Chapter 2

ISSUES ON THE INTERNATIONAL COMPARISON OF PRODUCTIVITY: THEORY AND MEASUREMENT

by

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Introduction: Theoretical background of productivity measurement

Decomposition of sources of economic growth

The purpose of this first section is to present a framework for the measurement of aggregate economic growth in a single country over a given period of time. Sources of growth in output for the economy as a whole can be broken down into the rate of aggregate technical change and the contributions of aggregate capital and labour inputs. In this chapter we construct measures of growth in output, the rate of technical change, and the contributions of capital and labour inputs for the economy as a whole.

Our first objective is to measure value added for the economy as a whole. Our measurement of sectoral gross output are based on the input-output accounting framework. The sectoral models of production employed in our framework are specified in terms of either the production function or the price function. Our input-output accounting framework and the sectoral production or price functions give aggregate measures of value added and factor input both in quantities and prices. The quantities of aggregate value added and factor inputs are defined as the dual indices in which nominal accounting balances in each sector and in the economy as a whole are maintained. It should be emphasized that we do not necessarily assume the existence of an aggregate production function or an aggregate price function. The existence of such aggregate functions imply stringent restrictions on the sectoral models of production and technical changes utilised: all sectoral production or price functions must be identical to the aggregate functions, and all sectoral value-added prices, capital service prices and labour service prices must be equal to each aggregate price, respectively. Unless these assumptions of the aggregate production model are met, analysis of sources of economic growth generates differences between sectoral and aggregate models of production and technical change.

The differences can be identified with the contribution of reallocations of value added and primary factor inputs among sectors to the rate of aggregate technical change.

In the following section we present estimates of aggregate value added based upon our input-output accounting framework. We then allocate the growth of value added among its components – the contribution of capital and labour inputs in the economy as a whole, and the rate of aggregate technical change. We further decompose the contribution of capital and labour inputs into the contribution of the quantity of inputs – the contributions of capital stock and hours worked – and the contribution of the quality of capital and labour inputs. In the following section we present the methodological framework to allocate the rate of aggregate technical change among a weighted sum of rates of sectoral technical change and reallocations of value added and primary factor inputs among sectors.

Finally, we will close this first section by presenting the results of the decomposition of the rate of aggregate technical change in the Japanese economy.

Aggregate output

Our measurement of sectoral gross output is based on the input-output accounting framework. The quantity of aggregate output, that is aggregate value added, is defined as the sum of the quantities of value added over all sectors. We begin with a description of our input-output accounting framework in order to confirm the definition of the quantity and the price of the aggregate output.

Our input-output accounting framework is based on the system of national accounts. Sectoral accounting balance is composed of two concepts of classification – commodity and industry. Relationships between commodity and industry are represented by two tables: the Make matrix – the so-called V table; and the Absorption matrix – the so-called U table. The V table provides information on the commodity product mix within each industry, while the U table provides the composition of the intermediate inputs by commodities in each industrial sector. Each industry generates value added, composed of factor compensation imputed to labour and capital inputs, business consumption and indirect taxes less subsidies.

Imports are divided into two categories – competitive (transferred) imports and non-competitive (directly allocated) imports. Competitive imports are included in each transaction of intermediate and final demand. Non-competitive imports are allocated into each industry as an imported intermediate input, or into each final use as an imported final demand input.

The accounting balance in the j-th industrial sector is represented as follows:

$$\left(\frac{1}{1+t^j}\right)p_I^j Z_I^j = \sum_{i=1}^{n} p_{oi} X_i^j + p_d d^j + p_{bc} b^j + P_L^j L^j + p_k^j K^j \ , \qquad [1]$$

where:

t^j = the effective rate of net indirect tax, defined by:

$$t_j = \frac{Indirect\ tax - subsidies}{\sum_{i=1}^{n} p_{oi} X_i^j + p_d d^j + p_{bc} b^j + p_L^j L^j + p_K^j K^j} \qquad [2]$$

p_I^j, Z_I^j = output price and quantity in the j-th industry, defined as commodity aggregates produced within the j-th industry.

P_{oi} = overall price of the i-th commodity which is composed of domestically produced goods and transferred imports.

X_i^j = quantity of the i-th intermediate good including domestic goods and transferred imports used in the j-th industry.

$p_d d^j$ = price and quantity of directly allocated imports of the j-th sector.

$p_{bc} b^j$ = price and quantity of business consumption of the j-th sector.

$p_L^j L^j$ = price and quantity of labour service inputs of the j-th sector.

$p_K^j K^j$ = price and quantity of capital service inputs of the j-th sector.

Rearranging [1], we can deduce the value added of the j-th sector.

$$\begin{aligned} p_v^i V^j &= p_L^j L^j + p_K^j K^j \\ &= \left(\frac{1}{1+t_j}\right) p_I^j Z_i^j - \sum_{i=1}^{n} p_{oi} X_i^j - p_d d^j - p_{bc} b^j \\ &= p_i^{j*} Z_I^j - \sum_{i=1}^{n+2} p_i X_i^j \end{aligned} \qquad [3]$$

where p_v^j and V_i are respectively the value-added deflator and real value added of the j-th sector. To simplify, we replace:

$\left(\frac{1}{1+t^j}\right) p_I^j$ *to* $p_I^{j*}, P_{oi}(i=1,\ldots.n)$ *to* $p_i(i=1,\ldots.n), p_d$ *to* $p_i(i=n+1), p_{bc}$ *to* $p_i(i=n+2), d^j(j=1,\ldots.n)$ *to* $X_i^j(i=n+1, j=1,\ldots.n)$ *and* $b^j(j=1,\ldots.n)$ *to* $X_i^j(i=n+2, j=1,\ldots.n)$
in the last equation.

Differentiating [3] logarithmically with respect to time, we have:

$$\frac{\dot{p}_v^j}{p_v^j} + \frac{\dot{V}^j}{V^j} = \left[\frac{P_I^{j*} Z_I^j}{p_v^j V^j} \cdot \frac{\dot{p}_I^{j*}}{p_I^{j*}} - \sum_{i=1}^{n+2}\left(\frac{p_i X_i^j}{p_v^j V^j}\right) \cdot \left(\frac{\dot{p}_i}{p_i}\right)\right] + \left[\frac{p_I^{j*} Z^j}{p_v^j V^j} \cdot \frac{\dot{Z}_I^i}{Z_i^j} - \sum_{i=1}^{n+2}\left(\frac{p_i X_i^j}{p_v^j V^j}\right)\left(\frac{\dot{X}_i^j}{X_i^j}\right)\right] \qquad [4]$$

The growth rate of the Divisia price index is then subtracted from the rate of growth of net output values in current prices in order to obtain a measure of the growth rate of real value added. The discrete approximation for this deflation procedure for value added is as follows:

$$\begin{aligned} &\ln V^j(T) - \ln V^j(T-1) = \left[\ln p_v^j(T) V^j(T) - \ln p_v^j(T-1) V^j(T-1)\right] \\ &-\left[\frac{1}{2}\left[v^j(T) + v^j(T-1)\right]\left[\ln p_I^{j*}(T) - \ln p_I^{j*}(T-1)\right] - \Sigma \frac{1}{2}\left[v_i^j(T) + v_i^j(T-1)\right]\left[\ln p_i(T) - \ln p_i(T-1)\right]\right] \end{aligned} \qquad [5]$$

where:

$$v^j(T) = p_I^{j*}(T)Z_I^j(T) / p_v^j(T)V^j(T)$$

and:

$$v_i^j(T) = p_i(T)X_i^j(T) / p_v^j(T)V^j(T)$$

Our concept of sectoral value added is evaluated in terms of the factor cost. Each sectoral value added defined in [3] includes the following items:

Sectoral value added in current prices
= Gross domestic output at factor cost
- Intermediate inputs at the overall price
- Direct allocated imports in current prices
- Business consumption expenditure in current prices
= Labor compensation
(= Compensation for full-time employees
+ Compensation for temporary workers
+ Compensation for day labourers
+ Compensation for the self-employed
+ Compensation for unpaid family workers)
+ Capital compensation
(= Business surplus
- Compensation for the self-employed
- Compensation for unpaid family workers
+ Capital consumption allowance
+ Taxes on capital).

Next, we define gross domestic product (*GDP*) – the economy-wide aggregate measure of net output – as the sum of sectoral value added as follows:

$$\begin{aligned} p_v V &= \sum_{j=1}^{n} p_v^j V^j \\ &= \sum_{j=1}^{n} \left(p_L^j L^j + p_K^j K^j \right) \end{aligned} \qquad [6]$$

where p_v and V are the *GDP* deflator and real *GDP* respectively.

Differentiating [6] logarithmically with respect to time, we have:

$$\frac{\dot{p}_v}{p_v} + \frac{\dot{V}}{V} = \sum_{j=1}^{n} \frac{p_v^j V^j}{p_v V} \cdot \frac{\dot{p}_v^j}{p_v^j} + \sum_{j=1}^{n} \frac{p_v^j V^j}{p_v V} \cdot \frac{\dot{V}^j}{V^j} \qquad [7]$$

The growth rate of the Divisia price index, which is represented by the first term of the right-hand side of equation [7], is then subtracted from the rate of growth of nominal GDP to obtain a measure of the growth rate of real GDP. The discrete approximation for the growth rate of real GDP is as follows:

$$
\begin{aligned}
&\ln V(T) - \ln V(T-1) \\
&= \left[\ln p_v(T)V(T) - \ln p_v(T-1)V(T-1)\right] \\
&- \sum_{j=1}^{n} \frac{1}{2}\left[w^j(T) + w^j(T-1)\right]\left[\ln p_v^j(T) - \ln p_v^j(T-1)\right]
\end{aligned}
\qquad [8]
$$

where:

$$
w^j(T) = p_v^j(T)V^j(T) / p_v(T)V(T)
$$

The sum of value added in all sectors $p_v^j V^j$ is equal to the sum of capital compensation and labour compensation for the economy as a whole. Value added for the economy as a whole is equal to the sum of value added at current prices over all sectors:

$$
p_v V = \sum_{j=1}^{n} p_v^j V^j = \overline{p}_v \sum_{j=1}^{n} V^j \qquad [9]
$$

where p_v is the translog price index derived from the discrete approximation for the growth rate of the sectoral value added price, and $\overline{p}_v$ is the aggregate price index corresponding to the sum of the quantities of real value added in all sectors. The translog price index, p_v, is not necessarily equal to the aggregate price index, $\overline{p}_v$. They are equal if, and only if, the prices of value added in all sectors are identically equal to p_v, and value shares w^j in all sectors are constant.

Labour and capital compensation of different types are equal to the sectoral sum of compensation paid for the type of labour and capital:

$$
P_{Ll} L_l = \sum_{j=1}^{n} p_{Ll}^j L_l^j = \overline{P}_{Ll} \sum_{j=1}^{n} L_l^j \qquad [10]
$$

$$
P_{Kk} K_k = \sum_{j=1}^{n} p_{Kk}^j K_k^j = \overline{P}_{Kk} \sum_{j=1}^{n} K_k^j \qquad [11]
$$

where subscripts l and k denote l-th and k-th type of labour and capital inputs. $\overline{p}_{Ll}$ and $\overline{p}_{Kk}$ are the aggregate price indices corresponding to the sum of the quantities of real labour and capital inputs of different types over all sectors.

Similar to the aggregate value-added price index, $\tilde{p}_{Ll}$ and $\tilde{p}_{Kk}$ are not necessarily equal to the translog price index p_{Ll} and p_{Kk}. Labour and capital compensation for the economy as a whole is equal to the sum of each input's compensation at current prices over all input types:

$$
p_L L = \sum^{l} p_{Ll} L_l = \tilde{p}_L \sum^{l} L_l \qquad [12]
$$

$$p_K K = \sum^{k} p_{Kk} K_k = \tilde{p}_K \sum^{k} K_k \quad [13]$$

where p_L and p_K are the translog price indices of labour and capital input for the economy as a whole and $\tilde{p}_L$ and $\tilde{P}_K$ are the aggregate price indices corresponding to the sum of the quantities of real labour and capital inputs over all input types. If, and only if, the prices of labour and capital inputs in various types are identical to the aggregate translog price index p_L and p_K, respectively, $\tilde{p}_L$ and $\tilde{P}_K$ are equal to p_L and p_K.

Aggregate labour and capital input

According to our accounting identities, aggregate labour and capital compensations are equal to the sum of compensation paid for each type of labour and capital over all sectors, respectively. Let us denote the number of types of labour as subscript l and the number of types of capital as subscript k.

Rearranging from [10]to [13],

$$p_L L = \sum^{j} \sum^{l} p_{Ll}^{j} L_l^{j} \quad [14]$$

$$p_K K = \sum^{j} \sum^{k} p_{Kk}^{j} K_k^{j} \quad [15]$$

where subscript j stands for the j-th sector.

Considering labour and capital input data for the economy as a whole at any two discrete points of time, the translog quantity index of change from the discrete approximation can be written as the weighted average of the growth rates of hours worked and capital service inputs by different types of labour and capital, $\{L_l^j\}$and$\{K_k^j\}$, over all sectors:

$$\begin{aligned}\Delta \ln L &= \ln L(T) - \ln L(T-1) \\ &= \sum^{j} \sum^{l} \bar{v}_{Ll}^{j} \left[\ln L_l^j(T) - \ln L_l^j(T-1)\right]\end{aligned} \quad [16]$$

and:

$$\begin{aligned}\Delta \ln K &= \ln K(T) - \ln K(T-1) \\ &= \sum^{j} \sum^{k} \bar{v}_{Kk}^{j} \left[\ln K_k^j(T) - \ln K_k^j(T-1)\right]\end{aligned} \quad [17]$$

where the weights are given by the average value share of the l-th labour or the k-th capital compensation in the j-th sector accruing to respective total compensation for the economy as a whole:

$$\bar{v}_{Ll}^{j} = \frac{1}{2}\left[v_{Ll}^{j}(T) + v_{Ll}^{j}(T-1)\right]$$

$$v_{Ll}^{j} = \frac{p_{Ll}^{j} L_{l}^{j}}{\sum^{j}\sum^{l} p_{Ll}^{j} L_{l}^{j}} \quad [18]$$

$$\bar{v}_{Kk}^{j} = \frac{1}{2}\left[v_{Kk}^{j}(T) + v_{Kk}^{j}(T-1)\right]$$

$$v_{Kk}^{j} = \frac{p_{Kk}^{j} L_{k}^{j}}{\sum^{j}\sum^{l} p_{Kk}^{j} L_{k}^{j}} \quad [19]$$

Note that hours worked, L_l^j, and capital service input, K_k^j, can be expressed as the product of the following two terms, respectively.

$$L_l^j = d_l^j \left(\sum^{j}\sum^{l} L_l^j \right), \quad (l = 1,\ldots.,l; \; j = 1,\ldots.,n) \quad [20]$$

$$K_k^j = h_k^j \left(\sum^{j}\sum^{k} K_k^j \right), \quad (k = 1,\ldots.,k; \; j = 1,\ldots.,n) \quad [21]$$

where d_l^j and h_k^j denote the proportion of hours worked by the l-th type in the j-th sector to total hours worked for the economy as a whole, and the proportion of capital service input by the k-th type in the j-th sector to the total capital service input for the economy as a whole, respectively. The translog quantity index of change for the economy as a whole can be expressed alternatively as follows:

$$D\ln L = \left[\ln \sum^{j}\sum^{l} L_l^j(T) - \ln \sum^{j}\sum^{l} L_l^j(T-1) \right] + \sum^{j}\sum^{l} \bar{v}_{Ll}^{j} \left[\ln d_l^j(T) - \ln d_l^j(T-1) \right] \quad [22]$$

$$\Delta \ln K = \left[\ln \sum^{j}\sum^{k} K_k^j(T) - \ln \sum^{j}\sum^{k} K_k^j(T-1) \right] + \sum^{j}\sum^{k} \bar{v}_{Kk}^{j} \left[\ln h_k^j(T) - \ln h_k^j(T-1) \right] \quad [23]$$

The first terms of the right-hand side in [22] and [23] account for changes in the quantity of total labour and capital inputs. The second terms – the weighted average of the change in the hours worked and capital service input share by different type and different sector of labour and capital, can be interpreted to account for changes in the quality of labour and capital inputs for the economy as a whole.

$$\begin{aligned}\Delta \ln Q_L &= \ln Q_L(T) - \ln Q_L(T-1) \\ &= \sum^{j}\sum^{l} \bar{v}^{j}_{Ll}\left[\ln d^{j}_{l}(T) - \ln d^{j}_{l}(T-1)\right] \\ &= \Delta \ln L - \left[\ln \sum^{j}\sum^{l} L^{j}_{l}(T) - \ln \sum^{j}\sum^{l} L^{j}_{l}(T-1)\right]\end{aligned} \quad [24]$$

$$\begin{aligned}\Delta \ln Q_K &= \ln Q_K(T) - \ln Q_K(T-1) \\ &= \sum^{j}\sum^{k} \bar{v}^{j}_{Kk}\left[\ln d^{j}_{k}(T) - \ln d^{j}_{k}(T-1)\right] \\ &= \Delta \ln K - \left[\ln \sum^{j}\sum^{k} L^{Kj}_{k}(T) - \ln \sum^{j}\sum^{k} K^{j}_{k}(T-1)\right]\end{aligned} \quad [25]$$

An evaluation of changes in the quality of labour and capital inputs for the economy as a whole is presented in the following section.

Aggregate productivity index

We presented above indices of output and input for the economy as a whole. Our next objective is to formulate an index of TFP change for the economy as a whole. We have already presented an index of productivity at the sectoral level as follows:

$$v^{j}_{T} = \frac{\dot{Z}^{j}_{I}}{Z^{j}_{I}} - \sum^{i} \frac{p_i X^{j}_{i}}{p^{j*}_{I} Z^{j}_{I}}\left(\frac{\dot{X}^{j}_{i}}{X^{j}_{i}}\right) - \sum^{l} \frac{p^{j}_{Ll} L^{j}_{l}}{p^{j*}_{I} Z^{j}_{I}}\left(\frac{\dot{L}^{j}_{l}}{L^{j}_{l}}\right) - \sum^{k} \frac{p^{j}_{Kk} K^{j}_{k}}{p^{j*}_{I} Z^{j}_{I}}\left(\frac{\dot{K}^{j}_{k}}{K^{j}_{k}}\right) \quad [26]$$

Alternatively, using the definition of value added in the j-th sector, we can write the index of the rate of TFP change v^{j}_{T}:

$$v^{j}_{T} = \left(\frac{p^{j}_{v} V^{j}}{p^{j*}_{I} Z^{j}_{I}}\right)\left(\frac{\dot{V}^{j}}{V^{j}}\right) - \sum^{l} \frac{p^{j}_{Ll} L^{j}_{l}}{p^{j*}_{I} Z^{j}_{I}}\left(\frac{\dot{L}^{j}_{l}}{L^{j}_{l}}\right) - \sum^{k} \frac{p^{j}_{Kk} K^{j}_{k}}{p^{j*}_{I} Z^{j}_{I}}\left(\frac{\dot{K}^{j}_{k}}{K^{j}_{k}}\right) \quad [27]$$

The discrete approximation for the growth rate of the sectoral TFP change is as follows:

$$\begin{aligned}\hat{v}^{j}_{T} &= \frac{1}{2}\left[v^{j}(T) + v^{j}(T-1)\right]\left[\ln V^{j}(T) - \ln V^{j}(T-1)\right] \\ &- \sum^{l} \frac{1}{2}\left[v^{j}_{Ll}(T) + v^{j}_{Ll}(T-1)\right]\left[\ln L^{j}_{l}(T) - \ln L^{j}_{l}(T-1)\right]\end{aligned} \quad [28]$$

$$-\sum^{k}\frac{1}{2}\left[v_{Kk}^{j}(T)+v_{Kk}^{j}(T-1)\right]\left[\ln K_{k}^{j}(T)-\ln K_{k}^{j}(T-1)\right]$$

where:

$$v^{j}(T)=\frac{p_{v}^{j}V^{j}(T)}{p_{I}^{j*}Z_{I}^{j}(T)},v_{Ll}^{j}(T)=\frac{p_{Ll}^{j}L_{l}^{j}(T)}{p_{I}^{j*}Z_{I}^{j}(T)},v_{Kk}^{j}=\frac{p_{Kk}^{j}L_{k}^{j}(T)}{p_{I}^{j*}Z_{I}^{j}(T)}$$

We can aggregate the above sectoral accounts into the nation-wide account as follows:

$$\begin{aligned}\sum^{j}\frac{p_{I}^{j*}Z_{I}^{j}}{p_{u}V}v_{T}^{j} &= \sum^{j}\frac{p_{v}^{j}V^{j}}{p_{v}V}.\frac{\dot{V}^{j}}{V^{j}}\\ &-s_{L}.\sum^{j}\sum^{l}\frac{p_{Ll}^{j}L_{l}^{j}}{\sum^{j}\sum^{l}p_{Ll}^{j}L_{l}^{j}}.\frac{\dot{L}_{l}^{j}}{L_{l}^{j}}\\ &-s_{K}.\sum^{j}\sum^{k}\frac{p_{Kk}^{j}K_{k}^{j}}{\sum^{j}\sum^{k}p_{Kk}^{j}K_{k}^{j}}.\frac{\dot{K}_{k}^{j}}{K_{k}^{j}}\end{aligned} \qquad [29]$$

where:

$$s_{L}=\frac{\sum^{j}\sum^{l}p_{Ll}^{j}L_{l}^{j}}{p_{v}V},s_{K}=\frac{\sum^{j}\sum^{k}p_{Kk}^{j}K_{k}^{j}}{p_{v}V}$$

On the other hand, let us assume the existence of an the aggregate production function based on aggregate net output and aggregate labour and capital inputs, hypothetically, in order to clarify the relationship between aggregate productivity growth and sectoral productivity growth. We can define the aggregate rate of TFP change for the economy as a whole from the accounting identity:

$$p_{v}V=p_{L}L+p_{K}K \qquad [30]$$

The aggregate rate of TFP change can be written as follows:

$$v_{T}=\frac{\dot{V}}{V}-s_{L}\frac{\dot{L}}{L}-s_{K}\frac{\dot{K}}{K} \qquad [31]$$

where:

$$\frac{\dot{V}}{V}=\sum^{j}\frac{p_{v}^{j}V}{p_{v}V}.\frac{\dot{V}^{j}}{V^{j}}=\sum^{j}\frac{\tilde{p}_{v}V^{j}}{p_{v}V}.\frac{\dot{V}^{j}}{V^{j}},$$

$$s_{L}=\frac{p_{L}L}{p_{v}V},$$

$$\frac{\dot{L}}{L} = \sum^{l} \frac{p_{Ll} L_l}{p_L L} \cdot \frac{\dot{L}_l}{L_l} = \sum^{l} \frac{\tilde{p}_{Ll} L_l}{p_L L} \cdot \frac{\dot{L}_l}{L_l},$$

$$s_K = \frac{p_K K}{p_v V},$$

$$\frac{\dot{K}}{K} = \sum^{k} \frac{p_{Kk} K_k}{p_K K} \cdot \frac{\dot{K}_k}{K_k} = \sum^{k} \frac{\tilde{p}_{Kk} K_k}{p_K K} \cdot \frac{\dot{K}_k}{K_k}$$

In the aggregate production function, we assume that sectoral net output is homogeneous among sectors and the value-added price is identical among sectors. Then the growth rate of aggregate net output represented in the first item on the right-hand side of [31] is equal to the growth rate of the simple sum of sectoral value added, $\sum^{j} \frac{\dot{v}^j}{\sum^{j} v^j}$. On the other hand, as regards labour and capital inputs, it is assumed that each l-th type labour input price and each k-th type capital input price are identical among sectors, while the input prices of different types might not be identical, that is, $p_{Ll}^j = \tilde{p}_{Ll}$ and $p_{Kk}^j = \tilde{p}_{Kk}$. This also implies that the l-th type aggregate labour input and the k-th type aggregate capital input are equal to the simple sum of the l-th and k-th type of labour and capital among sectors, respectively, that is, $L_l = \sum^{j} L_l^j$ and $K_k = \sum^{j} K_k^j$.

Then the aggregate labour and capital index is defined by the Divisia aggregate index of the aggregate different type labour and capital inputs, as shown in [31].

Rearranging [31] with [27], we obtain the following relationship between sectoral productivity and aggregate productivity:

$$\begin{aligned}
v_T \cdot p_v V &= \sum^{j} \tilde{p}_v^j \dot{V}^j - \sum^{j} \tilde{p}_{Ll} \dot{L}_l - \sum^{k} \tilde{p}_{Kk} \dot{K}_k \\
&= \sum^{j} \tilde{p}_v^j \dot{V}^j - \sum^{j} p_v^j \dot{V}^j + \sum^{j} p_v^j \dot{V}^j - \sum^{j} \tilde{p}_{Ll} \dot{L}_l - \sum^{k} \tilde{p}_{Kk} \dot{K}_k \\
&= \sum^{j} \left[v_T^j p_I^{j*} Z_I^j + \sum^{l} p_{Ll}^j \dot{L}_l^j + \sum^{l} \tilde{p}_{Kk}^j \dot{K}_k^j \right] \\
&\quad + \left(\sum^{j} \tilde{p}_v \dot{V}^j - \sum p_v^j \dot{V}^j \right) - \sum^{l} \tilde{p}_{Ll} \dot{L}_l - \sum^{k} \tilde{p}_{Kk} \dot{K}_k \\
&= \sum^{j} v_T^j p_I^{j*} Z_I^j + \sum^{j} \left(\tilde{p}_v - p_v^j \right) \dot{V}^j \\
&\quad + \sum^{j} \sum^{l} \left(p_{Ll}^j - \tilde{p}_{Ll} \right) \dot{L}_l^j + \sum^{j} \sum^{k} \left(p_{Kk}^j - \tilde{p}_{Kk} \right) \dot{K}_k^j
\end{aligned} \qquad [32]$$

This formulation implies that we can understand the aggregate rate of TFP change for the economy as a whole as a compound of three components as follows. Rearranging equation [32], we obtain:

$$v_T = \sum^{j} \left(\frac{p_I^{j*} Z_I^j}{p_v V} \right) v_T^j + \sum^{j} \left(\frac{\tilde{p}_v - p_v^j}{p_v V} \right) \dot{V}^j + \sum^{j} \sum^{l} \left(\frac{p_{Ll}^j - \tilde{p}_{Ll}}{p_v V} \right) \dot{L}_l^j + \sum^{j} \sum^{k} \left(\frac{p_{Kk}^j - \tilde{p}_{Kk}}{p_v V} \right) \dot{K}_k^j \quad [33]$$

The first term on the right-hand side of [33] represents the weighed average of the rates of sectoral TFP change, in which the weight is defined by the proportion of nominal gross product of the j-th sector to total nominal value added. The sum of the weight among sectors is necessarily more than unity. Consequently, the aggregate rate of TFP change is necessarily more than the simple average of the rate of sectoral technical change. This implies that the aggregate rate of TFP change should be evaluated with respect to both the direct and indirect effects of increasing efficiency, because the TFP change in certain sectors might contribute not only to production efficiency in the own sector, but also to that in other related sectors. It is plausible that such interdependencies of technologies among sectors can cause the aggregate rate of technical change to be greater than the average of sectoral technical change.

The other three terms of [33] represent the contributions of the reallocation changes of value added, labour and capital inputs among sectors to the aggregate rate of TFP change. In the second term, if the prices of the net output in all sectors, p_{vj}, are equal to $\tilde{p}_v$, this term becomes zero. In this case the aggregate translog price index p_v is equal to $\tilde{p}_v$. This means that the second term can be deemed to represent the allocation bias stemming from the differences in prices of net output among sectors. If this second term is positive, the aggregate rate of technical change, v_T, might be under-estimated compared to the weighted average of the rate of sectoral technical change defined by the first term. If the second term is negative, v_T might be over-estimated.

Similarly, the third and the fourth terms of [33] represent the contributions of the allocation biases of labour and capital among sectors. If p_{Ll}^j and p_{Kk}^j are all equal to $\tilde{p}_{Ll}$ and $\tilde{p}_{Kk}$ respectively, these two terms must be zero. If they are not equal to zero, $p_{Ll}^j\left(j = 1, \ldots n\right)$ and $p_{Kk}^j\left(j = 1, \ldots n\right)$ are different among sectors. Therefore, certain allocation biases of factor inputs among sectors have some impact on the aggregate rate of TFP change for the economy as a whole. We call these three terms allocation biases of net output, labour and capital inputs among sectors contributing to the aggregate rate of technical change.

Finally, the discrete approximation of the aggregate rate of TFP change, $\hat{v}_T$, is formulated as follows:

$$\hat{v}_T = \sum^{j} \overline{w}^j \hat{v}_T^j + \left[\sum^{j} \left(\overline{w}_v - \overline{w}_v^j \right) \left(\ln V^j(T) - \ln V^j(T-1) \right) \right]$$

$$+ \left[\sum^{j} \sum^{l} \left(\overline{w}_{Ll}^j - \overline{w}_l \right) \left(\ln L_l^j(T) - \ln L_l^j(T-1) \right) \right] \quad [34]$$

$$+\left[\sum^{j}\sum^{k}\left(\overline{w}_{Kk}^{j}-\overline{w}_{k}\right)\left(\ln K_{k}^{j}(T)-\ln K_{k}^{j}(T-1)\right)\right]$$

where:

$$\overline{w}^{j}=\frac{1}{2}\left[\frac{p_I^{j*}Z^j(T)}{p_vV(T)}+\frac{p_I^{j*}Z^j(T-1)}{p_vV(T-1)}\right],$$

$$\overline{w}_v=\frac{1}{2}\left[\frac{\tilde{p}_VV^j(T)}{p_vV(T)}+\frac{\tilde{p}_VV^j(T-1)}{p_vV(T-1)}\right],$$

$$\overline{w}_v^j=\frac{1}{2}\left[\frac{p_v^jV^j(T)}{p_vV(T)}+\frac{p_v^jV^j(T-1)}{p_vV(T-1)}\right],$$

$$\overline{w}_{Ll}^j=\frac{1}{2}\left[\frac{p_{Ll}^jL_l^j(T)}{p_vV(T)}+\frac{p_{Ll}^jL_l^j(T-1)}{p_vV(T-1)}\right],$$

$$\overline{w}_L=\frac{1}{2}\left[\frac{\tilde{p}_{Ll}L_l^j(T)}{p_vV(T)}+\frac{\tilde{p}_{Ll}L_l^j(T-1)}{p_vV(T-1)}\right],$$

$$\overline{w}_{Kk}^j=\frac{1}{2}\left[\frac{p_{Kk}^jK_k^j(T)}{p_vV(T)}+\frac{p_{Kk}^jK_k^j(T-1)}{p_vV(T-1)}\right],$$

and:

$$\overline{w}_K=\frac{1}{2}\left[\frac{\tilde{p}_{Kk}K_k^j(T)}{p_vV(T)}+\frac{\tilde{p}_{Kk}K_k^j(T-1)}{p_vV(T-1)}\right]$$

Thus, we can divide the aggregate rate of TFP change into four components: the weighted average of the rate of sectoral TFP change and allocation biases by structural changes in net output, labour and capital inputs.

Sources of economic growth: aggregate

The purpose of this section is to decompose the sources of economic growth for the economy as a whole in Japan during the period 1960-85. Drawing on the US estimates of Jorgenson-Gollup-Fraumeni (1987), we can compare the sources of economic growth between the United States and Japan and depict specific features of economic growth in the two economies.

Table 1 presents a decomposition of the sources of Japanese economic growth during the period 1960-85. The rows show the average annual rate of growth of each item in the decomposition of the sources of economic growth for the economy as a whole. The items are broadly divided into three parts:

- The first is the decomposition of the source of economic growth based on the Divisia aggregate framework shown in [29].

- The second is the decomposition of the source of economic growth based on the aggregate accounts shown in the formulation of [31].

- The third is the reallocation biases shown in the second to the fourth items of the right-hand side of [33].

First, we will focus on the decomposition based on the Divisia aggregate. The first row represents the average annual rate of net aggregate output. It should be noted that, while the average rate per year over the whole period 1960-85 amounts to more than 6.7 per cent, it was remarkably higher (11.8 per cent) during the strong period of economic growth in Japan during 1965-70, compared to 3.78 per cent per year after the first oil crisis, 1975-80. Columns 7 and 8 represent the average annual growth rate of net output during 1960-72 and 1972-80. The growth of the Japanese economy declined by more than half of the growth rate in the high economic growth period at the time of the oil crisis. Rows 2 and 3 represent the growth rates of the labour and capital inputs in the aggregate.

The average annual growth rates of the labour and capital inputs are 1.72 and 7.61 per cent during the period 1960-85. As regards the labour input, the growth rate during the 1960s was more than 2 per cent, however, it slowed down after 1970: during 1970-75 the growth rate was negative due to the decrease in labour caused by labour cost-saving after the oil crisis. On the other hand, it can be seen that the capital input has grown remarkably in the Japanese economy: the average annual growth rate of capital inputs during the 1960s was more than 10 per cent. Although the growth rate after the oil crisis deteriorated by almost half the rate of the pre-crisis period, it was still more than 5 per cent on average. In comparison with the growth rate of output and inputs, we can point out that the average growth rate of the capital input was more than that of net output even at the aggregate level, while that of the labour input was clearly lower. This implies that the partial productivity of capital has gradually deteriorated, while the partial productivity of labour increased remarkably during the period 1960-85.

The weighted average of the rate of sectoral TFP change is shown in row 6, which corresponds to the left-hand side of [29] or the first item on the right-hand side of [33]. The average growth rate for sectoral productivity was 2.2 per cent during 1960-85, broken down into 3.41 per cent and 1.11 per cent during the 1960-1972 and 1972-1985 periods, respectively. It should be noted that the growth rate of sectoral productivity after the oil crisis deteriorated significantly – by almost 30 per cent of its pre-crisis level. During the 1960s the rate of sectoral productivity was more than 3 per cent annually, with 5.48 per cent recorded during the period 1965-70. The contributions of labour inputs, capital inputs and sectoral productivity to aggregate economic growth of net output were, on average, 14 per cent, 54 per cent and 32 per cent, respectively, during 1960-85.

The contributions of labour inputs in each five-year sub-period since 1960 were 14 per cent, 9 per cent, -1.5 per cent, 30 per cent and 24 per cent, respectively. Over the same period, the contributions of capital inputs were 55 per cent, 44 per cent, 80 per cent, 50 per cent and 52 per cent. The contributions of sectoral productivity growth were 31 per cent, 47 per cent, 21 per cent, 20 per cent and 24 per cent, respectively. As would be expected, capital inputs contributed significantly to Japan’s economic growth. In addition, it should be noted that during the high growth period of the 1960s, and particularly during the period 1965-70, increases in sectoral productivity contributed to economic growth by more than 40 per cent, while the contribution of labour inputs after the oil crisis increased remarkably in spite of the slowdown of the labour input growth rate.

Next, we will focus on the second part of the table; the decomposition of the sources of economic growth based upon the aggregate accounts formulated by [31]. If we assume that aggregate accounts exist, which implies that net output prices are identical among sectors and any l-th type labour input price and any k-th capital input price are also identical among sectors, we can decompose the 6.82 per cent average annual growth rate of net output during the period 1960-85 into the respective individual contributions of .93 per cent average annual growth rate of labour inputs, 3.94 per cent average annual growth rate of capital inputs and 1.96 per cent average annual growth rate of aggregate productivity. According to our formulation, the growth rate of net output based on the Divisia aggregate in the first row is decomposed into the growth rate of net output in aggregate accounts and the contribution of reallocation biases of value added. As shown in row 19 of the table, the contribution of reallocation biases of value added is .035 on average over the period 1960-85. This implies that if we assume the existence of aggregate production accounts, the growth rate of net output might be over-estimated by .035 per cent annually compared to that based on the Divisia aggregate. During the 1960s the reallocation biases in value added were negative, so the growth rate of net output by the aggregate accounts might be under-estimated compared to that based upon the Divisia aggregate. In other words, these values of reallocation biases represent the amount of structural adjustment in terms of sectoral value added, where the negative (positive) value of the reallocation biases in value added implies that reallocations of sectoral value added contribute (do not contribute) to economic growth in the nation-wide aggregate. According to our observations, structural adjustments in terms of reallocations of sectoral value added during the strong economic period in Japan contributed significantly to economic growth, while structural adjustments after the oil crisis did not necessarily contribute to economic growth. Using the same methodology, we can decompose the growth rate of labour and capital inputs based on the Divisia aggregate into growth rates of those based on the aggregate production accounts and the contribution of the reallocation biases. As shown in the [33], negative (positive) values of the reallocation biases in inputs imply that the efficiency of the input increased (decreased) by the structural adjustment of the reallocation of resources. According to our results, if we assume the existence of aggregate production accounts, the growth rates of labour and capital inputs are over-estimated by .204 and .612 per cent annually compared with those based on the Divisia aggregate on average during 1960-85. In other words, at the aggregate level, the efficiency of inputs was increased by the reallocation of inputs among the sectors. In the 1960s, in particular, structural adjustment in the allocation of resources among sectors was remarkably high both in labour and capital inputs in Japan.

According to our formulation of [33], aggregate productivity is decomposed into sectoral productivity and three components of the reallocation biases. If we assume the existence of aggregate production accounts, the growth rate of productivity is under-estimated by the contribution of three reallocation biases compared with that based on the weighted sum of sectoral productivity, because increases in efficiency at the aggregate level might be ignored due to structural adjustments in the reallocations of output and inputs among sectors.

The contributions of quantity and quality changes of labour and capital inputs are represented in rows 14 to 15 and rows 17 to 18, respectively. It should be noted that the contribution of quality change of labour was around 0.5 per cent. However, this contribution gradually declined during the 1960s and increased during the sub-periods following the oil crisis. The contribution of quality change of capital inputs also declined gradually, especially after 1973.

Table 1. Decomposition of sources in economic growth, Japan, 1960-85

Percentages

	Item	1960-65	1965-70	1970-75	1975-80	1980-85	1960-72	1972-85	1960-85
					Divisia aggregate				
(1)	Value added	9.725	11.798	4.733	3.784	3.896	9.760	4.043	6.787
(2)	Labour input	2.929	2.201	-.097	1.967	1.608	2.381	1.113	1.722
(3)	Capital input	10.274	10.190	7.958	4.647	4.990	10.105	5.310	7.612
(4)	Labour contribution	1.397	1.079	-.075	1.154	.953	1.156	.667	.902
(5)	Capital contribution	5.349	5.237	3.792	1.925	2.047	5.190	2.267	3.670
(6)	Sectoral productivity	2.979	5.482	1.016	.704	.895	3.415	1.108	2.215
					Aggregate account				
(7)	Value added	7.573	11.149	5.012	4.003	6.375	8.649	5.137	6.823
(8)	Labour input	3.049	2.339	-.090	1.962	1.661	2.528	1.098	1.784
(9)	Man-hours	1.288	2.608	-.718	1.047	.735	1.667	.369	.992
(10)	Capital input	10.817	11.210	8.517	5.055	5.189	10.829	5.692	8.158
(11)	Capital stock	5.578	7.689	6.973	4.484	3.648	6.829	4.608	5.674
(12)	Aggregate productivity	0.488	4.241	1.029	.757	3.261	1.860	2.043	1.955
					Contribution				
(13)	<Labour input>	1.453	1.146	-.074	1.151	.985	1.227	.660	.933
(14)	Quality	0.838	-0.125	.332	.537	.549	.419	.433	.426
(15)	Man-hours	0.616	1.272	-.406	.614	.436	.809	.227	.506
(16)	<Capital input>	5.631	5.762	4.056	2.095	2.129	5.561	2.433	3.935
(17)	Quality	2.739	1.812	.742	.238	.632	2.069	.460	1.233
(18)	Capital stock	2.892	3.950	3.314	1.856	1.497	3.492	1.973	2.702
					Reallocation				
(19)	Value added	-2.153	-.649	.279	.220	2.480	-1.111	1.094	.035
(20)	Labour input	-.056	-.067	-.001	.003	-.032	-.072	.007	-.031
(21)	Capital input	-.282	-.525	-.264	-.170	-.082	-.371	-.166	-.265

Sectoral productivity growth

We examine the theoretical foundation for the measurement of total factor productivity (TFP) change at the industry level of detail, explicitly recognising intermediate and energy inputs as factors of production in the underlying technology. We have to complete the measurement of sectoral output, labour, capital, energy and intermediate inputs. In the Japanese case, each input factor was measured in terms of its disaggregated components in each sector. The sectoral labour input is measured on the basis of its components – characterised by class, sex, occupation, education and age dimensions. The sectoral capital input was measured on the basis of its individual components – characterised by asset types and by the legal form of organisation for tax purposes. The sectoral energy and intermediate material input was measured on the basis of its components – characterised by the input-output transaction of each sector. We can consolidate these results to capture the sectoral TFP change.

The second section discusses the methodological framework, where two alternative measures of TFP change are derived as dual. Under competitive market conditions with constant returns, producer behaviour can be described either in terms of production functions or price possibility frontiers. Given the discrete database, the translog index of change in sectoral technology is derived from the translog aggregator function, first in terms of quantity and second in terms of price.[1] We then discuss salient features of Japanese economic growth and TFP change, followed by comparisons between the United States and Japan.

Methodological framework for sectoral TFP change

As a definition of the accounting balance in the j-th sector, the following equation can be introduced:

$$q^j Z^j = P^j X^j \tag{35}$$

where q^j and Z^j stand for the vector of prices and quantities of outputs of the j-th sector, and P^j and X^j represent the vector of prices and quantities of inputs of the j-th sector, respectively.

Differentiating through time,

$$\frac{\dot{Z}_j}{Z_j} = \frac{\dot{p}_j}{p_j} + \frac{\dot{X}_j}{X_j} \tag{36}$$

We can deduce the TFP growth rate of the j-th sector from equation [36] as follows:

$$\begin{aligned} \frac{\dot{\psi}}{\psi} &= \frac{\dot{Z}^j}{Z^j} - \frac{\dot{X}^j}{X^j} \\ &= \frac{\dot{P}^j}{P^j} - \frac{\dot{q}^j}{q^j} \end{aligned} \tag{37}$$

where ψ^j is Z^j / X^j, that is, an index of TFP. Equation [37] implies that the TFP growth rate as an integrated measure of the efficiency of production can be defined as the difference between the growth rates of output and inputs. Under the condition of producer's equilibrium in a competitive market, a linear homogeneous production function ensures that the value of output is fully distributed as returns to inputs. Thus, the growth rate of TFP can alternatively be written as the difference in growth rates between the input and output prices.

Suppose that an industry with a state of technology, T(t), at time period t is described by a linear homogeneous production function with n inputs,

$$Z^j = f^j\left(X_1^j, X_2^j, \ldots., X_n^j, T(t)\right) \tag{38}$$

where the function is twice differentiable, concave and monotonic. Under competitive market conditions, the producer is alternatively described by a price possibility frontier dual to [38]:

$$q^j = g^j\left(p_1^j, p_2^j, \ldots., p_n^j, T(t)\right) \tag{39}$$

From equations [38] and [39], the growth rate in technical efficiency in the production function and the growth rate of output price reduction derived from technical change are defined respectively as follows:

$$\frac{\partial \ln Z^j}{\partial T}.\frac{dT}{dt} = \frac{d \ln Z^j}{dt} - \sum_{i=1}^{n}\left(\frac{\partial \ln Z^j}{\partial \ln X_i^j}\right).\left(\frac{d \ln X_i^j}{dt}\right), \tag{40}$$

and:

$$-\frac{\partial \ln q^j}{\partial T}.\frac{dT}{dt} = \sum_{i=1}^{n}\left(\frac{\partial \ln q^j}{\partial \ln p_i^j}\right).\left(\frac{d \ln p_i^j}{dt}\right) - \frac{d \ln q^j}{dt} \tag{41}$$

Using Konus-Byushgen's lemma, under the condition of producers' equilibrium in a competitive market, we obtain:

$$\begin{aligned}\frac{\partial \ln Z^j}{\partial \ln X_i^j} &= \frac{\left(\partial Z^i / \partial X_i^j\right)X_i^j}{\sum_{i=1}^{n}\left(\partial Z_i^j / \partial X_i^j\right)X_i^j} \\ &= \frac{p_i^j X_i^j}{\sum_{i=1}^{n} p_i^j X_i^j} = v_i^j\end{aligned} \tag{42}$$

Symmetrically applying Shephard's lemma to the dual price possibility frontier function, we obtain:

$$\frac{\partial \ln q^j}{\partial \ln p_i^j} = \frac{p_i^j X_i^j}{\sum_{i=1}^{n} p_i^j X_i^j} = v_i^j \tag{43}$$

Inserting [42] and [43] into [40] and [41] respectively, and comparing them to [37], we obtain:

$$\begin{aligned}\frac{\dot{\varphi}^j}{\varphi} &= \frac{\partial \ln Z^j}{\partial T}.\frac{dT}{dt} \\ &= -\frac{\partial \ln q^j}{\partial T}.\frac{dT}{dt}\end{aligned} \tag{44}$$

If we assume that factor inputs in the j-th sector are separable into these four input categories; labour input, capital input, energy input and intermediate material input, the production function is defined as follows:

$$Z^j = f^j\left[K^j\left(K_l^j,\ldots.K_k^j\right), L^j\left(L_l^j,\ldots.L_l^j\right), E^j\left(E_l^j,\ldots.E_e^j\right), X^j\left(X_l^j,\ldots.X_m^j\right), T(t)\right] \tag{45}$$

We now consolidate these measures to capture the change in sectoral TFP. We begin by assuming a translog aggregator function for sectoral production as follows:

$$Z^j = \exp\begin{bmatrix} \alpha_o^j + \alpha_K^j \ln K^j + \alpha_L^j \ln L^j + \alpha_E^j \ln E^j + \alpha_X^j \ln X^j + \alpha_T^j.T \\ +\frac{1}{2}\beta_{KK}^j\left(\ln K^j\right)^2 + \beta_{KL}^j \ln K^j \ln L^j + \beta_{KE}^i \ln K^j \ln E^j \\ +\beta_{KX}^j \ln K^j \ln X^j + \beta_{KT}^j \ln K^j.T \\ +\frac{1}{2}\beta_{LL}^j\left(\ln L^j\right)^2 + \beta_{LE}^j \ln L^j \ln E^j + \beta_{LX}^j \ln L^j \ln X^j + \beta_{LT}^j \ln L^j.T \\ +\frac{1}{2}\beta_{EE}^j\left(\ln E^j\right)^2 + \beta_{EX}^j \ln E^j \ln X^j + \beta_{ET}^j \ln E^j.T \\ +\frac{1}{2}\beta_{XX}^j\left(\ln X^j\right)^2 + \beta_{XT}^j \ln X^j.T + \frac{1}{2}\beta_{TT}^j.T^2 \end{bmatrix}, \qquad [46]$$

$$(j = 1,2\ldots.N).$$

Superscript j represents sectors, z^j is gross output, K^j is aggregate capital input, L^j is aggregate labour input, E^j is aggregate energy input, X^j is aggregate intermediate material input, and T is time. Each aggregate measure of input, K^j, L^j, E^j and X^j, is represented as follows:

$$\ln K^j(T) - \ln K^j(T-1) = \sum_i \bar{v}_{Ki}^j\left[\ln K_i^j(T) - \ln K_i^j(T-1)\right], \qquad [47]$$

$$\ln L^j(T) - \ln L^j(T-1) = \sum_i \bar{v}_{Li}^j\left[\ln L_i^j(T) - \ln L_i^j(T-1)\right], \qquad [48]$$

$$\ln E^j(T) - \ln E^j(T-1) = \sum_i \bar{v}_{Ei}^j\left[\ln E_i^j(T) - \ln E_i^j(T-1)\right], \qquad [49$$

$$\ln X^j(T) - \ln X^j(T-1) = \sum_i \bar{v}_{Xi}^j\left[\ln X_i^j(T) - \ln X_i^j(T-1)\right], \qquad [50]$$

where the weights are given by the average value shares of the j-th industry's total input outlay accruing to respective disaggregated components of its input:

$$\bar{v}_{.i}^j = \frac{1}{2}\left[v_{.i}^j(T) + v_{.i}^j(T-1)\right], \qquad (. = K, L, E, X) \qquad [51]$$

Assuming linear homogeneity over inputs in the translog production function, [46], we can define the rate of sectoral TFP change, v_T^j, as the rate of growth of sectoral output with respect to time, holding sectoral capital, labour, energy and intermediate material inputs constant:

$$\begin{aligned} v_T^j &= \frac{\partial \ln Z^j}{\partial T}\left(K^j, L^j, E^j, X^j, T\right) \\ &= \alpha_T^j + \beta_{KT}^j \ln K^j + \beta_{LT}^j \ln L^j + \beta_{ET}^j \ln E^j + \beta_{XT}^j \ln X^j + \beta_{TT}^j \ln T^j \end{aligned} \qquad [52]$$

Assuming the necessary condition producer equilibrium and considering data for the j-th industrial sector at any two discrete points in time, the average rate of TFP change can be expressed as the difference between successive logarithms of output less a weighted average of the differences between successive logarithms of capital, labour, energy and intermediate inputs:

$$
\begin{aligned}
\bar{v}_T^j &= \ln Z^j(T) - \ln Z^j(T-1) \\
&-[\bar{v}_K^j \left\{\ln K^j(T) - \ln K^j(T-1)\right\} \\
&+ \bar{v}_L^i \left\{\ln L^j(T) - \ln L^j(T-1)\right\} \\
&+ \bar{v}_E^j \left\{\ln E^j(T) - \ln E^j(T-1)\right\} \\
&+ \bar{v}_X^j \left\{\ln X^j(T) - \ln X^j(T-1)\right\}]
\end{aligned}
\tag{53}
$$

The weights are given by the average shares of capital, labour, energy and intermediate material inputs in the value of output:

$$
\begin{aligned}
\bar{v}_K^j &= \frac{1}{2}\left[v_K^j(T) + v_K^j(T-1)\right], \\
\bar{v}_L^j &= \frac{1}{2}\left[v_L^j(T) + v_L^j(T-1)\right], \\
\bar{v}_E^j &= \frac{1}{2}\left[v_E^j(T) + v_E^j(T-1)\right], \\
\bar{v}_X^j &= \frac{1}{2}\left[v_X^j(T) + v_X^j(T-1)\right],
\end{aligned}
$$

and:

$$
\bar{v}_T^j = \frac{1}{2}\left[v_T^j(T) + v_T^j(T-1)\right] \tag{54}
$$

where $v_.^j(. = K, L, E, X)$ denote the cost shares of each input in the value of output for each sector.

As discussed above, the TFP growth rate can be written alternatively as the differences in growth rates between the aggregate input price and output price. Instead of the translog production function [46], we can suppose that the price function is specified in terms of the translog form as follows:

$$
\begin{aligned}
q^j = &\exp[\alpha_o^j + \alpha_K^j \ln p_K^j + \alpha_L^j \ln p_L^j + \alpha_E^j \ln p_E^j + \alpha_X^j \ln p_X^j + \alpha_T^j T \\
&+\frac{1}{2}\beta_{KK}^j\left(\ln p_K^j\right)^2 + \beta_{KL}^j \ln p_K^j \ln p_L^j + \beta_{KE}^j \ln p_K^j \ln p_E^j \\
&+\beta_{KX}^j \ln p_K^j \ln p_X^j + \beta_{KT}^j \ln p_K^j . T \\
&+\frac{1}{2}\beta_{LL}^j\left(\ln p_L^j\right)^2 + \beta_{LE}^j \ln p_L^j \ln p_E^j + \beta_{LX}^j \ln p_L^j \ln p_X^j + \beta_{LT}^j \ln p_L^j . T \\
&\frac{1}{2}\beta_{XX}^j\left(\ln p_X^j\right)^2 + \beta_{XT}^j \ln p_X^j . T + \frac{1}{2}\beta_{TT}^j T^2], \quad (j = 1,2\ldots N))
\end{aligned} \qquad [55]
$$

Superscript j represents sectors, q^j is output price, p_K^j, p_L^j, p_E^j and p_X^j stand for the aggregate index of each input price based on the price of disaggregated components and T is time.

Although the translog price frontier function is not itself a dual to the translog production function, we can derive an alternative measure of TFP change from [55]:

$$
\begin{aligned}
\bar{v}_T^j = &\bar{v}_K^j\left\{\ln p_K^j(T) - \ln p_K^j(T-1)\right\} \\
&+\bar{v}_L^j\left\{\ln p_L^j(T) - \ln p_L^j(T-1)\right\} \\
&\bar{v}_E^j\left\{\ln p_E^j(T) - \ln p_E^j(T-1)\right\} \\
&\bar{v}_X^j\left\{\ln p_X^j(T) - \ln p_X^j(T-1)\right\} \\
&-\left\{\ln q_j(T) - \ln q^j(T-1)\right\}
\end{aligned} \qquad [56]
$$

where the weights $\bar{v}_.^j\,(.= K, L, E, X)$ are given by the average shares of each input in the value of output as defined in [51]. $\bar{v}_T^j$ is an alternative measure of TFP change at any two discrete points in time.

Measurement of sectoral technical change

After completion of the measurement of quantity and price indices of sectoral output, labour input, capital input, energy input and intermediate material input, we can consolidate these indices in order to measure sectoral TFP change as shown in [53] and [56]. Tables 2 and 3 present sectoral sources of growth during 1960-85 from the formulation of both quantity and price indices.

Growth rates of output vary from 0.60 per cent per year in the agricultural sector to 12.79 per cent per year in the electrical machinery sector. The growth rate of capital inputs is higher than that of output in all sectors except five (electrical machinery, transport and communications, finance and insurance, real estate and government services). On the other hand, growth of labour inputs was lower than that of output in all sectors except real estate. This means that partial labour productivity improved significantly in every sector to the extent that it compensated for the decline of partial capital productivity in almost all industries. All but nine sectors (agriculture, construction, food and kindred products, textiles, printing and publishing, petroleum refinery, leather, stone and clay, and government services) show improvements in TFP on average during the period 1960-85.

Table 2. Average annual growth rate of output, input and technical change in quantity during 1960-85

Percentages

Industry	Output	K	L	E	M	TFPQ
1. Agriculture	.5964	4.0300	-2.3228	4.1340	2.5659	-1.5502
2. Mining	2.7773	3.7018	-4.8991	4.4319	3.8085	1.9162
3. Construct.	5.9218	11.6849	2.5638	8.7624	7.4038	-1.0001
4. Foods	4.9080	8.9092	1.6802	7.2730	4.8398	-.3951
5. Textiles	1.8618	4.7858	-1.5070	4.0681	2.8187	-.4023
6. Fab. text.	6.4785	7.0041	2.9404	11.0293	6.6408	.3565
7. Lumber	3.7066	5.1496	-2.5446	5.0436	2.1896	1.9444
8. Furniture	6.3384	8.1842	.1126	8.9426	6.5807	.9579
9. Paper	6.2368	8.6842	.7886	6.3695	5.9582	.4898
10. Printing	5.7754	8.0680	2.8588	11.0855	7.8183	-.5861
11. Chemicals	7.8852	8.4576	.7632	7.4024	6.1619	1.8691
12. Pet., coal	7.7724	9.2621	1.9767	9.6554	11.8963	-3.0400
13. Rubber	7.0618	11.5216	1.7024	5.6336	6.4556	1.1098
14. Leather	3.2509	7.4047	.6683	5.3355	3.8212	-.3947
15. Stone, clay	5.7281	10.0885	1.4596	6.7409	6.2849	-.2038
16. Iron, steel	6.5286	9.3523	.1145	7.1027	5.7859	.5791
17. Non-ferrous	5.7890	8.9179	2.0811	7.6347	5.2417	.3588
18. Fab. metal	7.6271	14.3725	2.3516	10.4972	8.0878	.3462
19. Machinery	9.2249	11.3748	2.3504	9.1797	8.8761	1.1906
20. Elec. mach.	12.7895	12.1206	4.3599	10.1901	9.9463	3.3469
21. Mot. veh.	9.7967	12.1448	4.4931	11.4700	8.5980	1.2991
22. Trsp. equip.	6.0509	8.1650	-.5841	4.6037	6.7106	1.2278
23. Prec. inst,	8.1437	13.7679	1.9152	9.6950	8.0893	.8085
24. Misc. mfg.	9.9599	13.3210	2.4964	11.3769	9.3673	1.1529
25. Trsp. comm.	6.3915	5.8879	2.1650	6.1791	7.3300	1.7472
26. Utilities	7.2287	9.3286	1.8704	10.3832	7.6298	.1108
27. Trade	7.2431	9.2615	2.7517	7.3272	5.8313	1.5621
28. Finance	9.7530	7.9238	3.8740	6.1195	6.4804	3.7236
29. Real estate	7.0999	4.7312	8.0804	12.9406	9.1650	1.7622
30. Services	6.9294	10.3429	3.6169	9.0783	7.2687	.1726
31. Gov. services	3.0154	.0000	1.4955	7.5719	6.8633	-.0216
Average	6.4474	8.6435	1.6024	7.9760	6.6618	.6593

Table 3. Average annual growth rate of output, input and technical change in price during 1960-85

Percentages

Industry	Price	PK	PL	PE	PM	TFPP
1. Agriculture	5.8782	1.9092	9.2892	5.5746	4.4117	-1.3885
2. Mining	3.9569	4.0434	9.7004	5.9245	4.6777	2.2822
3. Construct.	5.9877	.7459	10.4740	5.2155	3.8217	-1.0967
4. Foods	4.5952	-1.6012	10.4802	5.0747	4.6321	-.3980
5. Textiles	3.3209	-1.0387	10.5519	4.8064	3.1560	.7758
6. Fab. text.	3.8098	6.3258	10.8066	4.9389	3.5625	1.4799
7. Lumber	3.3089	-9.6539	10.9795	4.7980	4.4170	1.2118
8. Furniture	4.6962	3.8246	10.8865	4.8847	3.7524	.7257
9. Paper	3.9326	1.5157	10.0531	4.7173	3.8757	.4275
10. Printing	6.5713	2.7592	10.3232	4.8489	4.1407	-.7439
11. Chemicals	2.2476	2.6133	10.0104	5.3107	3.8418	2.2143
12. Pet., coal	6.5607	1.0279	10.2514	5.2905	4.1022	-2.7026
13. Rubber	2.9831	-3.7990	11.2063	5.0030	3.0088	.9787
14. Leather	4.8752	4.8220	10.3290	4.9816	4.0606	.2682
15. Stone, clay	4.6083	-3.6542	10.3144	5.1437	4.9539	.2282
16. Iron, steel	2.6335	.5411	9.7850	5.3672	2.9734	.6700
17. Non-ferrous	3.7772	-3.8386	9.8346	4.4816	4.5863	.6168
18. Fab. metal	3.7270	-.6939	10.5944	5.1339	3.8142	1.2672
19. Machinery	3.2806	-.5864	10.4325	5.2514	3.7677	1.1094
20. Elec. mach.	.0995	1.0241	10.2973	5.0139	3.1651	3.8217
21. Mot. veh.	3.4848	1.7470	10.6371	4.7959	4.1693	1.3208
22. Trsp. equip.	3.1954	1.9188	10.6270	5.1334	4.0202	1.9104
23. Prec. inst,	1.7674	-6.2851	10.2834	4.9916	3.6983	2.3073
24. Misc. mfg.	3.4781	.9499	11.2132	4.9693	3.5180	.9973
25. Trsp. comm.	5.3225	4.1493	9.5687	5.4414	5.1664	1.5526
26. Utilities	5.9442	5.1565	9.9338	5.7556	5.5343	.6730
27. Trade	4.6010	2.1815	10.3664	5.1997	5.0458	1.5772
28. Finance	3.6283	5.8501	10.0677	4.6701	5.7087	3.6737
29. Real estate	6.0577	8.1490	9.8377	4.8347	5.8466	1.8582
30. Services	6.4057	3.6207	9.6366	4.9189	4.8683	-.2778
31. Gov. services	9.8041	.0000	11.6579	5.4369	5.0301	-.0852
Average	4.3400	1.0879	10.3364	5.0938	4.2364	.8792

Table 3 presents sectoral sources of growth based on price indices in terms of average annual growth rates. Negative average growth rate of TFP in terms of the quantity side for textile products, leather, and stone and clay became positive in the growth rate of the price side, while the positive average growth rate of TFP in the other services sector in Table 2 became negative on the price side. Average annual growth rates of TFP based on price indices are higher than those based on quantity indices in many sectors, implying that the improvement in production efficiency was significantly reflected in reductions in output prices. The growth rate of output prices was 4.34 per cent per year, while the growth rates of capital, labour, energy and intermediate input prices were 1.09, 10.33, 5.09 and 4.24 per cent, respectively. As discussed above, during the 1960-85 period, the growth rate of capital inputs was more than 2 percentage points higher than that of gross output, and the growth rate of labour input was lower than that of gross output by almost 4 per cent.

This pattern of input growth is consistent with changes in relative prices among inputs, where the price increase for the labour input was remarkably higher than those for capital and energy inputs.

An international comparison of growth patterns

Tables 4 to 9 present an international comparison of the average annual growth rate of Japan and the United States for gross output, capital, labour, energy and intermediate inputs and TFP by industry during the period 1960-85, this period being divided into three sub-periods 1960-70, 1970-80 and 1980-85. For our international comparison, several points of our database have to be adjusted: *i)* an adjustment was made for the industry classification, where iron and steel and non-ferrous metal products, as well as finance, insurance and real estate, are consolidated into primary metal products and financial services respectively; *ii)* because of differing statistical concepts relating to government services, for the purposes of our comparison this sector was excluded; *iii)* as mentioned above, our measurements for output and inputs may still contain some measurement errors – to smooth such errors, we tried to construct a three-year moving average of each output and input series in both countries in order to estimate average annual rate of growth.

Average annual growth rates of gross output for Japan during the period 1960-85 were higher than those of the United States in almost all industries except agriculture, forestry and fisheries. One of the most remarkable features of Japanese economic growth is the extraordinarily high growth of capital inputs. In all industries except mining, transportation equipment, and transport and communications, the growth rate of capital inputs in Japan was double that of the United States. On the other hand, differences in the growth rate of labour inputs between Japan and United States were far less pronounced during the period studied. As regards energy inputs, the Japanese growth rate was on average significantly higher than that of the United States. Finally, the Japanese growth rate for material inputs was also higher than the US growth rate in all industries except lumber. Table 9 presents the growth rates of sectoral TFP in Japan and the United States.

Average annual growth rates of TFP in Japan were higher than those of the United States in all industries, with the exception of agriculture, forestry and fisheries, construction, foods, printing, petroleum refinery, rubber, stone and clay, machinery, transport and communications, and other services, although the growth rates were fairly diversified among industries and among the observed periods.

Average annual growth rates of gross output by industry in Japan and the United States are presented in Table 4 for the three sub-periods: 1960-70, 1970-80 and 1980-85. During the first sub-period, the growth rates of gross output in Japan were substantially higher than those for the United States, with the exception of agriculture, forestry and fisheries. Differences in growth rates by industry in the two countries were particularly significant in the second half of the 1960s, when the Japanese economy had reached the peak of its rapid post-war economic growth, while the US economy was heading into the economic impacts of the Vietnamese War. In the second sub-period (which includes the oil crisis), the growth pattern in Japan changed dramatically, and average annual growth rates of sectoral gross output were quite similar in the United States and Japan for almost all industries except a few manufacturing industries such as electrical machinery, motor vehicles, precision instruments, etc.

Table 5 presents average annual growth rates of capital inputs by industry during the three sub-periods. High growth of capital inputs in the Japanese economy was observed until the second sub-period. During the first sub-period, 1960-70, annual growth rates of capital inputs in Japan were more than three times those of the United States. During the second sub-period, the annual growth rates of capital input in the United States increased relative to those in the first period in spite of the deterioration in the annual growth of gross output. However, during the third sub-period the growth of capital input in the United States slowed down in spite of the recovery of the US economy. In the Japanese economy, rapid capital formulation continued until the oil crisis in spite of the gradual slowdown of the growth of gross output in the 1970s.

After the oil crisis, the Japanese economy experienced dramatic changes in growth of capital inputs in almost all industries. In the 1980s, some industries, such as fabricated textiles, lumber, fabricated metals and transportation equipment (except motor vehicles) continued to experience negative growth rates for capital inputs.

Table 6 presents average annual growth rates for labour inputs by industry during each sub-period. During the first sub-period, Japanese industries posted high growth rates for labour inputs; they were significantly higher than those in US industries [except agriculture, forestry and fisheries, mining, textiles, rubber and transportation equipment (except motor vehicles)]. In the second sub-period, 1970-80, annual growth rates of labour inputs slowed down in almost all industries in Japan. After the oil crisis, in particular, some manufacturing industries in Japan experienced negative growth of labor inputs. This negative trend for labour input growth in Japanese industries continued into the 1980s in several industries.

Table 7 presents the average annual growth rate of energy inputs during three sub-periods. During the period 1960-70, energy inputs showed significantly higher growth both in Japan and the United States. This rate dipped sharply due to the impact of the oil crisis. While energy inputs in Japanese industry increased again in the 1980s, the negative growth rate continued in the United States through the 1980s.

Table 8 presents average annual growth rates for intermediate inputs by industry. During the first sub-period, annual growth rates for intermediate inputs in Japan were significantly higher than those in the United States. Since 1970 the Japanese growth rates declined dramatically, while the growth rates of some US industries increased compared with the rates of the previous sub-periods.

Finally, Table 9 presents the average annual growth rates of TFP by industry. During the period of strong economic growth, 1960-70, annual growth rates of TFP in Japan were significantly higher than in the United States. Since 1970, however, while Japanese growth rates for TFP decreased dramatically, the inter-industry variation in productivity performance increased as dramatically. After the oil crisis, variations of annual growth rates of TFP among industries were remarkably similar in the US and Japanese economies. However, there were significant differences between annual growth rates of TFP in US and Japanese industries in the 1980s.

Table 4. Comparison of average growth rate of real output between Japan and the United States, 1960-85

Percentages

Industry	1960-70		1970-80		1980-85		1960-85	
	Japan	United States	Japan	United States	Japan	United States	Japan	United States
1. Agriculture	.489	1.773	.456	1.709	.983	.983	.561	1.608
2. Mining	5.351	3.463	1.920	.489	-1.689	-1.175	2.635	1.363
3. Construct.	10.642	2.040	4.246	1.335	-1.235	.804	5.795	1.519
4. Foods	7.732	2.407	3.802	1.981	1.600	1.718	4.957	2.102
5. Textiles	6.490	3.352	.599	1.404	1.362	.168	3.037	1.951
6. Fab. text.	14.361	4.073	3.821	1.571	-.327	1.174	7.224	2.481
7. Lumber	9.704	2.897	-.175	2.775	-2.009	.537	3.372	2.434
8. Furniture	13.402	4.203	2.913	2.670	-.928	2.432	6.349	3.228
9. Paper	11.179	4.344	3.021	2.490	2.466	1.675	6.117	3.074
10. Printing	10.762	2.710	1.958	2.662	3.367	3.005	5.648	2.740
11. Chemicals	14.430	6.016	4.522	2.724	2.948	.503	8.125	3.626
12. Pet., coal	15.483	4.035	3.331	2.962	.441	-2.069	7.584	2.507
13. Rubber	10.313	7.335	3.604	3.484	4.165	3.328	6.327	4.964
14. Leather	9.453	.152	.263	-2.117	-1.992	-4.911	3.467	-1.715
15. Stone, clay	14.506	3.047	1.983	1.392	-.086	-1.493	6.523	1.538
16. Prim. metals	12.292	3.186	4.035	.514	-.945	-7.506	6.400	.165
17. Fab. metals	16.070	4.041	1.736	1.770	2.714	-.489	7.515	2.266
18. Machinery	14.992	5.857	5.495	6.011	2.654	.677	8.717	5.023
19. Elec. mach.	15.749	6.195	8.814	4.799	15.332	4.188	12.661	5.239
20. Mot. veh.	15.205	4.686	7.745	1.643	2.333	4.933	9.723	3.406
21. Trsp. equip.	17.410	4.738	-.753	.826	-5.034	.662	5.610	2.328
22. Prec. inst.	14.738	5.847	7.891	6.296	4.519	3.480	9.984	5.631
23. Misc. mfg.	15.310	5.117	6.382	-2.794	6.409	-7.601	9.880	-.534
24. Trsp. comm.	10.814	6.019	3.799	7.109	2.398	-1.155	6.300	5.245
25. Utilities	10.510	5.881	5.628	-.458	3.177	-2.691	7.112	1.634
26. Trade	11.245	4.578	5.624	3.231	2.527	3.162	7.285	3.746
27. Finance	11.865	4.376	5.707	3.476	5.013	2.213	7.996	3.608
28. Services	10.509	4.587	3.942	4.312	3.859	3.409	6.497	4.263

Table 5. Comparison of average growth rate of capital input between Japan and the United States, 1960-85

Percentages

Industry	1960-70 Japan	1960-70 United States	1970-80 Japan	1970-80 United States	1980-85 Japan	1980-85 United States	1960-85 Japan	1960-85 United States
1. Agriculture	3.516	.986	4.192	1.177	3.761	-.010	3.852	.895
2. Mining	7.790	3.299	1.268	3.487	1.499	5.310	3.860	3.731
3. Construct.	17.321	3.342	8.277	3.789	5.034	.565	11.252	3.053
4. Foods	13.419	2.076	6.977	2.984	4.464	1.207	9.060	2.319
5. Textiles	6.607	2.065	5.072	1.324	4.749	-.801	5.617	1.244
6. Fab. text.	11.615	6.268	6.142	3.324	-.195	-.109	7.182	3.879
7. Lumber	6.458	2.653	24.601	4.030	-11.629	-1.436	11.201	2.541
8. Furniture	11.186	4.688	8.220	3.608	3.411	1.586	8.544	3.679
9. Paper	11.763	3.589	9.648	3.360	4.753	1.984	9.624	3.210
10. Printing	9.364	4.088	7.081	3.211	7.340	3.233	8.019	3.558
11. Chemicals	12.722	4.785	4.151	3.987	5.032	.892	7.658	3.761
12. Pet., coal	15.314	1.804	-6.944	4.180	9.924	1.612	4.699	2.804
13. Rubber	19.049	4.951	11.342	2.675	.123	5.267	12.407	4.017
14. Leather	15.088	1.281	3.765	.299	.277	.196	7.589	.665
15. Stone, clay	15.365	1.631	7.568	3.443	8.582	-1.306	10.795	1.908
16. Prim. metals	14.511	-.157	6.953	3.761	6.750	-14.980	9.875	-1.031
17. Fab. metals	20.577	4.794	3.011	3.339	-6.053	1.261	8.308	3.547
18. Machinery	17.685	5.608	6.827	5.471	6.941	4.131	11.095	5.292
19. Elec. mach.	15.109	7.600	7.663	4.687	11.594	6.780	11.260	6.191
20. Mot. veh.	16.986	4.240	8.640	.476	8.457	7.736	11.874	3.212
21. Trsp. equip.	13.796	-5.841	-2.787	1.843	-2.390	35.788	3.771	4.740
22. Prec. inst.	17.203	5.454	10.127	5.518	15.307	4.337	13.797	5.288
23. Misc. mfg.	15.931	4.257	11.340	4.014	7.820	-7.440	12.524	2.117
24. Trsp. comm.	10.476	5.294	1.616	6.329	1.215	1.487	5.013	5.082
25. Utilities	5.704	3.174	10.543	1.671	9.007	.619	8.383	2.076
26. Trade	11.720	4.158	8.218	4.504	1.156	4.019	8.360	4.284
27. Finance	7.512	3.125	4.331	3.566	2.684	4.878	5.289	3.622
28. Services	12.037	4.325	9.662	4.358	9.355	4.429	10.538	4.357

Table 6. Comparison of average growth rate of labour input between Japan and the United States, 1960-85

Percentages

Industry	1960-70 Japan	1960-70 United States	1970-80 Japan	1970-80 United States	1980-85 Japan	1980-85 United States	1960-85 Japan	1960-85 United States
1. Agriculture	-4.671	-2.278	-.389	-.484	-1.260	-.278	-2.216	-1.150
2. Mining	-7.907	.273	-7.351	6.246	-3.233	-2.536	-6.852	2.381
3. Construct.	3.653	1.920	3.050	2.211	-.235	1.320	2.715	1.942
4. Foods	4.415	.809	.408	.238	1.939	-.843	2.242	.273
5. Textiles	-.636	.362	-4.121	-.354	-1.617	-2.816	-2.321	-.502
6. Fab. text.	4.254	.755	2.242	.351	-.364	-.238	2.576	.407
7. Lumber	1.168	.855	-4.220	1.515	-8.310	-.750	-2.823	.863
8. Furniture	4.309	2.265	1.915	1.415	-2.888	1.441	2.017	1.752
9. Paper	1.096	1.542	-.273	.298	-.123	-.793	.289	.595
10. Printing	5.103	1.456	1.966	1.745	2.636	2.660	3.310	1.791
11. Chemicals	2.035	2.317	-.969	1.783	1.026	-.811	.554	1.541
12. Pet., coal	1.791	1.539	1.647	4.232	.555	-4.191	1.514	1.714
13. Rubber	.644	3.518	2.169	2.564	1.047	-.176	1.377	2.461
14. Leather	2.236	-1.522	-1.047	-2.224	1.160	-5.018	.621	-2.435
15. Stone, clay	2.984	1.035	.738	.963	-1.362	-2.557	1.252	.379
16. Prim. metals	2.114	1.192	-.225	-.270	1.123	-3.088	.925	-.188
17. Fab. metals	5.485	1.862	-1.066	.835	.547	1.090	1.778	1.281
18. Machinery	4.071	3.608	1.257	3.642	3.582	-1.195	2.762	2.787
19. Elec. mach.	2.571	2.433	2.123	2.129	5.819	1.465	2.941	2.133
20. Mot. veh.	8.964	2.439	1.983	1.027	-.082	1.294	4.355	1.626
21. Trsp. equip.	-.782	2.168	-1.973	2.036	-2.303	-3.465	-1.565	1.131
22. Prec. inst.	3.850	2.886	2.198	4.953	4.322	.431	3.214	3.358
23. Misc. mfg.	5.526	.576	2.367	-.262	5.281	-4.421	4.110	-.658
24. Trsp. comm.	4.005	1.617	.996	.758	1.932	-3.481	2.336	.357
25. Utilities	2.067	1.807	.020	2.536	1.100	.678	1.009	1.927
26. Trade	5.286	1.838	2.226	1.012	.660	.750	3.151	1.290
27. Finance	5.316	3.679	3.755	3.261	3.328	2.959	4.292	3.372
28. Services	6.591	2.954	3.889	3.417	6.568	4.169	5.412	3.367

Table 7. Comparison of average growth rate of energy input between Japan and the United States, 1960-85

Percentages

Industry	1960-70 Japan	1960-70 United States	1970-80 Japan	1970-80 United States	1980-85 Japan	1980-85 United States	1960-85 Japan	1960-85 United States
1. Agriculture	9.445	1.416	1.122	.983	-4.686	-3.953	3.369	.294
2. Mining	13.359	6.041	-.907	4.061	-9.617	-7.149	3.160	2.886
3. Construct.	16.878	2.834	2.196	-.097	.840	.155	7.705	1.093
4. Foods	10.584	4.017	4.942	-.727	1.448	-5.469	6.542	.305
5. Textiles	6.316	5.504	.512	-.964	.724	-5.788	2.820	.728
6. Fab. text.	18.345	9.377	.759	-2.079	10.836	-3.500	9.393	2.157
7. Lumber	11.963	9.230	-1.181	-2.208	-4.313	-5.613	3.418	1.675
8. Furniture	18.044	7.335	.818	-.081	-2.006	-1.827	7.068	2.517
9. Paper	7.937	6.164	4.505	3.178	.740	-2.746	5.193	3.316
10. Printing	15.719	6.132	7.331	.528	2.348	1.478	9.747	2.886
11. Chemicals	12.167	6.963	3.113	2.970	.374	-5.300	6.180	3.094
12. Pet., coal	11.267	4.131	6.472	7.079	10.894	-8.366	9.117	3.239
13. Rubber	7.344	9.894	2.998	4.252	.769	-1.482	4.311	5.463
14. Leather	13.336	4.593	-3.465	-4.787	1.411	-10.402	3.957	-2.093
15. Stone, clay	13.552	4.375	2.193	.346	-3.178	-6.544	5.704	.724
16. Prim. metals	15.552	5.103	1.450	.674	-3.992	-13.876	6.022	-.123
17. Fab. metals	22.142	5.765	1.035	-1.847	.107	-6.082	9.133	.395
18. Machinery	14.490	8.201	2.826	-.808	6.301	-6.320	7.995	1.759
19. Elec. mach.	11.883	6.595	4.495	-.455	12.947	-.915	8.856	2.224
20. Mot. veh.	15.252	5.809	6.229	-2.572	5.938	.402	9.709	1.225
21. Trsp. equip.	9.924	7.450	-2.839	-1.216	4.315	-3.385	3.400	1.798
22. Prec. inst.	14.249	8.967	5.275	2.642	2.172	-1.233	8.247	4.443
23. Misc. mfg.	18.425	8.000	4.735	-2.343	3.963	-6.663	9.958	.953
24. Trsp. comm.	11.263	4.029	2.198	1.862	1.085	-.786	5.551	2.250
25. Utilities	21.381	6.679	5.055	2.290	-1.270	-1.947	10.344	3.270
26. Trade	16.219	3.584	-1.072	-1.004	1.567	-.874	6.153	.814
27. Finance	15.361	4.817	2.524	-1.017	1.998	-.228	7.456	1.403
28. Services	10.204	5.452	7.883	.150	3.465	2.611	8.023	2.653

Table 8. Comparison of average growth rate of material input between Japan and the United States, 1960-85

Percentages

Industry	1960-70 Japan	1960-70 United States	1970-80 Japan	1970-80 United States	1980-85 Japan	1980-85 United States	1960-85 Japan	1960-85 United States
1. Agriculture	2.959	1.928	1.136	1.406	1.333	-1.224	1.883	1.153
2. Mining	4.429	3.154	5.384	6.521	-1.155	-1.490	3.873	3.810
3. Construct.	12.516	2.184	4.161	2.573	.604	.127	6.812	1.995
4. Foods	6.447	2.080	3.081	2.297	1.918	.924	4.196	1.973
5. Textiles	6.306	2.495	-.595	.841	.879	-.139	2.362	1.317
6. Fab. text.	14.890	4.008	.882	-.527	-1.614	.714	5.929	1.464
7. Lumber	7.827	2.865	-2.208	3.976	-5.610	-1.040	1.127	2.669
8. Furniture	13.875	4.130	2.571	2.011	-3.498	2.318	5.939	2.893
9. Paper	10.363	4.147	2.428	3.311	.658	.901	5.225	3.219
10. Printing	12.680	3.645	4.459	3.392	2.174	4.743	7.279	3.726
11. Chemicals	11.062	5.277	4.244	4.664	1.088	-1.415	6.363	3.847
12. Pet., coal	18.500	2.424	10.019	5.593	1.118	-6.023	11.789	2.333
13. Rubber	8.989	6.674	4.109	4.299	3.202	2.891	5.861	4.983
14. Leather	8.530	.076	.579	-1.386	-4.491	-5.684	2.808	-1.561
15. Stone, clay	15.026	3.362	1.959	1.421	.117	-2.450	6.752	1.507
16. Prim. metals	11.447	4.098	2.947	-.002	-1.118	-9.523	5.566	-.054
17. Fab. metals	15.466	4.041	1.720	1.687	3.721	-2.501	7.447	1.880
18. Machinery	14.459	5.877	5.449	5.105	3.655	-1.618	8.663	4.238
19. Elec. mach.	14.165	5.243	5.652	3.215	12.871	4.276	10.239	4.193
20. Mot. veh.	13.334	4.207	7.421	2.164	3.096	5.120	8.983	3.478
21. Trsp. equip.	18.532	5.156	-1.340	1.407	-2.530	.446	6.229	2.707
22. Prec. inst.	14.015	5.051	4.792	5.528	2.807	2.710	8.056	4.852
23. Misc. mfg.	15.132	4.435	5.405	1.355	5.302	-4.817	9.193	1.487
24. Trsp. comm.	11.153	5.711	6.370	4.625	2.439	-.480	7.558	4.162
25. Utilities	5.804	5.227	9.591	4.315	6.316	3.535	7.540	4.536
26. Trade	9.582	6.290	3.736	4.871	2.340	2.194	5.781	4.961
27. Finance	9.929	4.097	4.558	2.913	6.675	3.387	7.028	3.459
28. Services	9.661	5.873	4.568	4.580	4.568	5.720	6.561	5.284

Table 9. Comparison of average growth rate of technical change between Japan and the United States, 1960-85

Percentages

Industry	1960-70 Japan	1960-70 United States	1970-80 Japan	1970-80 United States	1980-85 Japan	1980-85 United States	1960-85 Japan	1960-85 United States
1. Agriculture	-1.305	1.066	-1.533	.884	-.484	2.102	-1.261	1.167
2. Mining	3.763	.877	1.523	-4.638	.927	-2.120	2.296	-2.042
3. Construct.	-.530	-.159	-.251	-1.090	-2.281	.203	-.713	-.501
4. Foods	.202	.508	.331	-.015	-.705	1.132	.101	.389
5. Textiles	1.137	1.276	1.455	.857	.775	1.070	1.212	1.058
6. Fab. text.	1.515	.944	2.498	1.702	.517	.882	1.769	1.263
7. Lumber	2.902	.568	.296	-.415	4.795	1.818	2.098	.358
8. Furniture	1.816	.675	-.122	.860	1.551	.581	.927	.739
9. Paper	1.822	.954	-.133	.060	1.341	1.288	.888	.624
10. Printing	.798	-.142	-2.201	-.034	.477	-.818	-.562	-.213
11. Chemicals	3.977	1.461	1.005	-1.030	1.310	1.691	2.221	.418
12. Pet., coal	-.692	1.594	-5.221	-2.528	-1.850	3.521	-2.862	.137
13. Rubber	1.565	1.862	-.549	-.074	2.091	1.553	.737	.967
14. Leather	1.473	.539	-.286	-.496	.667	.183	.568	.027
15. Stone, clay	1.860	.720	-.753	.041	-.439	1.266	.324	.520
16. Prim. metals	.843	.298	.963	.302	-.531	.705	.656	.371
17. Fab. metals	2.430	.659	.259	.333	.795	.426	1.202	.477
18. Machinery	1.863	.801	.757	1.544	-1.435	1.643	.808	1.270
19. Elec. mach.	2.934	1.757	3.520	1.994	3.913	.816	3.359	1.697
20. Mot. veh.	2.008	.816	1.028	-.103	-.896	.602	1.077	.379
21. Trsp. equip.	4.773	1.190	.098	-.838	-1.954	.911	1.571	.260
22. Prec. inst.	2.590	1.515	3.006	1.067	.248	1.615	2.364	1.338
23. Misc. mfg.	1.519	1.947	.711	-3.714	.854	-2.820	1.052	-1.343
24. Trsp. comm.	2.836	2.213	.933	3.972	.383	.274	1.582	2.641
25. Utilities	2.971	1.686	-1.314	-3.327	-1.452	-3.509	.339	-1.397
26. Trade	2.328	1.110	1.514	.525	1.162	1.416	1.772	.909
27. Finance	4.177	.752	1.446	.288	1.443	-1.359	2.514	.183
28. Services	1.115	.321	-1.342	.420	-2.117	-1.286	-.515	.085

It could be expected that the above-mentioned trends of output, inputs and TFP in the two countries might be highly correlated to their price trends during the 1960-85 period: these price trends are summarised in terms of growth rates below:

	1960-70		1970-80		198-85	
Price	Japan	United States	Japan	United States	Japan	United States
Capital p_K	2.45	2.36	1.62	6.66	-1.39	7.61
Labour p_L	12.29	4.89	11.58	7.92	3.72	5.39
Energy p_E	-1.18	.26	13.98	17.15	-.65	6.36
Material p_M	-1.96	2.33	7.54	8.03	1.30	3.99

According to the above figures, a relationship between factor inputs and their relative prices clearly exists. In the 1960s, relatively higher increases in labour input prices can be observed compared with other input prices in the Japanese economy, where there were rapid increases of capital, energy and material inputs. In the 1970s as would be expected as an impact of energy crisis, energy input prices in both countries increased dramatically, as did labour input prices. This would seem to reflect relative growth rates of inputs. It is also interesting to compare trends for each input in Japan and the United States from the viewpoint of relative price changes.

Issues regarding measurement of productivity

Let us now summarise the issues pertaining to the measurement of productivity from the point of view of an international comparison of growth at the aggregate and sectoral levels. Broadly speaking, these can be divided into two aspects of productivity measurement: *i)* the theoretical aspect; and *ii)* the statistical or empirical aspect.

Theoretically speaking, homogeneous measures of output and inputs have to be defined in both international and intertemporal comparisons of productivity. With regard to measures of output, the classification must be standardised on the basic level of commodity classification. Output by industry should be defined as an aggregated index of the commodities classified in the specific industry. Compositional changes of commodities within an industry are regarded as quality changes of output. Similarly, measures of inputs such as labour and capital should also be standardised according to the specific characteristics of the inputs, so that each item of input in each specific category is homogeneous. Inputs by industry should be defined as an aggregated index of the categorised items included in the industry. Compositional changes of items within an industry are regarded as quality changes of inputs.

The aggregation of output and inputs by industry requires the selection of a given type of index numbers. Although there are no theoretical reasons for selecting one particular type among the various types of index numbers available, a chained index would seem to be preferable to indices with a constant weight at the reference period of time. This is because constant weight indices might have a statistical bias along with actual changes in the weight. A difficulty exists, however, where constructing a chained index requires further data collection. Also, superlative indices such as the Törnquist (discrete translog) index or the Fisher linked index are consistent with the functional forms such as transcendental logarithm functions or quadratic root functions. Therefore, superlative index numbers may have advantages for the analysis of producers' behaviour.

With regard to primal or dual approaches for quantity and price indices, either approach can be chosen depending on the objectives for analysis. Theoretically, the growth rate of the productivity index obtained by a primal approach should be equal to that obtained from a dual approach. Dual price and primal quantity indices must satisfy the factor reversal test, where changes of multiplication of both indices correspond to changes of nominal value. However, empirically, as mentioned in the previous section, two estimates of productivity growth using the primal and dual approaches are not necessarily consistent. As the translog function is not self-dual, we have to evaluate which estimates of productivity growth have an empirical validity.

Quality adjustment is an important issue in measurement of output and inputs. As mentioned above, it may be possible to evaluate quality changes of output and inputs as indices influenced by compositional changes of homogeneously classified components in a given industry. For example, the quality index for labour inputs in a given industry is defined by changes in the composition of labour inputs classified by sex, age, education and employment status. In addition, the quality index of output by industry may be defined by changes in the product-mix of homogeneous commodities within an industry, observed through changes in the Make matrix. These measures of quality changes in output must be distinguished from quality changes in the commodity itself, defined as a homogeneous item through product innovation. It might also be expected that the same types of quality changes in inputs such as labour and capital could occur through human investment or technological progress. A hedonic approach to evaluating quality changes of this type would appear to be one of the most promising approaches.

International comparison of productivity levels

The purpose of this section is to provide a theoretical foundation for the international comparison of productivity levels by industry. In this case, productivity is defined as total factor productivity, instead of partial productivity – such as labour or energy productivity. Comparisons of levels of total factor productivity by industry on a bilateral or multilateral basis must be based on the theoretical framework of the production model and estimate measures of prices and quantities of industrial outputs and inputs and productivity, where these indices are internationally comparable bilaterally or multilaterally. A theoretical foundation for the relative producer's price must be provided. Here, the relative producer's price is defined as a parity index for the international comparison of prices of output and inputs in terms of producer prices. The OECD and UN projects have engaged in constructing a purchasing power parity index (PPP index). To date, the PPP index aims to estimate purchasing power parities among countries and real expenditure on GDP with internationally comparable measures. For international comparisons of productivity level by industry, a parity index for output and inputs by industry should be constructed, so as to estimate real measures of output and inputs in production. For comparisons of real expenditure the purchasing parity index should be defined in terms of purchaser’s prices.

A bilateral model of production

We can describe the implications of the bilateral translog price index from the point of view of production theory in terms of a *bilateral production function* for each industrial sector. This provides a framework for a theoretical description of the observed differences in prices of output and inputs between the two countries. The point of departure of this theory is a production function for each industry giving output as a function of inputs, a dummy variable equal to zero for country L and one for country K and time. Production is considered under constant returns to scale. In analysing differences in each industry's production patterns between the two countries, we combine the production function with the necessary condition for producer equilibrium. We express these conditions as equalities between the shares of each input in the value of output of each industry and the elasticity of output with respect to the input in the industry. The elasticities depend on input levels, the dummy variable for each country and time. Under constant returns to scale the sum of the elasticities with respect to all inputs is equal to unity, so that the value shares also sum to unity.

To represent our bilateral models of production we require the following notation:

q^j = producers price of the output of the j-th industry;

$p_K^j, p_L^j, p_E^j, p_M^j$ = prices of capital, labour, energy and other intermediate inputs in the j-th industry;

$v_K^j, v_L^j, v_E^j, v_M^j$ = value shares of capital, labour, energy and other intermediate inputs in the j-th industry;

v^j = the vector of value shares of input in the j-th industry;

$\ln p^j$ = the vector of logarithms of input prices of the j-th industry;

T = a time trend as an index of technology; and

D = a dummy variable D, equal to one for Japan and zero for the United States to represent differences in technology between the two countries.

Under competitive conditions we can represent technology by a price function that is dual to the production function relating each industry's output to the corresponding inputs, the level of technology and differences in technology between the two countries:

$$\ln q^j = \ln p^{j'} \alpha^j + \alpha_t^j T + \alpha_d^j D + \frac{1}{2} \ln p^{j'} B^j \ln p^j + \ln p^{j'} \beta_t^j T + \ln p^{j'} \beta_d^i D + \frac{1}{2} \beta_{tt}^j T^2 + \beta_{td}^j TD + \frac{1}{2} \beta_{dd}^j D^2, \quad (j = 1,2\ldots, J) \qquad [57]$$

For each industry the price of output is a transcendental or, more specifically, an exponential function of the logarithms of the input prices. In this translog representation the scalars – $\alpha_t^j, \alpha_d^j, \beta_{tt}^j, \beta_{dd}^j$, the vectors – $\alpha^j, \beta_t^j, \beta_d^i$, and the matrices – B^j, are constant parameters that differ among industries. These parameters reflect differences in technology among industries. Within each industry, differences in technology among time periods are represented by time as an index of technology. Differences in technology between country K and country L are represented by a dummy variable, equal to one for country K and zero for country L.

Applying the necessary conditions for producer equilibrium for each industry, the value shares are equal to the logarithmic derivatives of the price function with respect to the logarithms of the input prices:

$$v^j = \alpha^j + B^j \ln p^j + \beta_d^j D \quad (j = 1,2\ldots, J) \qquad [58]$$

We can define the *rates of productivity growth*, say v_T^j, as the negative of rates of growth of the price of output with respect to time, keeping input prices constant:

$$-v_T^j = \alpha_t^j + \beta_t^{j'} \ln p^j + \beta_{tt}^j T + \beta_{td}^j D \quad (j = 1,2\ldots, J) \qquad [59]$$

Similarly, we can define *differences in technology* between two countries, say v_D^j, as the negative of rates of growth of the price of output with respect to the dummy variable, keeping input prices constant:

$$-v_D^j = \alpha_d^j + \beta_d^{j'} \ln p^j + \beta_{td}^j T + \beta_{dd}^j D \qquad (j = 1,2\ldots, J) \tag{60}$$

We can construct a series of relative prices for producers' price of output and prices of factor inputs, where prices are comparable between countries on a bilateral basis. The price of output, the prices of inputs, and the value shares for all four inputs are observable for each industry. The rates of productivity growth are not directly observable, but average rates of productivity growth between two points of time, say T and T-1, can be expressed as the difference between a weighted average of the growth rates of input prices and the growth rates of the price of output in the form of the discrete approximation for each industry:

$$-\bar{v}_T^j = \ln q^j(T) - \ln q^j(T-1) - \bar{v}^{j'}\left[\ln p^j(T) - \ln p^j(T-1)\right] \qquad (j = 1,2\ldots, J) \tag{61}$$

where the average rates of technical change are:

$$\bar{v}_T^j = \frac{1}{2}\left[v_T^j(T) + v_T^j(T-1)\right] \tag{62}$$

and the weights are given by the average value shares:

$$v^j = \frac{1}{2}\left[v^j(T) + v^j(T-1)\right] \tag{63}$$

We refer to the index numbers [61] as *translog price indices of the rates of productivity growth*.

Similarly, differences in productivity v_D^j are not directly observable. However, the average of these differences for country K and country L can be expressed as a weighted average of the differences between the logarithms of the input prices, less the difference between the logarithms of the output price:

$$-\bar{v}_D^j = \ln q^j(\mathit{country\ K}) - \ln q^j(\mathit{country\ L}) - \bar{v}^{j'} = [\ln p^j(\mathit{country\ K}) - \ln p^j(\mathit{country\ L})] \qquad (j = 1,2\ldots, J) \tag{64}$$

where the average differences in productivity are:

$$\bar{v}_D^j = \frac{1}{2}\left[v_D^j(\mathit{country\ K}) + v_D^j(\mathit{country\ L})\right] \tag{65}$$

and the weights are given by the average value shares:

$$\bar{v}^j = \frac{1}{2}\left[v^j(\mathit{country\ K}) + v^j(\mathit{countryL})\right] \tag{66}$$

We refer to the index numbers [64] as t*ranslog price indices of differences in productivity*.

In our bilateral model of production, the capital, labour, energy and other intermediate input prices are aggregates that depend on the prices of individual capital, labour, energy and other intermediate inputs in the framework of input-output tables for both countries.

Parity index for producers' price/relative producers' price

Suppose that we can observe the absolute producers' price per one dollar's worth a of well-defined commodity in the K-th and L-th countries at time *T**. *The absolute producers' price parity* of the i-th commodity basket,[2] PPP_i^A, is defined as:

$$PPP_i^A\left(T^*\right) \equiv \frac{p_i^K\left(T^*\right)}{p_i^L\left(T^*\right)} \qquad [67]$$

where p_i^K and p_i^L are the absolute producers' prices of the i-th commodity in country K and country L, respectively. Assuming Japan and the United States as country K and country L, respectively, for example, the term PPP_i^A expresses the number of yen for one dollar in exchanging the i-th commodity between Japan and the United States.

The *relative producers' price* of the i-th commodity in country L and country K, p_{Ai}^L and p_{Ai}^K, is measured as follows:

$$p_{Ai}^L\left(T^*\right) = \frac{e\left(T^*\right)}{PPP_i^A}, \quad p_{Ai}^K\left(T^*\right) = \frac{1}{p_{Ai}^L\left(T^*\right)} \qquad [68]$$

where *e* is the nominal exchange rate which expresses the number, such as yen per dollar. The relative producers' price in country K relative to country L, p_{Ai}^K, represents the number of quantity units of the i-th commodity in country L exchangeable for one unit of the market basket in country K.

We consider the relative producers' price as one measure of international competitiveness between two countries. For example, in 1970 the $PPP_i^A(T*)$ for agricultural products was 376.4 yen per dollar, while the nominal exchange rate was 360.0 yen per dollar. The real price of Japanese agricultural products was thus 1.0456. This means that 1.0456 units of US products could be exchanged for 1 unit of Japanese product. In other words, it implies that the relative producers' price of Japanese agricultural products was 1.0456 times higher than that of the United States.

It is rather difficult, however, to observe the time series of the absolute producers' price parity (PPP) of the two countries. It is easier to measure the relative change in prices. Very often, instead of the direct observation of the absolute version of $PPP_i^A(T)$, we use *the relative producers' price parity*, $PPP_i^R(T)$, defined as:[3]

$$PPP_i^R(T) \equiv PPP_i^A(T*)\left[\frac{p_i^K(T)/p_i^K(T*)}{p_i^L(T)/p_i^L(T*)}\right] = PPP_i^A(T*)\frac{\tilde{p}_i^K(T)}{\tilde{p}_i^L(T)} \quad [69]$$

where $\tilde{p}_i^K$, and $\tilde{p}_i^L$ are price indices of the i-th commodity in country K and country L normalised to unity at time *T**.

Corresponding to the absolute $PPP_i^A(T*)$, we can obtain parity index for the real producers' price of the i-th commodity for both countries, p_{Ri}^L, and p_{Ri}^K at time T, as follows:

$$P_{Ri}^L(T) = \frac{e(T)}{PPP_i^R(T)} \quad [70]$$

$$\begin{aligned} P_{Ri}^K(T) &= \frac{1}{p_{Ri}^L(T)} \\ &= \left[\frac{p_{Ai}^K(T^*)}{\tilde{e}(T)}\right]\left[\frac{\tilde{p}_i^K(T)}{\tilde{p}_i^L(T)}\right] \end{aligned} \quad [71]$$

where $\tilde{e}$ is an index of the nominal exchange rate normalised to unity at time *T**.

Taking logarithms of equation [71], we obtain the proportional difference of producers' price of the i-th commodity between two countries:

$$\ln p_{Ri}^K = \ln\left[\frac{p_{Ai}^K(T^*)\tilde{p}_i^K(T)}{\tilde{e}(T)}\right] - \ln \tilde{p}_i^L(T) \quad [72]$$

Similarly, we can apply this method to obtain a proportional difference of factor input prices, such as labour and capital, bilaterally.

Measurement of bilateral parity between Japan and the United States

We have attempted to construct an index of parities of producers' prices of output and prices of inputs at the base year and the time series for the corresponding relative prices between Japanese and US industries. For this purpose we developed purchasing power parities for industry outputs based on the Department of Economics and Statistics of the OECD's *Purchasing Power Parities and Real Expenditure*. Data include Japanese price indices for 197 expenditure items, normalised by the US prices for corresponding items, and nominal expenditure in Japan and the United States in 1985 and 1990. These provide purchasing power parities between the yen and the dollar for 197 commodity groups for the years 1985 and 1990. These commodity groups are components of each country's GDP, corresponding to final demand deliveries at purchasers' prices. They include 163 items of consumption expenditure and 29 items of capital formation.

We would like to construct a parity index of producers' prices for industry outputs, which are classified according to a uniform classification of 163 commodities defined in the 1985 United States-Japan linked input-output table.[4] Basically, the following problems remain to be solved:

- ♦ Prices in OECD sources are purchasers' prices. They must therefore be transformed into producers' prices. Data allowing the transformation from purchasers' prices to producers' prices is available from the trade and transportation margin matrices in the input-output table. Data for the trade and transportation margin matrices are available for Japan for 1985 and for the United States for 1977.
- ♦ Expenditure items in the OECD statistics focus on items of final demand, mainly consumption expenditure and (partly) capital formation. No information is given for intermediate input prices such as energy inputs and other materials. Therefore, when we try to map the 197 commodity groups used by the OECD to the US-Japan linked input-output 163 commodity classification, it is not easy to obtain a complete correspondence between the two systems. In addition, there are no information commodities for price parities, especially for intermediate goods. We eliminated the gap between the two systems by utilising the purchasing power parities of close substitutes for the missing commodity groups or by collecting additional data.

To obtain an index of parities of producers' prices for industry outputs, we adjusted the price indices for the commodity groups in Japan and the United States by "peeling off" indirect taxes paid and trade and transportation margins for each industry.

We estimated these margin matrices for Japan in 1985 and for the United States in 1977, respectively. To obtain the parities of producers' price for the 163 commodity industrial classification, we attempted to make a bridge table between the OECD 197 and IO 163 commodity classifications; the OECD 197 commodity classification was converted into the 163 IO classification using as weights the relative shares of each commodity in the value of expenditure in the OECD statistics. We were able to obtain producers' price parities between the United States and Japan for 109 commodity classifications: leaving 54 commodities (163 items) unclassified – mainly intermediate goods not covered by the OECD statistics. More data will be required in order to solve this problem.

Table 10 presents tentative results of the relative producers' price parity index between Japan and the United States in 1985. The first column represents the common industry classification of the United States-Japan linked international input-output table. The second and third columns show the absolute purchasers' and producers' prices per one dollar's worth of a well-defined commodity in Japan in 1985. The producers' price is transformed by the trade and transportation margin matrix. The fourth and fifth columns show relative purchasers' and producers' prices between Japan and the United States, evaluated at the 1985 current exchange rate. The last two columns represent nominal expenditure on each item at current exchange rates in Japan and the United States ("n.a." in the table refers to "no answer" in the OECD statistics; no information is available in the base heading commodities of the OECD purchasing power parity data).

Next, we turn to the estimation of relative factor prices, such as labour and capital inputs. In a similar way to the output index, factor inputs, such as capital and labour, are only comparable when measured in homogeneous units. The situations seems to be the same for international comparisons of levels of inputs as for international comparisons of the growth rates of inputs. Therefore, factor inputs such as labour and capital must be categorised in homogenous units. Capital inputs such as capital stocks are broken down into various types of depreciable and non-depreciable assets for each industry. These assets are further sub-divided among the legal forms of organisation. We employ equality between the price of an asset and the discounted flow of future capital services to derive service prices for capital inputs. Although we estimate the decline in efficiency of capital goods for each component of capital inputs separately for Japan and the United States, we assume that the relative efficiency of new capital goods in a given industry is the same in both countries. The appropriate parity index for new capital goods is the parity index of producers' price for the corresponding component of investment goods output. Moreover, in order to obtain the parity index for capital inputs, we consider the difference in the real rate of returns on capital by industry and the difference in the economic rate of depreciation between Japan and the United States. The resulting price index represents the parity index of prices for capital service inputs.

For both Japan and the United States, labour inputs are cross-classified by employment status, sex, age, education and occupation. Given the detailed classification of labour inputs for each industry in our database, we construct a parity index of prices for labour inputs on the basis of relative wage levels for each component of the labour input in each industry.

Extension to multilateral comparisons

We can apply our method of estimation for the bilateral parity index of producers' price of output and prices of factor inputs to the multilateral parity index. In the OECD compilation of purchasing power parities for multilateral comparisons, prices are collected at the level of the basic heading. In principle, a basic heading consists of a group of similar well-defined commodities from which each country selects some commodities as being representative of each basic heading. However, selected commodities at the basic heading level are not the same across all participating countries. The OECD multilateral PPP comparisons are based on a matrix of binary comparisons in which each country is compared to each of the other participating countries. According to the report:

"In a multilateral comparison, it is not necessary for all countries to price all items because it is not necessary to calculate a direct binary party for each pair of countries. Countries need only price their own products and a share of the products nominated by other countries for parties to be calculated, either directly or indirectly, between pairs of countries".

In compiling the PPP for specific commodity groups in the expenditure basket at the basic heading level, the relative prices for individual goods and services are averaged to obtain unweighted parities.[5] Parities in the matrix of binary comparisons at the basic heading level are made complete and transitive by applying the Elteto-Koves-Szulc (EKS) method.

Thus a bilateral parity is identical to a multilateral one at the basic heading level. However, for aggregated PPPs at the sectoral or economy-wide level, weighting problems appear with the extension of a bilateral comparison to a multilateral one. The bottom line of this problem is the trade-off between "transitivity" and "additivity" in the methodology for multilateral comparisons. "Transitivity" is the property that the PPP between country A and country C can be derived from that of country A and country B and that of country B and country C. "Additivity" is the property that the real value of the aggregate is the sum of the real values of its components.

Two indices are commonly used for multilateral comparisons: the Elteto-Koves-Szulc (EKS) method and the Geary-Khamis (GK) method. The EKS method satisfies for "transitivity", but not for "additivity", while the GK method satisfies for "additivity", but not for "transitivity". In the EKS method, countries are treated as a set of independent entities with equal weight, and an aggregated PPP is derived as a geometric mean of bilateral Fisher indices at the basic heading level. On the other hand, the GK method is basically a weighted average of bilateral parities using each country's nominal GDP as a weight. Both methods have their advantages and disadvantages. It is important to use the appropriate method depending on one's analytical needs. OECD, like other international organisations, publishes both EKS-based and GK-based PPPs.

Table 10. PPPs for Japan-United States bilateral I-O consumption, 1985

Percentages

No.	Purchaser (nominal)	Producer (nominal)	Purchaser (real)	Producer (real)	Expenditure (Japan)	Expenditure (United States)
001	n.a.	n.a.	n.a.	n.a.	0.10547.	
002	286.19	324.21	1.19976	1.35914	119330.	112882.
003	287.78	280.10	1.20643	1.17422	60685.	77762.
004	281.13	228.21	1.17854	0.95668	201.	231.
005	n.a.	n.a.	n.a.	n.a.	0.	0.
006	n.a.	n.a.	n.a.	n.a.	0.	0.
007	257.50	253.44	1.07949	1.06244	38514.	52017.
008	n.a.	n.a.	n.a.	n.a.	0.	1964.
009	281.94	270.45	1.18193	1.13376	15412.	40004.
010	337.01	206.62	1.41278	0.86617	1381.	6073.
011	217.63	217.63	0.91233	0.91233	1201.	3597.
012	n.a.	n.a.	n.a.	n.a.	0.	10786.
013	n.a.	n.a.	n.a.	n.a.	0.	0.
014	230.59	156.54	0.96665	0.65625	77325.	9356.
015	n.a.	n.a.	n.a.	n.a.	0.	0.
016	n.a.	n.a.	n.a.	n.a.	0.	0.
017	234.67	581.89	0.98376	2.43937	-695.	723.
018	218.28	157.43	0.91505	0.65996	141.	7067.
019	n.a.	n.a.	n.a.	n.a.	525.	0.
020	367.47	354.50	1.54049	1.48613	175486.	679021.
021	n.a.	n.a.	n.a.	n.a.	27.	0.
022	307.42	295.25	1.28877	1.23772	69731.	404933.
023	279.52	249.16	1.17181	1.04453	215070.	42511.
024	322.32	379.17	1.35120	1.58956	177225.	47778.
025	322.32	321.37	1.35120	1.34726	48626.	17044.
026	305.28	296.78	1.27979	1.24415	130266.	413366.
027	357.97	342.86	1.50067	1.43733	7420.	32556.
028	333.40	322.57	1.39768	1.35227	16448.	36176.
029	316.00	299.77	1.32474	1.25667	50856.	279326.
030	308.31	350.12	1.29249	1.46776	199283.	430716.
031	365.30	482.25	1.53139	2.02167	155613.	383325.
032	303.41	312.96	1.27195	1.31198	59068.	160764.
033	272.75	125.69	1.14343	0.52692	8862.	72721.
034	198.35	357.40	0.83150	1.49828	120693.	318220.
035	223.25	206.31	0.93589	0.86488	1517.	6425.
036	223.60	183.46	0.93735	0.76911	12948.	26571.
037	222.70	211.28	0.93361	0.88571	424213.	1262863.
038	335.16	328.66	1.40505	1.37778	7755.	62202.
039	229.27	201.59	0.96112	0.84510	46005.	148029.
040	n.a.	n.a.	n.a.	n.a.	0.	0.
041	n.a.	n.a.	n.a.	n.a.	0.	0.
042	305.58	231.54	1.28105	0.97066	5481.	15409.
043	419.96	423.16	1.76056	1.77396	30977.	262729.
044	n.a.	n.a.	n.a.	n.a.	-6324.	0.
045	224.35	295.28	0.94053	1.23785	9996.	7412.
046	n.a.	n.a.	n.a.	n.a.	0.	3431.
047	230.62	191.68	0.96682	0.80355	996.	10616.
048	238.84	259.86	1.00125	1.08937	6206.	136317.
049	240.61	151.95	1.00867	0.63698	49155.	103974.
050	240.61	240.00	1.00867	1.00613	30877.	214307.
051	278.27	393.34	1.16655	1.64897	288.	3090.
052	259.82	169.45	1.08922	0.71038	820.	1411.
053	260.34	243.39	1.09140	1.02035	677.	7376.
054	n.a.	n.a.	n.a.	n.a.	0.	0.

No.	Purchaser (nominal)	Producer (nominal)	Purchaser (real)	Producer (real)	Expenditure (Japan)	Expenditure (United States)
055	n.a.	n.a.	n.a.	n.a.	0.	0.
056	170.49	154.08	0.71471	0.64591	14119.	255806.
057	170.49	127.40	0.71471	0.53406	4751.	116649.
058	170.49	147.52	0.71471	0.61844	23139.	223760.
059	223.51	234.54	0.93700	0.98323	640.	3050.
060	216.90	199.97	0.90928	0.83830	14842.	93194.
061	328.36	304.01	1.37653	1.27448	220045.	1120571.
062	468.62	656.42	1.96455	2.75182	3511.	136469.
063	309.75	294.06	1.29853	1.23277	44264.	59710.
064	219.58	209.12	0.92052	0.87668	49468.	245259.
065	n.a.	n.a.	n.a.	n.a.	0.	0.
066	255.54	321.34	1.07126	1.34709	21761.	86826.
067	248.55	298.47	1.04194	1.25123	3437.	34246.
068	n.a.	n.a.	n.a.	n.a.	0.	0.
069	n.a.	n.a.	n.a.	n.a.	0.	0.
070	n.a.	n.a.	n.a.	n.a.	0.	43.
071	264.54	324.42	1.10900	1.36003	8422.	34061.
072	n.a.	n.a.	n.a.	n.a.	0.	0.
073	280.30	316.25	1.17506	1.32577	10046.	9606.
074	220.84	317.29	0.92579	1.33014	1355.	402.
075	n.a.	n.a.	n.a.	n.a.	0.	0.
076	n.a.	n.a.	n.a.	n.a.	6427.	0.
077	n.a.	n.a.	n.a.	n.a.	0.	364.
078	202.65	184.98	0.84953	0.77549	18233.	1575.
079	225.18	260.21	0.94398	1.09084	9180.	1671.
080	n.a.	n.a.	n.a.	n.a.	2220.	0.
081	250.21	288.74	1.04894	1.21046	85626.	115830.
082	n.a.	n.a.	n.a.	n.a.	0.	4304.
083	217.74	329.80	0.91281	1.38257	686.	7139.
084	n.a.	n.a.	n.a.	n.a.	0.	0.
085	n.a.	n.a.	n.a.	n.a.	0.	541.
086	n.a.	n.a.	n.a.	n.a.	0.	3170.
087	n.a.	n.a.	n.a.	n.a.	0.	0.
088	260.12	357.24	1.09049	1.49762	275.	26015.
089	361.65	393.29	1.51609	1.64875	1812.	11525.
090	209.35	205.41	0.87765	0.86111	43825.	187992.
091	207.80	193.59	0.87113	0.81158	56597.	209897.
092	n.a.	n.a.	n.a.	n.a.	8462.	0.
093	243.91	173.87	1.02251	0.72889	5718.	18077.
094	n.a.	n.a.	n.a.	n.a.	0.	0.
095	n.a.	n.a.	n.a.	n.a.	0.	15470.
096	n.a.	n.a.	n.a.	n.a.	0.	990.
097	n.a.	n.a.	n.a.	n.a.	0.	20772.
098	275.46	293.00	1.15478	1.22830	5669.	21974.
099	156.46	176.19	0.65591	0.73863	3790.	181317.
100	267.92	369.90	1.12319	1.55068	31035.	93255.
101	189.07	140.91	0.79261	0.59070	111093.	1235449.
102	208.37	231.07	0.87354	0.96869	15236.	40209.
103	n.a.	n.a.	n.a.	n.a.	0.	55807.
104	n.a.	n.a.	n.a.	n.a.	0.	0.
105	n.a.	n.a.	n.a.	n.a.	0.	6301.
106	219.10	195.73	0.91852	0.82055	2.	35167.
107	291.20	381.06	1.22076	1.59748	29133.	96332.
108	201.54	204.87	0.84490	0.85885	19284.	52506.

No.	Purchaser (nominal)	Producer (nominal)	Purchaser (real)	Producer (real)	Expenditure (Japan)	Expenditure (United States)
109	252.62	222.77	1.05903	0.93390	5624.	3039.
110	n.a.	n.a.	n.a.	n.a.	0.	26472.
111	211.24	270.45	0.88557	1.13376	34807.	180519.
112	228.93	292.58	0.95970	1.22656	9863.	51386.
113	251.37	316.33	1.05378	1.32611	7347.	16607.
114	216.22	213.55	0.90643	0.89525	27920.	173578.
115	n.a.	n.a.	n.a.	n.a.	0.	15793.
116	209.84	259.37	0.87967	1.08731	75940.	71840.
117	n.a.	n.a.	n.a.	n.a.	0.	0.
118	n.a.	n.a.	n.a.	n.a.	0.	0.
119	n.a.	n.a.	n.a.	n.a.	0.	0.
120	n.a.	n.a.	n.a.	n.a.	0.	0.
121	n.a.	n.a.	n.a.	n.a.	0.	0.
122	n.a.	n.a.	n.a.	n.a.	0.	0.
123	n.a.	n.a.	n.a.	n.a.	0.	0.
124	n.a.	n.a.	n.a.	n.a.	0.	0.
125	281.94	281.88	1.18195	1.18167	125178.	576143.
126	393.07	392.84	1.64780	1.64686	26173.	250765.
127	204.54	204.43	0.85748	0.85700	34129.	86340.
128	223.42	223.42	0.93663	0.93663	1084.	20132.
129	n.a.	n.a.	n.a.	n.a.	572.	0.
130	n.a.	n.a.	n.a.	n.a.	16174.	0.
131	122.57	112.58	0.51383	0.47195	29283.	699978.
132	149.13	148.79	0.62519	0.62375	325590.	673740.
133	188.03	188.02	0.78825	0.78819	1162306.	3945523.
134	211.22	212.17	0.88549	0.88944	109679.	46328.
135	211.22	208.59	0.88549	0.87444	106238.	82289.
136	276.97	849.77	1.16112	3.56236	12875.	117810.
137	211.22	308.79	0.88549	1.29450	4732.	26341.
138	211.22	158.60	0.88549	0.66486	34950.	179539.
139	247.02	243.58	1.03553	1.02114	28139.	127321.
140	246.61	243.13	1.03385	1.01923	11822.	52705.
141	157.72	157.58	0.66117	0.66061	61709.	421971.
142	217.49	217.40	0.91177	0.91139	14082.	3788.
143	n.a.	n.a.	n.a.	n.a.	166075.	0.
144	626.60	626.60	2.62682	2.62682	121950.	529688.
145	212.98	212.97	0.89284	0.89283	206323.	896746.
146	n.a.	n.a.	n.a.	n.a.	0.	0.
147	175.79	175.78	0.73694	0.73691	499248.	2622247.
148	n.a.	n.a.	n.a.	n.a.	0.	482.
149	464.27	464.27	1.94629	1.94629	2047.	8395.
150	375.28	375.28	1.57322	1.57322	306.	11992.
151	375.28	375.28	1.57322	1.57322	1241.	246979.
152	375.28	375.28	1.57322	1.57322	12286.	31529.
153	225.69	223.66	0.94611	0.93761	3813.	32361.
154	225.69	224.83	0.94611	0.94254	237004.	157798.
155	335.50	329.85	1.40647	1.38278	453886.	1403697.
156	257.81	238.34	1.08076	0.99917	132640.	169131.
157	269.47	269.39	1.12968	1.12934	154921.	141980.
158	262.59	264.00	1.10083	1.10674	167777.	307557.
159	229.05	229.05	0.96020	0.96020	5248.	66010.
160	556.96	562.35	2.33488	2.35748	61314.	431554.
161	321.44	321.44	1.34752	1.34752	2200.	56611.
162	190.17	458.41	0.79722	1.92173	-2809.	279074.
163	n.a.	n.a.	n.a.	n.a.	0.	318922.

As mentioned above, producers' price parities for international productivity level comparisons pose the same problems as purchasing power parities. In international productivity comparisons, we are interested not only in a productivity level comparison of the aggregated economy, but also in comparing sectoral production. Our analysis is principally based on the international linked input-output tables, compiled in 1975 and 1985 by the Japanese Institute of Developing Economies. The tables include domestic and international inter-industrial transactions covering 24 industrial sectors for eight countries in 1975 – Japan, Korea, the Philippines, Singapore, Indonesia, Malaysia, Thailand, the United States – and ten countries in 1985 – the eight countries used in the 1975 table, plus China and Chinese Taipei – in the Pan-Pacific region. Their transactions are evaluated by US dollar values at current prices. It might be expected that the system of relative prices in terms of producers' price of output across industries might be different for each country because of differences in technology, factor prices and demand structure. Even within a country, the system of relative prices in 1975 is different from that in 1985.

Therefore, when the usual methodologies of input-output analysis are applied to explain structural changes in time series and structural differences across countries, deflators for domestically produced commodities, for imported commodities and for factor inputs such as labour and capital must be introduced. These deflators provide comparable input-output tables at constant prices between 1975 and 1985 in each country. Moreover, parity indices of prices of output and factor inputs must be prepared, along the lines proposed above. These parity indices enable international comparisons of the structure of the economy across countries.

In multilateral and intertemporal comparisons, parity indices of prices of output and inputs must be constructed, which satisfy the "transitivity" condition of index numbers simultaneously across multiple countries and across multiple periods. Instead of a specific reference country, we assume that there is one hypothetical reference country in the world. The price parity index of output and inputs in a given country is defined as the parity index normalised by prices of output and inputs in the hypothetical reference country. The price index in the hypothetical reference country is defined as a weighted average of prices in all countries. Diewert (1978) recommends that the weight in this formulation should be the real share of output as follows:

$$\begin{aligned}\sigma_J^S &= \frac{x_J^{ST}}{\sum_{s=1}^{S}\sum_{t=1}^{T} X_j^{st}} \\ &= \frac{PX_j^{st}}{P_{Rj}^{st}} \Big/ \sum_{s=1}^{S}\sum_{t=1}^{T}\frac{PX_j^{st}}{P_{Rj}^{st}}\end{aligned} \qquad [73]$$

where s denotes the number of countries s = 1,...,S and t denotes number of periods, t = 1,...,T. X_j^{st} and PX_j^{st} are real and nominal values of output of the j-th industry in the s-th country at year t, and P_{Rj}^{st} represents the relative producers' price parity index in the s-th country at year t bilaterally estimated against the reference country.

The price index in the hypothetical reference country is defined as follows:

$$\overline{P_j} = \sum_{s=1}^{S}\sum_{t=1}^{T} P_{Rj}^{st}\sigma_j^s \qquad [74]$$

In addition, the price index in country s is defined as the following index based on the index of the hypothetical reference country:

$$P_j^{st} = \frac{P_{Rj}^{st}}{\overline{P}_j} \qquad [75]$$

where P_{Rj}^{st} represents the bilateral price index of country s at year t, where the reference country is defined as country A in all the bilateral indices.

Concluding remarks

The international comparison of productivity has two main aspects: *i)* the comparison of the growth rate of productivity at both the aggregate and the sectoral levels; and *ii)* the comparison of levels of productivity by commodity and by industry. Many unsolved theoretical and statistical problems persist in international comparisons.

- ♦ Basically, we have a choice as to what measures of productivity are appropriate. Productivity can be defined as so-called partial productivity such as labour productivity, energy productivity, and so on. We can not deny that such partial productivity measures and their international comparisons are meaningful from the viewpoint of comparisons of the efficiency of a given input in production. However, where we wish to account for the international competitiveness of a commodity in production and its contribution to economic growth, we need to evaluate total efficiency of production with appropriate internationally comparable measures. Total factor productivity is one measure which can possibly be used to answer such questions.

- ♦ International comparisons of productivity by commodity, not only in terms of total factor productivity, but also in terms of partial productivity, must be based on a well-defined commodity. The commodity chosen for comparison must be homogeneous in quality – as defined by well-defined commodity properties. If differences in quality exist in the selected commodity, we must adjust for these in the comparison. Quality adjustment can be performed using the hedonic approach, while other possibilities include index approaches in which the index is constructed as a weighted average of specific categories of quality measures by commodity. The most important issue in international comparison is, therefore, the selection of the base heading commodity classification.

- ♦ Similarly, well-defined measures of factor inputs such as labour and capital must be selected. Many differences in quality measures exist in factor inputs. In the case of the labour input, it must be broken down into specific labour classified by sex, age, occupation, education and employment status, and the constructed index needs to be adjusted for changes in composition of categorised labour inputs. In addition, we need to adjust quality changes of capital inputs. However, in the case of capital inputs, it is very difficult to find quality-adjusted measures which satisfy the theoretical requirements.

- ♦ Even once well-defined measures of output and inputs have been selected, some aggregation problems still remain in comparisons of productivity at the aggregated level. As mentioned in the first section, we need to take into account compositional changes among sectors.

- ♦ The purchasing power parity index constructed by the OECD and the UN represents literally an international comparison of purchasing power based on purchasers' price, and not on producers' price. This implies that the index reflects not only differences in cost structure in production, but also differences in the demand structure of the economy. We would like to propose an approach allowing estimation of international parity indices of producers' price by commodity instead of exchange rate or purchasing power parity indices by commodity from the point of view of a comparison of factor cost and other costs in production. When comparing levels of productivity, we have to define and construct comparable measures of prices in output and inputs. We therefore need a *relative producer's price parity index* for output price by commodity and a *relative factor price parity index* for input prices. These indices differ from the purchasing power parity index, whose objective is to construct a measure of international comparison of purchasers' power in the market basket. For international comparisons of productivity, we need to construct price indices which allow comparisons of cost structures reflecting differences in technology and input prices.

- Similar to the discussion of the purchasing power parity index, the relative producers' price parity index must satisfy appropriate properties such as transitivity and additivity as an index number. One possibility to solve this requirement is to prepare the index proposed above, in which a hypothetical reference country is chosen as a centre of gravity among all countries and all observed time periods. Each index in each country is measured against the relative unit of prices in the hypothetical reference country. This satisfies the transitivity condition as an index number.

- The multilateral index is based upon any bilateral index. The bilateral index is constructed as an bilateral index based on a given reference country. However, unsolved problems remain even in the relative measures based on the hypothetical reference country as a centre of gravity: the centre of gravity might vary if a number of countries and a number of observed periods were added. In this chapter we tried to estimate bilateral parity indices of producers' price of output for 163 commodities based on OECD statistics in Japan and the United States. Estimated parity indices by commodity are quite different from the market exchange rate. Moreover, we tried to estimate bilateral parity indices of prices of factor inputs such as labour and capital. Our methodology is principally based on production theory, in which each producer behaves so as to maximise his profit in a competitive market. Applying our methodology to the international comparison of levels of technology, and introducing our estimated data of bilateral parity indices in terms of producers' price and factor prices into the input-output framework, we can deduce *rates of productivity growth* by industry and *proportional differences in technology* between two countries. Our estimates of bilateral parity indices of producers' price make clear that sizeable differences exist in relative prices across countries. In order to evaluate the differences in relative prices across countries in the input-output framework, one possibility might be to use our estimated parity indices of producers' prices of output, although some unsolved problems remain.

- Here, we tried to estimate bilateral parity indices of producers' price by commodity, where estimated indices are always based on a reference country – the United States in our estimations. Transitivity conditions are not guaranteed in our bilateral parity indices. In the multilateral linkages of the international input-output tables, we have to construct multilateral parity indices in which transitivity conditions are always satisfied. In order to estimate the multilateral parity indices for the input-output framework, we must observe the absolute producers' price per quantity unit of well-defined commodity in each country, *i.e.* not only those countries explicitly included in the international input-output framework, but also those countries which are not included. This is because relative prices in the rest of the world must be estimated in order to evaluate imported prices from the rest of the world.

NOTES

1. We should note here that the translog function is not self-dual.
2. In the United Nations International Comparison Project(ICP), Kravis and his associates (1975, 1978) constructed these absolute price indices based upon a survey of the purchasers' price as absolute purchasing power parity indices in the context of the international income and expenditure comparison project. OECD engaged in estimating purchasing power parities in the framework of the Eurostat-OECD Purchasing Power Parity Programme. Our concept of the absolute producers' price parity is defined at the producers' price for each commodity.
3. In the PPP literature (see, for example, Levich, 1985; and Dornbush, 1988), the relative version of PPPs is defined as:

$$PPP^R = e(T^*)\frac{\tilde{p}^J(T)}{\tilde{p}^{US}(T)}$$

   This formulation assumes that in bench year *T** the absolute PPP is equal to the nominal exchange rate. If the absolute $PPP_i^A(T^*)$ is known in the bench year, we consider our formulation [69] to be superior.
4. The 1985 United States-Japan linked input-output table was published in 1994.
5. Two parities are calculated for each pair of countries. The first is the geometric men of relative prices for products representative of the first country; the second is the geometric mean of relative price for products representative of the second country. The geometric average of these two parities is then taken in order to derive a single parity for the two countries.

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