^U l_j^U.$$

where $j=1,\ldots,n$; and P_i^{Mh} is the price of imports of ith commodity from the rest of the world to the hth country.

The solution to equation (4.5) is

$$(3.6)\quad \left[P^J\right] = \left[I - A'^J T^{JJ}\right]^{-1}$$

$$x\{\left[\tilde{k}^J\right]\left[q_K^J\right] + \left[\tilde{l}^J\right]\left[q_L^J\right] + \left[A^J(I-T^{JJ})\right]\left[P^{MJ}\right]\}.$$

The solution to the equation (4.5') is

$$(3.6')\quad \left[P^U\right] = \left[I - A'^U T^{UU}\right]^{-1}$$

$$x\{\left[\tilde{k}^{U}\right]\left[q_K^U\right] + \left[\tilde{l}^{U}\right]\left[q_L^U\right] + \left[A^U(I-T^{UU})\right]\left[P^{MU}\right]\}.$$

where $[\tilde{k}^h]$ ($[\tilde{l}^h]$)= a vector of k_j^h, capital input coefficient;

$[q_K^h]$ ($[q_L^h]$)= a vector of the price of capital (labor) in the hth country;

P^{Mh}= a vector of the price of imports from the rest of the world (countries other than Japan and the U.S.) into the hth country.

The growth rate of the prices for Japan or the U.S. is

$$(3.7)\quad \hat{P}_j^h = \sum_{i=1}^{n} \frac{b_{ji}^{Ih} k_i^h q_{Ki}^h}{P_j^h} (\hat{b}_{ji}^{Ih} + \hat{k}_i^h + \hat{q}_{Ki}^h)$$

$$+ \sum_{i=1}^{n} \frac{b_{ji}^{Ih} l_i^h q_{Li}^h}{P_j^h} (\hat{b}_{ji}^{Ih} + \hat{l}_i^h + \hat{q}_{Li}^h)$$

$$+ \sum_{i=1}^{n} \frac{b_{ji}^{Ih} a_{ij}^h (1-t_i^{hh}) P_i^{Mh}}{P_j^h} (\hat{b}_{ji}^{Ih} + \frac{-t_i^{hh}}{1-t_i^{hh}} \hat{t}_i^{hh} + \hat{a}_{ij}^h + \hat{P}_i^{Rh}),$$

where h = J or U; j=1,...,n; and b_{ji}^{Ih} is the jith element of the inverse matrix in equation (3.6) in the case of h = J and equation (3.6') in the case of h = U.

The TFP index IJ or IU is

$$(3.8)\quad \hat{\Pi}_j^{Ih} = -\sum_{i=1}^{n} \frac{b_{ji}^{Ih} k_i^h q_{Ki}^h}{P_j^h} (\hat{b}_{ji}^{Ih} + \hat{k}_i^h) - \sum_{i=1}^{n} \frac{b_{ji}^{Ih} l_i^h q_{Ki}^h}{P_j^h} (\hat{b}_{ji}^{Ih} + \hat{l}_j^h)$$

$$- \sum_{i=1}^{n} \frac{b_{ji}^{Ih} a_{ij}^h (1-t_i^{hh}) P_i^{Mh}}{P_j^h} \left(\hat{b}_{ji}^{Ih} + \frac{-t_i^{hh}}{1-t_i^{hh}} \hat{t}_i^{hh} + \hat{a}_{ij}^h \right),$$

where $h = J, U$; and $j=1,\ldots,n$.

H Index

This is also direct and indirect TFP. However, imported and domestically produced intermediate inputs are not distinguished. All intermediate inputs are treated as if they are domestically produced. Thus, all intermediate inputs are eliminated from the system. Only capital and labor contribute to the direct and indirect TFP. On the other hand, in the case of T index the imports of intermediate inputs from third countries also contribute to TFP and in the case of I index all imported intermediate inputs contribute to the TFP.

The basic price equations underlying the index HJ and HU are

$$(3.9)\quad P_j^J = \sum_{i=1}^{n} P_i^J a_{ij}^J + q_{Kj}^J k_j^J + q_{Lj}^J l_j^J,$$

and

$$(3.9')\quad P_j^U = \sum_{i=1}^{n} P_i^U a_{ij}^U + q_{Kj}^U k_j^U + q_{Lj}^U l_j^U \quad (j=1,\ldots,n)$$

The solutions of these systems in terms of endogenous prices are

$$(3.10)\quad \left[P^J\right] = \left[I - A'^J\right] x\{\left[k^J\right]\left[q_K^J\right] + \left[l^J\right]\left[q_L^J\right]\},$$

and

$$(3.10')\quad \left[P^U\right] = \left[I - A'^U\right] x\{\left[k^U\right]\left[q_K^U\right] + \left[l^U\right]\left[q_L^U\right]\}.$$

The growth rate of the prices for Japan or the U.S. is

$$(3.11)\quad \hat{P}_j^h \doteq \sum_{i=1}^{n} \frac{b_{ji}^{Hh} k_i^h q_{Ki}^h}{P_j^h} (\hat{b}_{ji}^{Hh} + \hat{k}_j^h + \hat{q}_{Kj}^h)$$

$$+ \sum_{i=1}^{n} \frac{b_{ji}^{Hh} l_i^h q_{Li}^h}{P_j^h} (\hat{b}_{ji}^{Hh} + \hat{l}_j^h + \hat{q}_{Lj}^h),$$

where h = J or U; j=1,...,n; and b_{ji}^{Hh} is the jith element of the inverse matrix in equation (3.10) in the case of h = J and equation (3.10') in the case of h = U.

The TFP index HJ or HU is

$$(3.12)\quad \hat{\Pi}_j^{Hh} = - \sum_{i=1}^{n} \frac{b_{ji}^{Hh} k_i^h q_{Ki}^h}{P_j^h} (\hat{b}_{ji}^{Hh} + \hat{k}_j^h)$$

$$- \sum_{i=1}^{n} \frac{b_{ji}^{Hh} l_i^h q_{Li}^h}{P_j^h} (\hat{b}_{ji}^{Hh} + \hat{l}_j^h),$$

where h = J, U; j=1,...n.

The difference between I and H indices is not easily seen from the comparison of equations (3.8) and (3.12). The difference is two-fold. First, each element of the Leontief inverse is different. Although it is always true that [I-A] ≤ [I-AT], it may or may not be true that $[I-A]^{-1} \leq [I-AT]^{-1}$, where A and T are matrices of I-O coefficients and trade coefficients, respectively. Second, only equation (3.8) includes the term representing the effect of the change in productivity of imported intermediate inputs. The sign of the last term depends on the sign of the growth rate of three coefficients. Thus, this general comparison of these two indices does not help understanding the implication of the differences. It may worth examining a special case of the recursive model used in chapter II.

I index is based on the model which distinguishes imported and domestically produced intermediate inputs. Price equations of each industry are

$$(3.13)\quad P_1 = q_K v_{K1} + q_L v_{L1} + P_2^M m_2 a_{21} + P_2 (1-m_2) a_{21}$$

$$(3.14)\quad P_2 = q_K v_{K2} + q_L v_{L2},$$

where P_j is the price of gross output of jth industry; P_j^M is the price of imports in the jth industry; q_K and q_L are prices of capital and labor inputs, respectively; v_{Kj} and v_{Lj} are the quantity of capital and labor inputs per unit of output, respectively; and m_2 is the import ratio of the second industry. Totally differentiating these two equations, we obtain

$$(3.15)\quad \hat{P}_1 = \frac{q_K v_{K1}}{P_1}(\hat{q}_K + \hat{v}_{K1}) + \frac{q_L v_{L1}}{P_2}(\hat{q}_L + \hat{v}_{L1})$$

$$+ \frac{P_2^M m_2 a_{21}}{P_1}(\hat{P}_2^M + \hat{m}_2 + \hat{a}_{21})$$

$$+ \frac{P_2(1-m_2)a_{21}}{P_1}(\hat{P}_2 + \frac{-m_2}{1-m_2}\hat{m}_2 + \hat{a}_{21}),$$

$$(3.16)\quad \hat{P}_2 = \frac{q_K v_{K2}}{P_2}(\hat{q}_K + \hat{v}_{K2}) + \frac{q_L v_{K2}}{P_2}(\hat{q}_L + \hat{v}_{L2}),$$

where a circumflex indicates the growth rate of the variable.

Direct TFP of each industry is

$$(3.17)\quad \hat{E}_1 = -\frac{q_K v_{K1}}{P_1}\hat{v}_{K1} - \frac{q_L v_{L1}}{P_1}\hat{v}_{L1} - \frac{P_2^M m_2 a_{21}}{P_1}(\hat{m}_2 + \hat{a}_{21})$$

$$+ \frac{P_2 m_2 a_{21}}{P_1}\hat{m}_2 - \frac{P_2(1-m_2)a_{21}}{P_1}\hat{a}_{21},$$

$$(3.18)\quad \hat{E}_2 = -\frac{q_K v_{K2}}{P_2}\hat{v}_{K2} - \frac{q_L v_{L2}}{P_2}\hat{v}_{L2}.$$

By substituting equation (3.18) into equation (3.17) direct and indirect TFP of the first industry can be derived as follows:

$$(3.19)\quad \hat{E}_1 + \frac{P_2(1-m_2)a_{21}}{P_1}\hat{E}_2 = -\frac{q_K v_{K1}}{P_1}\hat{v}_{K1} - \frac{q_{L1} v_{L1}}{P_1}\hat{v}_{L1}$$

$$+ \left(\frac{P_2 m_2 a_{21}}{P_1} + \frac{P_2^M m_2 a_{21}}{P_1}\right)\hat{m}_2$$

$$+ \left(\frac{P_2^M m_2 a_{21}}{P_1} + \frac{P_2(1-m_2)a_{21}}{P_1}\right)\hat{a}_{21}$$

$$- \frac{P_2(1-m_2)a_{21}}{P_1}\left(\frac{q_K v_{K2}}{P_2}\hat{v}_{K2} + \frac{q_L v_{L2}}{P_2}\hat{v}_{L2}\right).$$

On the other hand, H index is based on the model which treats every intermediate inputs as if they are all domestically produced, the price equations of these two industries are

$$(3.20)\quad P_1^* = q_K v_{K1} + q_L v_{L1} + P_2 a_{21},$$

$$(3.21)\quad P_2^* = q_K v_{K2} + q_L v_{L2}.$$

Totally differentiating these equations,

$$(3.22)\quad \hat{P}_1^* = \frac{q_K v_{K1}}{P_1}(\hat{q}_K + \hat{v}_{K1}) + \frac{q_L v_{L1}}{P_1}(\hat{q}_L + \hat{v}_{L1})$$

$$+ \frac{P_2 a_{21}}{P_1}(\hat{P}_2 + \hat{a}_{21}),$$

$$(3.23)\quad \hat{P}_2^* = \frac{q_K v_{K2}}{P_2}(\hat{q}_K + \hat{v}_{K2}) + \frac{q_L v_{L2}}{P_2}(\hat{q}_L + \hat{v}_{L2}).$$

Direct TFP of these two industries are

$$(3.24)\quad \hat{E}_1 = - \frac{q_K v_{K1}}{P_1}\hat{v}_{K1} - \frac{q_L v_{L1}}{P_1}\hat{v}_{L1} - \frac{P_2 a_{21}}{P_1}\hat{a}_{21},$$

$$(3.25)\quad \hat{E}_2 = - \frac{q_K v_{K2}}{P_2}\hat{v}_{K2} - \frac{q_L v_{L2}}{P_2}\hat{v}_{L2}.$$

Direct and indirect TFP of the first industry is

$$(3.26)\quad \hat{\Pi}_1^H = \hat{E}_1 + \frac{P_2 a_{21}}{P_1}\hat{E}_2 = -\frac{q_K v_{K1}}{P_1}\hat{v}_{K1} - \frac{q_L v_{L1}}{P_1}\hat{v}_{L1}$$

$$-\frac{P_2 a_{21}}{P_1}(\hat{a}_{21} + \frac{q_K v_{K2}}{P_2}\hat{v}_{K2} + \frac{q_L v_{L2}}{P_2}\hat{v}_{L2}).$$

The difference between I and H indices is

$$(3.27)\quad \hat{\Pi}_1^I - \hat{\Pi}_1^H = (\frac{P_2 m_2 a_{21}}{P_1} - \frac{P_2^M m_2 a_{21}}{P_1})\hat{m}_2$$

$$+ (\frac{P_2 a_{21}}{P_1} - \frac{P_2^M m_2 a_{21}}{P_1} - \frac{P_2(1-m_2)a_{21}}{P_1})\hat{a}_{21}$$

$$+ (\frac{P_2 a_{21}}{P_1} - \frac{P_2(1-m_2)a_{21}}{P_1})(\frac{q_K v_{K2}}{P_2}\hat{v}_{K2} + \frac{q_L v_{L2}}{P_2}\hat{v}_{L2})$$

$$= \frac{(P_2 - P_2^M)m_2 a_{21}}{P_1}(\hat{m}_2 + \hat{a}_{21})$$

$$+ \frac{P_2 m_2 a_{21}}{P_1}(\frac{q_K v_{K1}}{P_2}\hat{v}_{K1} + \frac{q_L v_{L1}}{P_2}\hat{v}_{L1}),$$

The second term represents indirect TFP of the first industry originating in the second industry. The effect of indirect TFP is the stronger, the larger are import ratios,

m_2 and input-output coefficient, a_{21}. Presumably, the difference between H and I index is zero when m_2 is zero. The sign of the first term depends on two factors: the relative magnitude of P_2, the domestic price of the output of the second industry, and P_2^M, the import price of the same good, on the one hand, and the relative magnitude and signs of $\hat{m}_2$, the rate of change in import ratio and $\hat{a}_{21}$, the rate of change in input-output coefficients, on the other. If the domestic price is higher than the import price, import substitution ($\hat{m}_2>0$) and the decline in the productivity of intermediate inputs ($\hat{a}_{21}>0$) make the difference positive. If the domestic price is lower than the import price, exactly the opposite is true. The difference between H and I indices reflects the effect of using cheaper intermediate inputs. It suggests that if the domestically produced (imported) inputs are cheaper, using less imported (domestically produced) inputs reduce production costs.

It should be emphasized that the difference is not based on a comparison between an economy in which only domestic TFP can be utilized and the economy which can also use foreign TFP. thus, the difference between H and I indices should not be interpreted as the difference in direct and indirect TFP between an autarky and an open economy. It is safer to regard the difference as an estimation error due to the failure to distinguish properly the difference between domestically produced and imported intermediate inputs. At the same time, it suggests that the accurate estimation of the price differential between domestic and foreign inputs is crucial to the TFP analysis incorporating international dependence of production costs.

M Index

This is direct TFP. Productivity of direct inputs is calculated. Imported and domestically produced intermediate inputs are treated as separate inputs.

The basic price equation underlying index MJ and MU are exactly the same as those of IJ and IU respectively. See equations (3.5) and (3.5'). The growth rate of the price for Japan or the U.S. is

$$(3.28)\quad \hat{P}_j^h = \sum_{i=1}^{n} \frac{t_i^{hh} a_{ij}^h P_i^{Mh}}{P_j^h} (\hat{t}_i^{hh} + \hat{a}_{ij}^h + \hat{P}_i^{Mh})$$

$$+ \sum_{i=1}^{n} \frac{(1-t_i^{hh}) a_{ij}^h P_i^h}{P_j^h} \left(\frac{-t_i^{hh}}{1-t_i^{hh}} \hat{t}_i^{hh} + \hat{a}_{ij}^h + \hat{P}_i^h\right)$$

$$+ \sum_{i=1}^{n} \frac{q_{Ki}^h k_i^h}{P_j^h} (\hat{k}_i^h + \hat{q}_{Ki}^h) + \sum_{i=1}^{n} \frac{q_{Lj}^h l_j^h}{P_j^h} (\hat{l}_j^h + \hat{q}_{Lj}^h),$$

where h = J or U; j=1,...,n.

TFP index MJ or MU is

$$(3.29)\quad \hat{E}_j^{Mh} = -\sum_{i=1}^{n} \frac{t_i^{hh} a_{ij}^h P_i^{Mh}}{P_j^h} (\hat{t}_i^{hh} + \hat{a}_{ij}^h)$$

$$- \sum_{i=1}^{n} \frac{(1-t_i^{hh}) a_{ij}^h P_i^h}{P_j^h} \left(\frac{-t_i^{hh}}{1-t_i^{hh}} \hat{t}_i^{hh} + \hat{a}_{ij}^h\right)$$

$$- \sum_{i=1}^{n} \frac{q_{Ki}^h k_i^h}{P_j^h} \hat{k}_i^h - \sum_{i=1}^{n} \frac{q_{Li}^h l_i^h}{P_j^h} \hat{l}_i^h,$$

where h = J or U; j=1,...,n.

N Index

This is also direct TFP. It is different from M index; N index does not distinguish domestically produced and imported inputs. All intermediate inputs are treated as if they are produced domestically. Thus, the difference between M and N indices is quite analogous with that between I and H indices. Let us first derive N index itself.

The basic price equation underlying index NJ and NU are exactly the same as those of HJ an HU respectively. See equations (3.9) and (3.9').

The growth rate of the price for Japan or the U.S. is

$$(3.30)\quad \hat{P}_j^h = \sum_{i=1}^{n} \frac{P_i^h a_{ij}^h}{P_j^h} (\hat{a}_{ij}^h + \hat{P}_i^h)$$

$$+ \sum_{i=1}^{n} \frac{q_{Ki}^h k_i^h}{P_j^h} (\hat{k}_i^h + \hat{q}_{Ki}^h) + \sum_{i=1}^{n} \frac{q_{Li}^h l_i^h}{P_j^h} (\hat{l}_i^h + \hat{q}_{Li}^h),$$

where h = J or U; j=1,...,n.

TFP index NJ or NU is

$$(3.31)\quad \hat{E}_j^{Nh} = - \sum_{i=1}^{n} \frac{P_i^h a_{ij}^h}{P_j^h} \hat{a}_{ij}^h - \sum_{i=1}^{n} \frac{q_{Ki}^h k_i^h}{P_j^h} \hat{k}_i^h - \sum_{i=1}^{n} \frac{q_{Li}^h l_i^h}{P_j^h} \hat{l}_i^h,$$

where h = J or U; j=1,...,n.

Comparing E_j^{Mh} and E_j^{Nh} the following relationship between the M and N indices can easily be derived:

$$(3.32)\quad \hat{E}_j^M - \hat{E}_j^N = \sum_{i=1}^{n} \frac{t_i a_{ij}}{P_j} \hat{t}_i \, [P_i - P_i^M]$$

$$+ \sum_{i=1}^{n} \frac{t_i a_{ij}}{P_j} \hat{a}_{ij} \, [P_i - P_i^M].$$

This difference, which is caused by the difference in the treatment of imports, increases as the price difference between import price (P_i^M) and domestic price (P_i), and as the growth rate of trade coefficient ($\hat{t}_i$) and input-output coefficient ($\hat{a}_{ij}$) increases. Here, superscripts of countries are omitted for the simplicity of exposition.

V Index

This is value added TFP. No intermediate inputs are incorporated

The basic price equation underlying the index VJ or VU is

$$(3.33)\ P_j^{Vh} = q_{Kj}^h k_j^{Vh} + q_{Lj}^h l_j^{Vh},$$

where h = J or U; j=1,...,n; P_j^{Vh} is the price of the value added in the jth industry in the hth country; k_j^{Vh} (l_j^{Vh}) is the capital-value added (labor-value added) ratio in the jth industry in the hth country.

The growth rate of the price is

$$(3.34)\ \hat{P}_j^{Vh} = \sum_{i=1}^{n} \frac{q_{Ki}^h k_i^{Vh}}{P_j^{Vh}} (\hat{k}_i^{Vh} + \hat{q}_{Ki}^h) + \sum_{i=1}^{n} \frac{q_{Li}^h l_i^{Vh}}{P_j^{Vh}} (\hat{l}_i^{Vh} + \hat{q}_{Li}^h),$$

where h= J or U; j=1,...,n.

A TFP index VJ or VU is

$$(3.35)\ \hat{E}_j^{Vh} = \sum_{i=1}^{n} \frac{q_{Ki}^h k_i^{Vh}}{P_j^h} \hat{k}_i^{Vh} + \sum_{i=1}^{n} \frac{q_{Li}^h l_i^{Vh}}{P_j^h} \hat{l}_i^{Vh},$$

where h = J or U; j=1,...,n.

There is a systematic relation between value added TFP and gross output TFP. Comparing E_j^{Vh} and E_j^{Nh} (equations (3.35) and (3.31)), the following relationship can be obtained.[28]

$$(3.36)\quad \hat{E}_j^V = \hat{E}_j^N \frac{P_j X_j}{P_j^V},$$

where j=1,...,n; P_j^V is the price of value added. V_j is real value added; P_j is the price of a gross output; and X_j is the quantity of the gross output. Since normally $P_j X_j > P_j^V V_j$, value added TFP is usually considerably larger than gross output TFP. Again, country superscripts are omitted for simplicity.

The last indices, VJ and VU, use value added functions rather than gross output production function. Indeed, previous TFP studies have often used value added functions, whose dependent variable is real value added and whose independent variables are primary inputs. Since the use of the value added function eliminates intermediate inputs from TFP analysis, effects of interindustry and international relationships of production costs cannot be examined. Thus, it is worthwhile to examine the validity of using the value added function because it provides a justification for my study in which intermediate inputs play essential role.

Recent TFP studies have been skeptical about the use

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[28]For the proof see, e.g. Gollop [1979]. Gollop and Roberts [1981] and Gollop [1983] examine a more complicated case, which includes imported intermediate inputs.

of value added functions and the concept of real value added. For example, Lave [1966] entirely dismissed the notion of real value added. Most economists seem to agree with Arrow [1974], who suggested that "without the separability assumption,[29] however, it is hard to assign any definite meaning to real value added and probably the best thing to say is that the concept should not be used when capital and labor are not separable from materials in production." (p. 5.)

Nominal value added is normally defined as the nominal gross output minus nominal intermediate inputs. It is perhaps natural to define real value added as the difference between real gross output and real intermediate inputs. Other definitions are possible, but under this definition the familiar identity of national income accounting (aggregate production and aggregate expenditure are identically equal) holds not only in nominal terms, but in real terms. Indeed this is the only definition of real value added which is widely used.

Actual calculation of real value added defined in this way usually uses the double deflation method, i.e., gross output and intermediate inputs are separately deflated. The double deflation method sometimes results in negative real value added even when the corresponding nominal value added is positive. However, this is a deficiency of an index

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[29]The separability assumption will be discussed in detailed later.

number, in particular a Laspeyres index, and does not necessarily mean real value added is a meaningless concept.[30] Indeed, the "true index" of real value added will never be negative as long as nominal value added is positive.[31]

The real issue for studies of TFP is whether or not real value added defined in this way can be a function of primary inputs alone so that real value added is independent of intermediate inputs. The answer is in general no. Necessary and sufficient conditions for real value added to be independent of intermediate inputs and for its Divisia index to be unique and path independent are:

1. The value marginal products of intermediate inputs are equal to their prices.

2. In the production function primary inputs and technical change or TFP are jointly separable with intermediate inputs, i.e., the function can be written as a "nested" form, $X = X(f(V,t), M)$, where X is a gross output; V is a vector of primary inputs; t is a shift parameter

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[30]David [1962, 1966], Hansen [1974, 1975], and Sims [1969] have discussed the issues of the double deflation method and concept of real value added.

[31]The formal definition of the "true index" of real value added is

$$F(V^1, V^0 \mid P) = f(V^1, P)/f(V^0, P)$$

where $f(V^t, P)$ is the maximum nominal value added producible from primary input (V) under the prices (P) of gross output and intermediate inputs in the period t. See Sato [1976], p. 438.

representing TFP; and M is a vector of intermediate inputs.[32]

3. The production function is subject to constant returns to scale in f(.) and M.

If the elasticity of substitution between f(.) and M is either zero or infinite, the first condition is redundant.

Generally, however, the separability assumption is regarded with skepticism. First, Berndt et al [1973] demonstrated that separability requires that the marginal rate of substitution between any pair of arguments within the value-added sub-function, f(.), is independent of intermediate inputs, thus implies that all the Allen partial elasticity of substitution between intermediate inputs and primary inputs are equal. This assumption seems to be too restrictive even as a rough approximation.

Secondly, while many researchers have empirically tested the separability of production functions, a few have failed to reject the separability hypothesis.[33]

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[32]The separability issue was first analyzed by Sono [1945] and Leontief [1947] independently.

[33]An exception is Ohta [1978]. Griliches and Ringstadt [1971] concluded that the value-added function is better than the gross output function from their empirical study, which does not directly test the separability hypothesis. Maddala [1979] claimed that "within the limited class of functions considered here (viz. Cobb-Douglas, generalized Leontief, homogeneous trans-log , and homogeneous quadratic) differences in the functional form produce negligible differences in measures of multi-factor productivity." (P. 109.) This may suggest the validity of the separability assumption, since, for example, Cobb-Douglas production functions are a priori separable, while trans-log production functions are not necessarily separable. Berndt and Christensen [1973] is an early test

Thus, the elimination of intermediate inputs is generally not appropriate. Moreover, even if the above three conditions are met, it is not necessarily clear that the value added function should be used rather than the gross output production function.

These two functions analyze different objects. The value added function analyzes a process of generating value added from primary inputs, or the addition of value to intermediate inputs. On the other hand. The gross output production function analyzes the whole production process in a particular industry. All inputs are accounted for: intermediate inputs as well as primary inputs. The choice between the value added function and the gross output production function should reflect such difference in the objectives of analysis. It is worth noting that real value added is a meaningful concept as long as the first condition mentioned above holds. Other conditions are needed only to guarantee the uniqueness and path independence of the Divisia index of real value added.

Therefore, separability is not necessarily an essential issue in an analysis of TFP. The more important point here is that the exclusion of intermediate inputs makes impossible an analysis of interindustry and international relations of TFP. Recent studies of TFP have made progress by introducing intermediate inputs. However,

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rejecting the separability hypothesis. See Fuss et al. [1978] for a survey of these tests.

they are still not adequate because intermediate inputs are treated completely symmetrically with primary inputs. The most substantial contribution of this study is, therefore to make a clear distinction between primary and intermediate inputs. The latter are endogenous variables in the sense that they are produced by some sectors in the model, while the former are exogenous variables since they are introduced into the model from outside without explaining how they are produced.[34]

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[34] If the model is further elaborated to include investment functions, capital input will be endogenized. Even though population growth itself is difficult to model, accumulation of human capital may also be endogenized. The model of this study, though, remains static so that all primary inputs are treated as exogenous variables.

CHAPTER IV

EMPIRICAL RESULTS

This chapter will report major empirical results for 28 industries in the U.S. and Japan, and discuss their policy implications. For detailed results see Tables 4.4 through 4.15, which are located at the end of this chapter beginning on Page 81. See Statistical Appendix A for the description of each industry and Statistical Appendix B for data sources.

Six kinds of TFP indices are calculated. Each index is symbolized by a two letter title. The last letter identifies the country: U for the U.S. and J for Japan. The first letter identifies the kind of TFP: T, I, M, N, and V. Indices T, I, and H represent direct and indirect TFP. Indices M, N, and V are direct TFP indices. Only T index incorporates Japanese-American interdependence of production costs. Indices I and M both distinguish imported and domestically produced intermediate inputs, while H and N both treat all intermediate inputs as domestically produced. Index V is value added TFP and the only index which totally ignores the existence of intermediate inputs. See Chapter II for the detail of the definition and derivation of these indices.

Empirical Findings

Detailed results of TFP indices themselves are presented in the first column of Tables 4.4-4.15. Explanations will be given for the results of the variables presented in other columns of these tables.

TABLE 4.1

SUMMARY RESULTS OF TFP INDICES

Index	Mean*	S.D.
TJ	36.698	17.182
TU	15.202	11.214
IJ	31.824	17.392
IU	15.159	11.216
HJ	38.844	19.140
HU	11.605	8.8759
MJ	13.026	12.842
MU	7.1800	8.1082
NJ	13.217	12.808
NU	5.3193	6.0212
VJ	45.640	39.091
VU	27.022	66.297

*Means are percentage

Table 4.1 summarizes the estimation of TFP indices. "Mean" is the arithmetic average of indices of 28 industries. "S.D." stands for standard deviation. TFP indices are calculated as cumulative (not average annual) percentage growth rate between 1963 and 1970. For example, TJ increased 36.698 % from 1963 to 1970, i.e., TJ in 1970 was about 1.37 times higher than that in 1963.

The mean TFP indices are all positive. Major Japanese indices have more than twice as large a mean and standard deviation as U.S. indices. Detailed industry-by-industry examination of each TFP also concluded that in almost all industries TFP indices are positive in both countries and Japanese indices are greater than U.S. indices.

These are consistent with the results of previous studies on TFP of these two countries. Japanese economic growth has been accompanied by high rate of TFP improvement. This is because Japan has taken advantage of the situation as a "late comer" in economic development, that is, it could have used relatively new and efficient technology borrowed from abroad, particularly from the U.S., without worrying about depreciating old capital equipments. This is more true in the post war period. Since World War II disrupted technology transfer from abroad to Japan and destroyed a huge amount of the capital stock of Japanese industries, technological progress after the war has been particularly rapid. Indeed, the growth rate of TFP is positively correlated with the growth rate of gross output.

On the other hand, industries in which the Japanese and U.S. difference in TFP growth rate is high include motor vehicle, primary metals, and electric machinery. The differential growth of TFP may have increased the competitiveness of Japanese exports of these industries vis-a-vis U.S. exports and may have become the source of trade frictions in the later period.

So far, we have not explicitly distinguished the different kinds of TFP. Indeed, interindustry patterns of the growth rate of six different TFP indices are quite similar.[35] However, there are differences between the six indices. The difference between T and I indices is that the T index includes the effect of TFP of U.S. industries on the production cost of Japanese industries and vice versa, while the I index does not.

As expected the T index is larger than I index in most industries. On average TJ is 1.15 times greater than IJ and TU is 1.003 times greater than IU. This asymmetry may be due to the fact that the U.S. share in Japanese imports is much greater than the Japanese share in U.S. imports.

In the U.S., the difference in T and I is high particularly in motor vehicles, transportation equipment, and primary metals. It is interesting that the U.S. industries which receive great benefit from imports of Japanese intermediate inputs have faced severe Japanese competition. At the same time this evidence suggests that the Local Content Legislation discussed in the U.S. Congress may harm rather than protect the U.S. auto industry,

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[35]Correlation coefficients between TFP indices exceed 0.85 in most cases in both countries.

contrary to its intention.

The difference between the I and M indices is that the former includes indirect TFP as well as direct one, while the latter includes only direct TFP. In almost all cases I index exceeds M index. On average IJ is about 2.4 times large as MJ and IU is about 2.1 times as large as MU. The indirect TFP of an industry, which originates in other industries, quite significantly contributes to the reduction in production costs of the industry concerned. The difference is large in manufactures, in particular, natural resource intensive industries such as rubber and lumber, while it is small in service industries such as financial institution and utilities. The former has, in general a low value added ratio while the latter has a high ratio.

A comparison of I and H indices reveals an interestingly sharp contrast between the U.S. and Japan. IJ is smaller than HJ in every industry, while IU is greater than HU in every industry. There is a temptation to draw a policy implication from this evidence that the Japanese economy has enjoyed a greater indirect TFP under autarky than in an open economy since the I index takes into account the existence of imports of intermediate inputs, while H index is calculated assuming no imports of intermediate inputs.

However, as pointed out in Chapter III (pp. 51-57), this implication is misleading because the difference between I and H indices is not caused by the difference between TFP which originated in domestic industries alone (in the case of H index) and that originated both in domestic and foreign industries (in the case of I index). Neither index incorporates foreign TFP. The difference is caused by the price differential between domestic and imported intermediate goods and whether the industry substitutes imports of intermediate inputs by its domestic production or replaces the domestic production by imports. In Japan domestic prices are higher than import prices in most industries, while in the U.S., exactly the opposite is true. Note that these "prices" are arithmetic average of price indices in 1963 and 1970 since the actual calculation of TFP indices are discrete approximations of Divisia index. Thus, the differences in the "prices" represent the differences in the rates of price increase in industries.

Besides TFP indices themselves the study calculates two other variables: (1) the proportion of TFP in the price change of gross outputs; and (2) the contribution of each input to TFP.

<u>The proportion of TFP in the price change</u>

The definition of the proportion is

$$100 \times \frac{\log\ [TFP(1970)/TFP(1963)]}{\log\ [P(1970)/P(1963)]}$$

where P is the price of gross output. Since both TFP and P are expressed as indices and 1963 is the base year, TFP(1963) = P(1963) = 1. The change in price of gross output can be decomposed into changes in prices of inputs and TFP. In general prices of outputs and inputs both increase, but an improvement in TFP counteracts the inflation in input prices and suppresses the output price inflation.

TABLE 4.2

PROPORTION OF TFP IN THE PRICE CHANGE

Index	Mean*	S.D.
TPJ	315.95	567.36
TPU	-10.046	660.17
IPJ	292.10	536.89
IPU	-9.9804	658.72
HPJ	339.27	604.36
HPU	-32.791	558.90
MPJ	146.72	310.43
MPU	4.5304	388.22
NPJ	147.75	311.86
NPU	-15.571	314.18
VPJ	431.45	867.38
VPU	76.087	1388.8

*Means are percentage

Table 4.2 summarizes the results concerning the proportion of TFP in the price change. The second column of Table 4.4-4.15 shows that the Japanese proportion exceeds 100%, while the U.S. proportion is smaller than 100% in most industries. TFP seems to play a larger role in reducing production costs in Japan than the U.S.

It is interesting that the Japanese and U.S. proportions are negatively correlated. Indeed, this is the only correlation between Japanese and U.S. industries. Japan and the U.S. seem to have quite different interindustry patterns of TFP. The rate of change in price of gross outputs is negatively and significantly correlated with all kinds of TFP. Thus, it is clearly shown that TFP plays an important role in reducing production costs.

Contributions of factors of production

The change in TFP can also be decomposed into contributions of factors of production. The contribution of a factor is defined as a product of the distributive share of each factor and the rate of change in the productivity of that factor. For example, value added TFP is defined as

$$\hat{E}_j^V = \theta_{Kj}(\hat{V}_j - \hat{K}_j) + \theta_{Lj}(\hat{V}_j - \hat{L}_j),$$

where θ_{Kj} (θ_{Lj}) is the distributive share of capital (labor) in the jth industry; K_j, L_j, V_j are quantity of capital input, labor input, and real value added in the jth industry, respectively. A circumflex indicates the growth rate of the variable. The contribution of capital to TFP is $(\theta_{kj}(\hat{V}_j - \hat{K}_j)/\hat{E}_j)$ x 100 and that of labor is $(\theta_{Lj}(\hat{V}_j -$

$\hat{L}_j)/\hat{E}_j)$ x 100. In other words, TFP growth rate is the sum of contributing factors and each contribution is expressed as a percentage. Thus, the sum of the contribution of each factor defined here is always either 100% (in the case of positive TFP, or - 100% (in the case of negative TFP). As can be seen shortly, it is very rare that the contributions of all factors have the same sign. Thus, absolute value of some factors may exceed 100%.

See Table 4.3 for the summary results of contributing factors. In this table "Index" identifies the kind of TFP to which production factors contribute. Each column shows the contribution of each factor as a percentage: K for capital, L for labor, D for domestically produced intermediate inputs, and M for imported intermediate inputs. Detailed results are presented in the third to the last columns of Tables 4.4-4.15. In these tables the contributions are symbolized by three letter titles. The first letter identifies the kind of TFP and the last letter identifies the country. The middle letter idenfifies the factor contributing to TFP: L for labor; K for capital; M for imported intermediate inputs; and D for domestically produced intermediate inputs.

<u>Contribution of labor</u>. As expected almost no industry has a negative contribution of labor. The sign of labor's contribution and the sign of TFP coincide in more than 90%

TABLE 4.3

CONTRIBUTIONS OF PRODUCTION FACTORS (%)

Index	K	L	D	M
TJ	-24.498	116.94	-	-6.7311
TU	-50.038	79.591	-	32.571
IJ	-30.596	127.71	-	-11.396
IU	-49.464	77.175	-	58.004
HJ	-21.444	107.16	-	-
HU	-42.264	120.84	-	-
MJ	-80.843	185.38	-27.689	-12.565
MU	-17.217	106.21	-74.083	56.516
NJ	-86.308	189.26	-38.665	-
NU	-18.284	156.86	-74.288	-
VJ	-89.019	153.30	-	-
VU	-21.310	92.739	-	-

K: Capital, L: labor, D: domestically produced intermediate inputs, M: imported intermediate inputs. All figures are percentage

of the cases. No other contribution of factor reveals such coincidence.

Labor contributes most to TFP among factors in both countries. The contribution of labor is higher in Japan than in the U.S. Since labor's contribution is the product of the distributive share and the growth rate of labor productivity, and the Japanese distributive share of labor is much smaller than the U.S. one in most industries,[36] this Japanese-U.S. difference is due to the differential growth

[36] On average the Japanese distributive share of labor is about two-thirds and the U.S. share is about three-fourths.

rate of labor productivity between these two countries. In other words, Japanese TFP growth has more heavily relied on labor productivity growth than the U.S. This tendency is more obvious in the case of direct and indirect TFP than of direct TFP.

<u>Contribution of capital</u>. On average the contribution is negative for all kind of TFP. The number of industries with negative contribution of capital is about twice as many as that with positive contribution. This evidence is consistent with the "stylized facts of the modern economic growth" (Kaldor[1961]): capital-labor ratio and labor productivity increased, while the capital-output ratio does not have a particular trend.

Previous studies (e.g., Kuroda and Imamura [1981]) dealing with direct TFP indicate that the tendency of low or negative growth rate of capital productivity is stronger in Japan than the U.S. This study confirm this observation for direct TFP. However, for direct and indirect TFP, capital's contribution is more negative in the U.S. than Japan. Thus, the U.S. seems to use more capital as indirect inputs than Japan.

<u>Contribution of intermediate inputs</u>. Since this study always treats capital and labor as primary inputs, these two factors appear in every formula of TFP. However, the contribution of intermediate inputs may not appear in the

formula to calculate TFP depending on the definition of the TFP. In the case of the T index, only intermediate inputs imported from the countries other than the U.S. and Japan appear as contributors. In the case of I index all imported intermediate inputs appear. In the case of H index, contribution of intermediate inputs never appears. In the case of M index imported and domestically produced intermediate inputs are treated as separate contributors. In the case of N index imported intermediate inputs do not appear as contributors. In the case of V index no intermediate input appears.

As far as imported intermediate inputs are concerned, Japan and the U.S. reveal contrasting results. Three kinds of contribution of imported intermediate inputs, TM, IM, MM, all show positive (negative) indices in almost every industry in the U.S. (Japan). This evidence suggests that Japanese industries have increased their dependence on imported inputs, while U.S. industries have developed import substitution with respect to intermediate inputs. This is partly because the import demand ratio has increased in about two thirds of the industries, while the ratio in the U.S. has decreased in about 60% of the industries. Japanese economic growth has been heavily dependent on imported raw materials. This tendency is stronger in the case of direct TFP rather than direct and indirect TFP.

A comparison of MDJ and MDU indices reveals that the productivity of domestically produced intermediate inputs increased in Japan and decreased in the U.S. in almost 70% of industries. On the other hand, both NDJ and NDU shows that the number of industries which increased their productivity of domestically produced intermediate inputs and decreased them is about the same. Considering that the calculation of ND index treats all intermediate inputs as produced domestically, the sign of the index indicates whether or not intermediate inputs as a whole are saved in the production process.

Thus, we can conclude that although it is not clear whether the productivity of intermediate inputs increased or decreased in both countries, the share of imported inputs clearly increased in Japan and decreased in the U.S. An interesting result is that the growth rate of the proportion of real intermediate inputs in the gross outputs is positively correlated with the TFP growth rate in both countries. This may suggest that TFP growth is accompanied by the production structure becoming more roundabout.

There are some other interesting findings concerning the correlation between TFP indices and variables representing the characteristics of each industry. TFP indices are negatively correlated with the growth rate of real imports and the real import demand ratio in Japan. This seems to support the popular hypothesis that the change in TFP is an important determinant of comparative advantage. Another finding is that in the U.S. the growth rate of the real capital-labor ratio is positively correlated with various TFP indices This is consistent with the view that TFP increase is accompanied by capital accumulation.

Summary of Results and a Comparison with Previous Studies

The empirical analysis of this study is based on data of the Japanese and U.S. economies. TFP indices are calculated as the growth rate between 1963 and 1970 for 28 industries. Major empirical results are summarized as follows:

(1) All kinds of TFP indices are positive in almost all industries. Japanese indices are larger and have greater standard deviation than U.S. indices.

(2) Direct and indirect TFP is on average more than twice greater than direct TFP in both countries.

(3) The incorporation of the Japanese and U.S. interdependence of production costs increases TFP indices in both countries.

(4) The rate of change in prices of gross outputs is negatively correlated with all kinds of TFP indices in both countries. TFP changes are greater than the price changes in Japan, while just the opposite is true in the U.S. The proportions of TFP change in price change of Japanese and U.S. industries are negatively correlated. This is the only significant correlation between Japanese and U.S. indices.

(5) Labor input is the most important contributor to TFP

change. This is more so in Japan than in the U.S.

(6) Capital productivity has decreased in about two thirds of industries in both countries. On average the contribution of capital input to TFP is more negative in Japan than the U.S.

(7) It is not clear whether productivity of intermediate inputs increased or decreased. However, import substitution proceeded in the U.S., while the replacement of domestic production by imports occurred in Japan with respect to intermediate inputs.

A brief comparison with previous empirical studies on TFP is in order. It limits its scope to the works which cover, at least partly, the period 1963-70, explicitly include intermediate inputs as factors of production, and deal with the Japanese and U.S. economies or both. Hulten and Nishimizu [1978] and Ezaki [1978] have investigated the Japanese economy. Kuroda and Imamura [1981] compared their own study on the Japanese economy with the work by Gollop and Jorgenson [1980], which analyzed the U.S. economy. Norsworthy and Malmquist [1983] conducted their own comparative study of the Japanese and U.S. economies.

Common features of these studies are: (a) the Japanese growth rate of TFP is much higher than the U.S. rate. (b) Japanese economic growth has been accompanied by rapid increase in labor productivity and the capital-labor ratio, and relatively stable or slightly declining productivity of intermediate inputs. The U.S. economy reveals similar patterns, though the rate of change has been much slower.

Jorgenson and Nishimizu [1978] compared the level (not the growth rate) of TFP in the Japanese and U.S. economies. Their conclusion (p. 723) is consistent with the above features:

> In 1952 the Japanese level of technology was merely one-fourth of the corresponding U.S. level....by 1973 and also in 1974 the aggregate level of technology in Japan stood ahead of that in the United States....For the period 1960-74 the dramatic reduction in the difference between U.S. and Japanese total output was due to the substantial increase in Japanese capital input relative to U.S. capital input and to the closing of the gap between Japanese and U.S. technology.

These results seem a close resemblance with the results of this study. In any event, these previous studies measured direct TFP; they never calculated direct and indirect TFP, so that a comparison concerning points (2) and (3) mentioned above is not possible.

TABLE 4.4

DETAILED RESULTS FOR JAPANESE T INDEX (%)

	Industry	TJ	TPJ	TMJ	TKJ	TLJ
1	AGRICULTURE	44.02	128.48	-1.56	-27.45	129.02
2	MINING	56.36	296.76	-4.23	4.15	100.09
3	CONSTRUCT.	37.67	112.09	-7.12	-10.25	117.37
4	FOOD	35.94	190.39	-0.16	-19.72	119.88
5	TEXTILE	51.98	447.07	-1.89	-2.88	104.77
6	APPAREL	45.19	314.62	-4.81	-9.47	114.28
7	LUMB. WOOD	31.39	83.08	-6.51	-29.33	135.84
8	FURNITURE	25.09	63.80	-13.64	-30.29	143.93
9	PAPER PULP	41.18	195.01	-1.61	-3.08	104.70
10	PRINTING	18.67	79.38	-5.13	-74.22	179.35
11	CHEMICALS	55.47	3028.32	3.16	13.70	83.14
12	PETROLEUM	33.39	321.28	-18.63	24.75	93.88
13	RUBBER	19.34	86.22	-3.83	-83.45	187.29
14	LEATHER	36.30	152.93	-4.63	-8.61	113.24
15	GLASS	33.50	152.40	-14.23	-0.91	115.14
16	PRI. METALS	36.53	114.35	-17.95	15.48	102.48
17	METAL PROD.	34.59	122.36	-9.45	-9.90	119.35
18	MACHINERY	63.18	366.10	-1.00	14.32	86.68
19	ELECT.MACH.	58.10	344.88	-1.64	23.52	78.12
20	TRANSP.EQU.	56.70	976.66	-1.25	7.89	93.36
21	MOTOR VEHC.	41.36	501.55	-3.34	3.42	99.92
22	INSTRUMENTS	51.13	285.98	-3.95	9.42	94.53
23	MIS. MANUF.	26.54	96.14	-6.12	-44.88	151.00
24	UTILITIES	33.77	233.76	-11.94	35.88	76.06
25	TRAN. COMM.	37.56	77.53	-5.36	-3.28	108.64
26	WHL. RETAIL	39.68	108.68	-2.57	-10.11	112.67
27	FINAN.INST.	-12.50	-25.68	-5.91	-184.19	90.10
28	SERVICES	-4.59	-7.67	-33.17	-286.45	219.63

TABLE 4.5

DETAILED RESULTS FOR JAPANESE I INDEX (%)

	Industry	IJ	IPJ	IMJ	IKJ	ILJ
1	AGRICULTURE	41.49	122.24	-3.11	-29.90	133.00
2	MINING	46.96	255.58	-5.86	-0.39	106.25
3	CONSTRUCT.	31.23	95.29	-10.98	-16.79	127.77
4	FOOD	32.88	176.27	-3.79	-21.81	125.59
5	TEXTILE	48.31	421.01	-2.41	-4.66	107.07
6	APPAREL	41.49	292.85	-5.15	-12.48	117.63
7	LUMB. WOOD	27.75	74.53	-16.40	-32.09	148.49
8	FURNITURE	21.69	55.95	-24.32	-35.67	159.99
9	PAPER PULP	37.09	178.37	-2.47	-5.93	108.40
10	PRINTING	15.46	66.67	-8.40	-93.80	202.21
11	CHEMICALS	51.23	2838.70	3.81	12.38	83.81
12	PETROLEUM	29.10	284.79	-30.48	28.40	102.08
13	RUBBER	16.42	74.14	-7.71	-100.65	208.36
14	LEATHER	31.72	136.07	-6.39	-13.00	119.39
15	GLASS	28.57	132.54	-20.26	-4.18	124.44
16	PRI. METALS	32.29	102.76	-22.90	15.22	107.67
17	METAL PROD.	30.68	110.21	-11.64	-13.94	125.57
18	MACHINERY	58.42	343.98	0.62	12.84	86.54
19	ELECT.MACH.	54.08	325.49	-2.20	23.31	78.89
20	TRANSP.EQU.	56.06	967.64	-1.64	8.03	93.62
21	MOTOR VEHC.	40.82	495.92	-1.55	3.09	98.46
22	INSTRUMENTS	47.57	269.44	-5.61	8.75	96.86
23	MIS. MANUF.	23.05	84.73	-11.08	-53.42	164.50
24	UTILITIES	30.11	211.42	-16.71	37.81	78.90
25	TRAN. COMM.	6.05	14.27	-53.68	-170.10	323.78
26	WHL. RETAIL	30.99	87.80	-5.11	-20.35	125.46
27	FINAN.INST.	-14.18	-29.39	-7.96	-164.25	72.21
28	SERVICES	-6.25	-10.53	-35.71	-213.11	148.82

TABLE 4.6

DETAILED RESULTS FOR JAPANESE H INDEX (%)

	Industry	HJ	HPJ	HKJ	HLJ
1	AGRICULTURE	44.62	129.95	-61.18	161.18
2	MINING	52.76	281.28	-1.94	101.94
3	CONSTRUCT.	38.20	113.43	-20.80	120.80
4	FOOD	41.14	213.67	-18.81	118.81
5	TEXTILE	56.62	479.21	-6.78	106.78
6	APPAREL	47.61	328.56	-17.41	117.41
7	LUMB. WOOD	36.97	95.73	-56.66	156.66
8	FURNITURE	27.54	69.32	-59.31	159.31
9	PAPER PULP	43.72	205.10	-6.10	106.10
10	PRINTING	19.11	81.07	-71.52	171.52
11	CHEMICALS	59.59	3207.78	5.95	94.05
12	PETROLEUM	54.64	486.08	2.77	97.23
13	RUBBER	21.88	96.47	-45.15	145.15
14	LEATHER	38.29	160.11	-20.01	120.01
15	GLASS	37.83	169.26	-8.60	108.60
16	PRI. METALS	44.47	135.09	-1.75	101.75
17	METAL PROD.	37.39	130.83	-13.78	113.78
18	MACHINERY	65.61	377.15	10.19	89.81
19	ELECT.MACH.	61.44	360.63	17.58	82.42
20	TRANSP.EQU.	63.17	1064.62	6.42	93.57
21	MOTOR VEHC.	47.49	563.03	1.29	98.71
22	INSTRUMENTS	54.51	301.29	6.54	93.47
23	MIS. MANUF.	29.38	105.21	-33.21	133.21
24	UTILITIES	39.17	265.50	10.38	89.62
25	TRAN. COMM.	9.30	21.63	-167.82	267.82
26	WHL. RETAIL	32.78	92.20	-24.74	124.74
27	FINAN.INST.	-13.26	-27.36	129.49	-229.49
28	SERVICES	-4.35	-7.25	-155.48	55.48

TABLE 4.7

DETAILED RESULTS FOR JAPANESE M INDEX (%)

	Industry	MJ	MPJ	MDJ	MMJ	MKJ	MLJ
1	AGRICULTURE	31.93	97.59	-5.37	-1.63	-30.58	137.58
2	MINING	34.61	197.30	17.57	1.87	-11.35	91.90
3	CONSTRUCT.	10.40	34.70	2.01	-7.78	-28.52	134.28
4	FOOD	10.54	62.15	51.48	-4.67	-23.85	77.04
5	TEXTILE	16.46	162.72	46.99	-5.17	-9.04	67.22
6	APPAREL	12.63	100.39	60.89	-12.35	-32.80	84.26
7	LUMB. WOOD	4.62	13.75	-25.27	-54.58	-33.17	213.01
8	FURNITURE	3.93	10.99	-148.23	-38.13	-88.57	374.93
9	PAPER PULP	13.22	70.23	29.08	2.33	-6.36	74.96
10	PRINTING	-1.08	-5.06	-414.60	-41.88	-922.34	1278.83
11	CHEMICALS	26.78	1628.57	54.22	4.92	1.35	39.50
12	PETROLEUM	14.12	147.29	129.32	-59.29	5.28	24.69
13	RUBBER	-2.82	-13.93	4.74	-4.20	-357.66	257.11
14	LEATHER	8.12	38.55	0.21	-7.61	-4.79	112.19
15	GLASS	14.43	71.12	56.38	-33.91	-26.45	103.98
16	PRI. METALS	9.30	32.65	17.38	-25.13	15.04	92.71
17	METAL PROD.	12.83	49.71	13.85	-1.65	-39.51	127.30
18	MACHINERY	30.53	199.18	21.44	2.58	8.99	66.99
19	ELECT.MACH.	26.32	175.94	16.98	-0.43	29.85	53.61
20	TRANSP.EQU.	26.95	518.76	11.31	-1.95	14.08	76.56
21	MOTOR VEHC.	13.38	181.88	28.75	4.77	-4.56	71.04
22	INSTRUMENTS	25.10	155.06	24.52	-3.41	10.40	68.49
23	MIS. MANUF.	1.73	7.00	-280.47	-45.63	-392.94	819.04
24	UTILITIES	19.48	142.96	2.36	-2.13	53.20	46.57
25	TRAN. COMM.	-3.43	-8.50	-479.93	-13.97	-87.93	481.84
26	WHL. RETAIL	28.54	81.65	-19.79	-0.43	1.10	119.12
27	FINAN.INST.	-8.81	-17.73	106.07	1.51	-259.90	52.32
28	SERVICES	-15.08	-26.66	-97.18	-3.86	-42.58	43.62

TABLE 4.8

DETAILED RESULTS FOR JAPANESE N INDEX (%)

	Industry	NJ	NPJ	NDJ	NKJ	NLJ
1	AGRICULTURE	32.20	98.31	-6.21	-30.35	136.56
2	MINING	34.77	198.09	19.76	-11.30	91.54
3	CONSTRUCT.	10.57	35.24	-4.13	-28.08	132.21
4	FOOD	11.41	66.98	50.64	-22.13	71.49
5	TEXTILE	17.08	168.45	43.80	-8.73	64.93
6	APPAREL	13.06	103.58	50.12	-31.79	81.67
7	LUMB. WOOD	5.76	17.05	-45.04	-26.75	171.78
8	FURNITURE	4.34	12.11	-159.84	-80.37	340.21
9	PAPER PULP	13.46	71.41	32.54	-6.25	73.71
10	PRINTING	-0.91	-4.25	-524.12	-1097.32	1521.44
11	CHEMICALS	26.95	1637.57	59.37	1.35	39.28
12	PETROLEUM	13.03	136.57	67.68	5.69	26.63
13	RUBBER	-2.54	-12.54	11.70	-397.32	285.63
14	LEATHER	8.26	39.18	-5.66	-4.72	110.38
15	GLASS	14.50	71.40	22.78	-26.35	103.57
16	PRI. METALS	9.33	32.74	-7.44	15.00	92.44
17	METAL PROD.	12.96	50.19	13.03	-39.13	126.10
18	MACHINERY	30.57	199.41	24.11	8.98	66.91
19	ELECT.MACH.	26.51	177.06	17.08	29.66	53.27
20	TRANSP.EQU.	27.02	520.07	9.59	14.04	76.37
21	MOTOR VEHC.	13.40	182.18	33.64	-4.56	70.92
22	INSTRUMENTS	25.25	155.91	21.54	10.34	68.11
23	MIS. MANUF.	1.98	8.03	-271.48	-342.57	714.05
24	UTILITIES	19.38	142.27	-0.25	53.45	46.80
25	TRAN. COMM.	-3.20	-7.90	-523.70	-94.59	518.29
26	WHL. RETAIL	28.71	82.08	-19.60	1.09	118.51
27	FINAN.INST.	-8.77	-17.65	108.51	-261.07	52.56
28	SERVICES	-15.00	-26.50	-101.04	-42.84	43.88

TABLE 4.9

DETAILED RESULTS FOR JAPANESE V INDEX (%)

	Industry	VJ	VPJ	VKJ	VLJ
1	AGRICULTURE	45.17	131.27	-32.06	132.06
2	MINING	60.25	313.08	-1.75	101.75
3	CONSTRUCT.	40.01	118.01	-29.90	129.90
4	FOOD	38.64	202.60	3.76	96.24
5	TEXTILE	74.61	595.34	1.35	98.65
6	APPAREL	50.96	347.48	-21.34	121.34
7	LUMB. WOOD	20.68	57.21	-54.61	154.61
8	FURNITURE	12.78	34.27	-122.68	222.68
9	PAPER PULP	64.09	280.03	6.41	93.59
10	PRINTING	-2.39	-11.24	-1091.42	991.42
11	CHEMICALS	91.81	4469.74	42.11	57.89
12	PETROLEUM	115.09	853.98	59.76	40.24
13	RUBBER	-7.79	-39.57	-357.31	257.31
14	LEATHER	34.72	147.18	-6.29	106.29
15	GLASS	39.23	174.58	-16.22	116.22
16	PRI. METALS	48.34	144.80	11.14	88.86
17	METAL PROD.	36.10	126.96	-34.90	134.90
18	MACHINERY	103.21	530.10	19.45	80.55
19	ELECT.MACH.	107.72	550.43	37.80	62.20
20	TRANSP.EQU.	113.53	1649.41	16.59	83.41
21	MOTOR VEHC.	56.63	650.14	15.04	84.96
22	INSTRUMENTS	86.25	430.67	16.48	83.52
23	MIS. MANUF.	5.52	21.96	-508.87	608.87
24	UTILITIES	38.88	263.88	53.38	46.62
25	TRAN. COMM.	-5.31	-13.27	-258.75	158.75
26	WHL. RETAIL	42.84	115.97	-5.25	105.25
27	FINAN.INST.	-10.95	-22.30	-174.26	74.26
28	SERVICES	-22.69	-41.98	-60.18	-39.82

TABLE 4.10

DETAILED RESULTS FOR U.S. T INDEX (%)

	Industry	TU	TPU	TMU	TKU	TLU
1	AGRICULTURE	18.39	92.35	27.64	-20.21	92.57
2	MINING	8.47	46.94	48.28	14.59	37.13
3	CONSTRUCT.	4.25	13.54	126.24	-66.25	40.00
4	FOOD	15.77	76.64	39.20	-12.64	73.43
5	TEXTILE	39.60	-2330.72	18.59	10.12	71.29
6	APPAREL	23.44	160.70	26.79	-2.08	75.29
7	LUMB. WOOD	26.22	127.52	40.03	1.08	58.88
8	FURNITURE	14.16	71.29	44.26	-13.40	69.14
9	PAPER PULP	16.28	113.07	60.46	-14.94	54.48
10	PRINTING	15.08	87.53	31.09	-1.20	70.11
11	CHEMICALS	24.87	-1843.22	24.45	11.42	64.14
12	PETROLEUM	51.86	1584.05	63.52	11.73	24.76
13	RUBBER	22.00	416.40	19.47	5.26	75.27
14	LEATHER	10.86	51.44	37.61	-23.84	86.23
15	GLASS	9.16	52.06	79.20	-21.77	42.57
16	PRI. METALS	3.36	13.27	288.44	-169.09	-19.35
17	METAL PROD.	10.88	52.43	62.25	-26.58	64.33
18	MACHINERY	12.16	65.50	30.99	-20.34	89.34
19	ELECT.MACH.	17.98	240.21	19.24	-12.00	92.75
20	TRANSP.EQU.	6.01	31.11	37.45	-98.88	161.43
21	MOTOR VEHC.	-1.33	-10.23	-295.61	-601.75	206.15
22	INSTRUMENTS	11.52	75.03	20.28	-22.78	102.50
23	MIS. MANUF.	13.32	86.86	40.92	-24.98	84.06
24	UTILITIES	19.83	281.12	26.93	28.29	44.78
25	TRAN. COMM.	11.54	74.19	10.29	-24.39	114.10
26	WHL. RETAIL	10.94	49.98	9.55	-14.39	104.84
27	FINAN.INST.	10.09	42.89	9.07	11.13	79.80
28	SERVICES	-1.04	-3.23	-34.63	-303.17	168.54

TABLE 4.11

DETAILED RESULTS FOR U.S. I INDEX (%)

	Industry	IU	IPU	IMU	IKU	ILU
1	AGRICULTURE	18.38	92.29	27.73	-20.02	92.29
2	MINING	8.41	46.64	47.97	15.15	36.89
3	CONSTRUCT.	4.28	13.65	134.90	-67.60	32.71
4	FOOD	15.76	76.59	39.69	-12.50	72.81
5	TEXTILE	39.47	-2324.17	21.01	9.49	69.49
6	APPAREL	23.27	159.68	31.76	-3.39	71.63
7	LUMB. WOOD	26.47	128.62	44.44	0.34	55.22
8	FURNITURE	14.23	71.66	48.88	-14.24	65.36
9	PAPER PULP	16.31	113.29	62.58	-15.24	52.66
10	PRINTING	15.06	87.40	31.60	-1.18	69.58
11	CHEMICALS	24.81	-1839.15	24.78	11.42	63.80
12	PETROLEUM	51.81	1582.90	63.61	11.77	24.62
13	RUBBER	21.92	415.00	20.63	5.03	74.34
14	LEATHER	10.79	51.11	40.30	-24.40	84.10
15	GLASS	9.16	52.06	81.76	-22.38	40.62
16	PRI. METALS	3.28	12.96	305.65	-177.16	-28.49
17	METAL PROD.	10.81	52.11	66.63	-28.25	61.62
18	MACHINERY	12.07	65.04	32.35	-20.87	88.52
19	ELECT.MACH.	17.84	238.42	20.43	-12.50	92.07
20	TRANSP.EQU.	5.81	30.11	32.01	-99.80	167.79
21	MOTOR VEHC.	-1.40	-10.78	293.79	-574.81	181.02
22	INSTRUMENTS	11.41	74.35	21.16	-23.21	102.05
23	MIS. MANUF.	13.25	86.42	44.23	-25.82	81.59
24	UTILITIES	19.82	281.03	26.89	28.38	44.73
25	TRAN. COMM.	11.50	73.96	9.74	-24.16	114.43
26	WHL. RETAIL	10.92	49.87	9.24	-14.16	104.91
27	FINAN.INST.	10.07	42.77	8.73	11.63	79.64
28	SERVICES	-1.05	-3.28	31.62	-296.51	164.89

TABLE 4.12

DETAILED RESULTS FOR U.S. H INDEX (%)

	Industry	HU	HPU	HKU	HLU
1	AGRICULTURE	15.07	76.79	-30.75	130.75
2	MINING	5.66	31.81	30.76	69.24
3	CONSTRUCT.	0.93	3.01	-91.49	191.49
4	FOOD	11.98	59.23	-16.58	116.58
5	TEXTILE	36.09	-2152.37	26.00	74.00
6	APPAREL	20.86	144.63	8.51	91.49
7	LUMB. WOOD	19.11	95.76	15.02	84.98
8	FURNITURE	10.49	53.70	-31.88	131.88
9	PAPER PULP	11.00	78.23	-14.50	114.50
10	PRINTING	12.56	73.72	9.73	90.27
11	CHEMICALS	21.34	-1605.61	23.30	76.70
12	PETROLEUM	28.97	964.52	42.35	57.65
13	RUBBER	19.82	378.67	18.86	81.14
14	LEATHER	9.21	43.96	-105.51	205.51
15	GLASS	4.54	26.39	-42.36	142.36
16	PRI. METALS	-2.27	-9.22	-129.66	29.66
17	METAL PROD.	7.12	34.91	-107.80	207.80
18	MACHINERY	10.12	55.04	-60.82	160.82
19	ELECT.MACH.	16.01	215.65	-33.44	133.44
20	TRANSP.EQU.	4.66	24.29	-130.80	230.80
21	MOTOR VEHC.	-3.23	-25.15	-153.77	53.77
22	INSTRUMENTS	10.28	67.30	-67.68	167.68
23	MIS. MANUF.	10.49	69.30	-82.59	182.59
24	UTILITIES	15.87	228.90	32.56	67.44
25	TRAN. COMM.	10.52	67.95	-54.26	154.26
26	WHL. RETAIL	10.05	46.09	-44.52	144.52
27	FINAN.INST.	9.05	38.64	10.67	89.33
28	SERVICES	-1.37	-4.29	-202.75	102.75

TABLE 4.13

DETAILED RESULTS FOR U.S. M INDEX (%)

	Industry	MU	MPU	MDU	MMU	MKU	MLU
1	AGRICULTURE	8.51	44.70	20.22	22.85	-36.04	92.97
2	MINING	3.08	17.51	-278.38	85.10	139.93	153.36
3	CONSTRUCT.	-2.33	-7.66	-14.94	98.94	-74.35	-109.64
4	FOOD	4.11	21.07	-15.49	56.31	3.75	55.42
5	TEXTILE	18.80	-1203.47	36.39	18.11	1.69	43.81
6	APPAREL	4.72	35.17	-47.63	61.48	-18.61	104.76
7	LUMB. WOOD	14.56	74.47	4.04	47.18	2.98	45.80
8	FURNITURE	4.46	23.51	-53.78	71.57	-21.14	103.35
9	PAPER PULP	6.05	44.01	-41.21	90.10	-13.54	64.65
10	PRINTING	7.73	46.42	-1.13	26.14	3.68	71.31
11	CHEMICALS	12.75	-996.19	33.14	15.84	6.00	45.03
12	PETROLEUM	38.12	1224.48	19.64	68.35	3.41	8.60
13	RUBBER	9.79	195.51	29.23	12.54	-3.27	61.50
14	LEATHER	2.07	10.20	-159.52	82.38	-37.59	214.74
15	GLASS	2.72	15.96	-117.43	171.58	-20.34	66.18
16	PRI. METALS	-1.18	-4.79	-681.57	491.47	-60.35	150.45
17	METAL PROD.	6.53	32.09	-1.64	46.63	-11.26	66.27
18	MACHINERY	6.80	37.55	-23.38	18.74	-7.35	111.99
19	ELECT.MACH.	11.00	151.55	18.03	9.23	-10.99	83.74
20	TRANSP.EQU.	1.04	5.49	-493.44	-7.09	-192.05	792.58
21	MOTOR VEHC.	-4.43	-34.72	-47.87	23.66	-95.67	19.88
22	INSTRUMENTS	6.26	41.74	-113.80	12.92	9.71	191.17
23	MIS. MANUF.	5.33	36.07	-24.50	46.66	-33.85	111.69
24	UTILITIES	14.15	205.65	10.43	25.17	31.27	33.12
25	TRAN. COMM.	7.59	49.66	-10.77	-3.03	-26.57	140.37
26	WHL. RETAIL	7.73	35.84	-5.74	-0.31	-16.20	122.25
27	FINAN.INST.	7.88	33.84	19.74	-7.37	54.14	33.49
28	SERVICES	-2.80	-8.81	-132.96	-2.71	-59.48	95.15

TABLE 4.14

DETAILED RESULTS FOR U.S. N INDEX (%)

	Industry	NU	NPU	NDU	NKU	NLU
1	AGRICULTURE	7.19	37.97	32.97	-42.43	109.46
2	MINING	1.26	7.24	-609.55	338.53	371.02
3	CONSTRUCT.	-3.67	-12.17	15.91	-46.84	-69.07
4	FOOD	2.65	13.70	8.98	5.77	85.25
5	TEXTILE	17.39	-1120.07	51.11	1.82	47.08
6	APPAREL	3.70	27.73	-9.27	-23.60	132.87
7	LUMB. WOOD	10.21	53.23	31.76	4.16	64.07
8	FURNITURE	2.68	14.23	-35.85	-34.94	170.79
9	PAPER PULP	3.23	23.82	5.58	-25.01	119.43
10	PRINTING	6.66	40.20	13.41	4.25	82.33
11	CHEMICALS	11.59	-910.53	44.17	6.56	49.27
12	PETROLEUM	20.18	696.93	78.89	5.99	15.12
13	RUBBER	9.26	185.51	38.63	-3.45	64.82
14	LEATHER	1.54	7.62	-137.13	-50.32	287.46
15	GLASS	-0.22	-1.28	-670.22	-252.90	823.12
16	PRI. METALS	-4.32	-17.77	-124.29	-16.27	40.56
17	METAL PROD.	5.18	25.61	31.07	-14.10	83.03
18	MACHINERY	6.26	34.66	-13.35	-7.96	121.31
19	ELECT.MACH.	10.51	145.16	24.05	-11.48	87.43
20	TRANSP.EQU.	0.90	4.77	-591.57	-221.16	912.73
21	MOTOR VEHC.	-4.82	-37.87	-30.51	-87.72	18.23
22	INSTRUMENTS	5.92	39.55	-112.01	10.25	201.77
23	MIS. MANUF.	4.26	28.98	3.09	-42.14	139.04
24	UTILITIES	11.44	168.31	21.31	38.21	40.47
25	TRAN. COMM.	7.46	48.89	-15.60	-26.99	142.58
26	WHL. RETAIL	7.54	34.98	-8.65	-16.60	125.24
27	FINAN.INST.	7.83	33.63	11.82	54.48	33.70
28	SERVICES	-2.87	-9.02	-134.82	-58.06	92.88

TABLE 4.15

DETAILED RESULTS FOR U.S. V INDEX (%)

	Industry	VU	VPU	VKU	TLU
1	AGRICULTURE	20.83	103.50	-20.46	120.46
2	MINING	6.35	35.56	27.09	72.91
3	CONSTRUCT.	-5.23	-17.47	-63.58	-36.42
4	FOOD	17.91	86.20	16.92	83.08
5	TEXTILE	63.60	-3438.60	14.49	85.51
6	APPAREL	13.78	98.56	-16.96	116.96
7	LUMB. WOOD	33.52	158.33	17.03	82.97
8	FURNITURE	10.59	54.19	-18.33	118.33
9	PAPER PULP	16.55	114.85	1.72	98.28
10	PRINTING	16.24	93.79	8.64	91.36
11	CHEMICALS	36.37	-2574.77	26.19	73.81
12	PETROLEUM	356.68	5758.61	39.38	60.62
13	RUBBER	24.75	463.14	5.33	94.67
14	LEATHER	4.90	23.86	-48.59	148.59
15	GLASS	5.89	33.97	-5.39	105.39
16	PRI. METALS	-3.24	-13.23	-110.14	10.14
17	METAL PROD.	15.57	73.42	-2.82	102.82
18	MACHINERY	14.10	75.27	-8.44	108.44
19	ELECT.MACH.	24.59	319.36	-6.13	106.13
20	TRANSP.EQU.	2.30	12.13	-245.44	345.44
21	MOTOR VEHC.	-12.37	-101.26	-104.27	4.27
22	INSTRUMENTS	11.47	74.69	-15.94	115.94
23	MIS. MANUF.	13.45	87.64	-29.71	129.71
24	UTILITIES	31.22	422.26	54.32	45.68
25	TRAN. COMM.	11.52	74.03	-30.93	130.93
26	WHL. RETAIL	11.58	52.73	-17.47	117.47
27	FINAN.INST.	17.10	70.38	61.24	38.76
28	SERVICES	-3.40	-10.70	-124.43	24.43

CHAPTER V

CONCLUSIONS

Theoretical Background

This study proposed a new measure of Total Factor Productivity (TFP). The novelty of the measure is as follows:

a. The conventional method of measuring TFP is to calculate how the direct input requirement per unit of output changes. Thus, the calculated TFP may be called direct TFP. On the other hand, the method proposed here measures how direct and indirect input requirement per unit of output changes. The calculated TFP may be called direct and indirect TFP. Direct and indirect input requirements are calculated by multiplying a matrix of direct input requirements from the left of the Leontief inverse. This new method is a combination of input-output analysis and TFP analysis. Although both are well-known methodologies, the combination of them is an original contribution of this study.

b. Direct TFP measures how production and cost functions of each industry shift, while direct and indirect

TFP measures how the production costs of an industry are affected directly by a shift of the cost function of the own industry and indirectly by the shift of cost functions of other industries which supply intermediate inputs to the industry concerned. In other words, the direct and indirect TFP of an industry is a weighted average of the direct TFP (originated in the own industry) and indirect TFP (originated in other industries). Note that these other industries include foreingn industries. TFP changes occurred in industries abroad affect production costs of industries in the own country.

c. The conventional method of TFP analysis has failed to recognize the fundamental difference between a primary input and an intermediate input: the latter is an endogenous variable in a sense that it is produced in some industry, while the former is an exogenous variable since it is given to the model without explaining how it is produced. A measurement of TFP can be regarded as a comparative static experiment, which measures how the change in exogenous variables (TFP) affects endogenous variables (prices of outputs), holding other exogenous variables (prices of primary inputs) constant. Thus, the distinction between primary and intermediate inputs is essential for measuring direct and indirect TFP.

In actual calculations TFP is derived as a residual by subtracting the rate of change in prices of gross output from a weighted average of the rate of change in prices of primary inputs. This is because TFP is not observable, while prices of gross outputs are observable. Therefore, TFP looks like an endogenous variable. However, it is important to recognize that the model does not explain why TFP changes. A more sophisticated model is necessary to endogenize TFP.[37]

d. Previous TFP analysis considered only direct input, while this study also considers indirect inputs. Indirect inputs are embodied in intermediate inputs used in the industry concerned. In other words, the new method replaces a change in the price of intermediate inputs by a change in prices of primary inputs and TFP used in the other industries which supply the intermediate goods to the industry concerned. Eventually this replacement process completely eliminates all intermediate inputs from the model.

The only exceptions are imported intermediate inputs, which are by definition produced abroad, and hence are treated as if they are primary inputs. If input-output tables of all countries or the table of "rest of the world" are available, no intermediate input appears in the model. Presumably, such tables do not exist. This study uses Japanese and U.S. input-output tables connected through matrices of trade flows between these two countries. Thus, the interdependence of production costs between Japan and

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[37]For instance, Binswinger and Ruttan [1970] summarize recent developments in studies on induced technical change.

the U.S. is incorporated although imports from countries other than these two countries are treated as primary inputs.

Empirical Results

The empirical analysis of this study is based on data for the Japanese and U.S. economies. TFP indices are calculated as the growth rate between 1963 and 1970 for 28 industries. Major empirical results are summarized as follows:

1. All kinds of TFP indices are positive in almost all industries. Japanese indices are larger and have greater standard deviation than U.S. indices. This evidence reflects that compared with the U.S. industries the Japanese industries have experienced more rapid technical change and each Japanese industry has enjoyed greater benefit of technical changes which occurred in other industries, as reductions in production costs, through the purchase of intermediate inputs. This is a popular notion concerning Japanese economic growth. The tendency of Japanese TFP indices to be higher than the U.S. ones is particularly evident in such industries as motor vehicle and primary metals, which have faced serious problems concerning competition with Japanese exports. The differential growth rate of TFP may be one of the most important factors creating trade frictions between these two countries.

2. Direct and indirect TFP is on average more than twice as great as direct TFP in both countries. The new method of measuring TFP contributes to analyzing the effects of TFP improvement on production costs because the above evidence indicates that direct TFP measured by the conventional method can capture less than half of the ultimate effects of TFP on cost reduction.[38]

3. The incorporation of Japanese and U.S. interdependence of production costs increased TFP indices in both countries. It is interesting that U.S. industries such as motor vehicle and primary metals, which have suffered from Japanese competition, reveal relatively large gains from indirect TFP embodied in their imports of intermediate inputs form Japan.[39]

4. The rate of change in prices of gross outputs is negatively correlated with all kinds of TFP indices in both countries. TFP changes are greater than the price changes, while just the opposite is true in the U.S. The proportion of TFP change in price change of Japanese industries and U.S. industries are negatively correlated. This is the only significant correlation between Japanese and U.S.

[38]However, it is not accurate to claim that the previous method "underestimates" TFP since they calculate direct TFP, which does not intend to measure the ultimate effect of TFP on production costs of each industry.

[39]Although the method used in this study does not analyze the imports as final demand; it focuses on imports of intermediate inputs, Japanese high competitiveness in these products, both as final and intermediate inputs is obvious from casual observations.

industries. The Japanese and U.S. economies have quite different industrial patterns of TFP growth.

5. Labor input is the most important contributor to TFP change. This is more so in Japan than the U.S. Japanese TFP growth has relied more heavily on the growth rate of labor productivity compared to the U.S.

6. Capital productivity has decreased in about two thirds of the industries in both countries. On average the contribution of capital input to TFP is more negative in Japan than the U.S. Japanese economic growth has been accompanied by heavy capital accumulation.

7. It is not clear whether productivity of intermediate inputs increased or decreased. However, import substitution proceeded in the U.S., while the replacement of domestic production by imports occurred in Japan for intermediate inputs.

Further Studies

One obvious way to extend this study is to estimate cost functions of each industry by time series data and flexible functional forms such as the trans-log.[40] Then the

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[40]Christensen et al. [1973] first derived trans-log production functions. Diewert [1976] proved that a linearly homogeneous trans-log production function or unit cost function is the only differentiable linear homogeneous function that is exact for the Tornqvist discrete form of quantity Divisia index. Thus, the Divisia index of TFP used in this study implicitly assumes trans-log production function as its background.

assumptions of constant returns to scale and Hicks neutrality of technical change are not necessary any more.[41] The model can estimate not only the degree of change in TFP, but also the degree of bias in TFP improvement.[42] It also makes possible the distinction between the effect of TFP changes and economies of scale.[43]

There are, however, several difficulties in this extension. First, estimation of I-O table for each year to generate time series data of input-output coefficients is difficult and costly. Second, simultaneous equation bias, multicollinearity and other serious econometric problems may arise. Finally, trans-log cost functions have at least $1+n+n^2/2$ terms, where n is the number of production factors. Thus, the estimation of trans-log functions has inherent difficulty due to the shortage of the degree of freedom.

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[41]There is a fundamental difficulty to estimate without specifying the form of production functions, the degree of the biases of technical changes as demonstrated by Sato [1970] and Diamond et al. [1978] in their Impossibility Theorem.

[42]Kuroda et al. [1982] and Jorgenson and Fraumeni [1981] measure biases of technical change using trans-log cost functions for Japanese and U.S. economy, respectively. Norsworthy and Malmquist [1983] compare the estimates of biased technical change between the U.S. and Japan. Ezaki [1978] uses the RAS method developed by Stone and Brown [1962] instead of trans-log functions in the estimation of the biases.

[43]Chun and Mountain [1983] developed a method to distinguish economies of scale and TFP changes. They concluded that, on average, TFP is about 0.95% per annum under the assumption of constant return to scale, while it is 0.33 % per annum without the assumption. See Greene [1983] for methodological issues of estimation of biases of technical change and economies of scale.

Another interesting extension is to apply the model to an empirical investigation of the Heckscher-Ohlin model, in particular, an examination of the Leontief paradox found by Leontief [1953]. For one thing, Horiba [1974] analyzed the validity of the factor content version of the H-O theorem for any arbitrary pair of countries when more than two countries exist. Although some empirical investigations of the H-O theorem have analyzed bilateral trade, Horiba's analysis has not been explicitly reflected in these studies. The other thing is that the H-O theorem assumes that production functions are identical between countries. By using the I-O tables of two countries, it is possible to quantitatively examine the relative importance of factor abundance and international differences in production functions as determinants of the international trade pattern.

The importance of this extension is two-fold. First, this would involve a comparison of two competing hypotheses concerning the determinants of trade: the H-O model, which emphasizes factor intensities of industries and factor abundance of countries, and the Ricardian model, which focuses on international differences in production functions.[44] Second, this extension allows an evaluation of the ordinary method of the examination of the Leontief

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[44]Bhagwati [1964] first suggested this contemporary interpretation of the classical Ricardian theory of comparative costs. Amano [1964] compared the Ricardian and H-O theories in his theoretical model of international trade.

paradox. More precisely, the previous examinations have used I-O coefficients of the own country to calculate the factor requirement of imports, which is presumably produced abroad.

STATISTICAL APPENDIX A

DESCRIPTION OF INDUSTRIES

	G-J	N	BEA	AMA
1. Agriculture including agricultural service	1,2	1	1-4	1-6
2. Mining	3-6	2	5-10	7-11
3. Construction	7	3	11,12	43,44
4. Food, beverage and tobacco	8,9	4	14,15	12-17
5. Textile	10	15	16-18.03	18-20
6. Apparel	11	6	18.07-19	21
7. Lumber and wood products	18	7	20,21	22
8. Furniture and fixture	19	8	22,23	23
9. Paper, pulp and their products	12	9	24,25	24
10. Printing and publishing	13	10	26	25
11. Chemicals	14	11	27-30	28-30
12. Petroleum refinery	15	12	31	31,32
13. Rubber and its products	16	13	32	27
14. Leather and its products	17	14	33,34	26
15. Grass, stone and clay	20	15	35,36	33
16. Primary metal, i.e., iron steel, and non-ferro alloy	21	6-17	37,38	34-36
17. Metal products	22	18	39-43	37
18. Machinery except for electric machinery	23	19	44,52	38
19. Electric machinery	24	20	53-58	39
20. Transportation equipment ex. motor vehicle	25	21	13,60, 61	3830, 40
21. Motor Vehicle	26	22	59	3830
22. Precision instruments	27	23	62,63	41
23. Miscellaneous manufactures	28	24	64	42
24. Public utilities, e.g., gas,water,electricity	38-40 52,54	25	68	45-47
25. Transportation and communication	29-37	26	65-67	51,52
26. Wholesale and retail trade	41,42	27	69	48
27. Financial institutions, insurance,real estate	43	28,29	70,71	49,50
28. Services	44-47,49 50,53,55	30	72,73, 75-77	54-55

Note:

G-J: Industrial classification used by Gollop and Jorgenson [1975]
N: Industrial classification used by Nishimizu [1974]
BEA: Industrial classification of U.S. I-O tables compiled by the Bureau of Economic Analysis
AMA: Industrial classification of Japanese I-O tables compiled by the Administrative Management Agency

STATISTICAL APPENDIX B

DATA SOURCES

This study uses five kinds of data: capital inputs, labor inputs, gross outputs, input-output (I-O) tables, and international trade. Professor Dale Jorgenson of Harvard University provided U.S. data on capital and labor inputs and gross outputs. Mieko Nishimizu of the World Bank provided the same set of data for Japan. For details see Gollop and Jorgenson [1975] and Nishimizu [1974], respectively.

Labor and capital inputs and gross outputs

Labor and capital inputs are service flows generated by man hour and capital stocks, respectively. However, capital service and corresponding rental prices are difficult to measure because many types of capital assets do not have a rental market. Unlike labor service, suppliers and purchasers often coincide for capital inputs. Therefore, capital service is assumed to be proportional to the capital stock, which is relatively easy to estimate.

The U.S. capital stock was estimated by the perpetual inventory method (Jorgenson [1983]). Japanese capital stock was estimated by the bench mark method. Data for U.S. labor are cross-classified by sex, eight age groups, five educational groups, two employment groups, and two occupational groups. Data for the U.S. Capital stock are cross-classified by six asset types and three legal form of ownership. Data for Japanese labor are cross-classified by sex, two occupational groups, three size groups of firm, four educational groups, and eight age groups. Data for Japanese capital are cross-classified by seven asset types and two legal form of ownership. These subcategories are aggregated into labor and capital input using Divisia index formula. Thus, "quality improvement" of capital and labor are partially reflected in the data used in the calculation of TFP. In other words, TFP represents productivity improvement not explained by the quality change of inputs.

Input-output tables

No official Japanese I-O table was estimated for 1963. This study used the table which Nishimizu estimated by interpolating the 1960 and 1965 official tables. The data of this table are supplemented by the 1963 table unofficially estimated by the Administrative Management Agency and several other government organizations, which also compiled the 1970 official Japanese I-O table. The U.S. Bureau of Labor Statistics provided the 1963 U.S. I-O table, which is essentially the same as the 1963 official table compiled by the U.S. Bureau of Economic Analysis. The 1970 U.S. table is based on the summary I-O table estimated by the Bureau of Economic Analysis, which is based on an extrapolation of 1967 table compiled also by the Bureau.

International trade

Import coefficients are the product of two terms: (1) proportion of imports in total supply, i.e., domestic output minus exports plus imports; and (2) the proportion of imports from the partner country (Japan for the U.S. and the U.S. for Japan) in total imports. The first term is calculated from I-O data and the second term from U.N. Commodity Trade Statistics (in the case of merchandise trade) and balance of payments statistics (in the case of invisible trade) compiled by the Bank of Japan (Monthly Statistics of Balance of Payments) and the U.S. Department of Commerce (Survey of Current Business).

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