A Comparison of Cost Structures in Japan and the U.S. Using Input-Output Tables[1]

By
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Abstract

This paper attempts to explain why prices are systematically higher in Japan than in the U.S. It is aimed at measuring *direct and indirect* productivity and input-price components of sectorial costs of production in Japan relative to the U.S. and presenting a methodology for a bilateral comparison of cost structure by using harmonized input-output tables and Purchasing Power Parity data. The empirical application reveals new elements that explain the difference in costs of production between Japan and the U.S. The main finding is that only in a few industries was the "direct" cost efficiency higher in Japan than in the U.S. during 1985, but even in these industries the "indirect" productivity component was significantly lower than that in the U.S.

1. Introduction

International competitiveness and trade disequilibrium between Japan and the United States have been thoroughly examined by many empirical studies. Among these, the path-breaking works carried out by Dale W. Jorgenson and his associates have established a methodology which has become standard in the economic literature aimed at accounting for intercountry differences in the rates of change and the levels of sectorial costs of production. The methodology was originated by Jorgenson and Nishimizu (1978), who established a theoretical framework for a bilateral comparison of aggregate economic growth in Japan and the U.S. Jorgenson and Nishimizu (1981) extended this analysis at the industry level for the first time by measuring the relative sectorial values of production and relative productivity. The most recent studies in this field are those made by Jorgenson and Kuroda (1990), Jorgenson, Sakuramoto, Yoshioka, and Kuroda (1990), Fuss and Waverman (1991), Nakamura (1991), Jorgenson and Kuroda (1992), and Denny, Bernstein, Fuss, Nakamura, and Waverman (1992)[2]. These studies compare costs of production by taking into account the *direct* input cost components.

The unit cost of an industry's output in a country relative to the unit cost of another country is explained by decomposing it into differences in primary and intermediate input prices and productivity levels in the same industry of the two countries. The output and input prices,

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[2] See Jorgenson (1988) for an overview of previous analyses. A more descriptive analysis is provided by van Art and Pilat (1993) and Pilat and van Art (1994). Among other studies that are not concerned directly with the analysis of relative cost and productivity levels but focus their attention on the international comparison of input substitution and technical change, see the recent works made by Boskin and Lau (1992) and Saito and Tokutsu (1992)(1993).

relative to those in the reference country, are measured by using sectorial Purchasing Power Parities (PPP). The intercountry difference in sectorial costs of production is accounted for with a good degree of approximation by postulating a sufficiently general functional form of the production or cost function. In the above-mentioned studies this function has a Translog functional form, which is applied either directly after having been econometrically estimated or implicitly by using Törnqvist index numbers. Diewert (1976), in fact, showed that, when there is no variation in technology, there is an exact correspondence between Translog production (or cost) functions and aggregating Törnqvist index numbers of input quantities (or prices). Variations in productivity may be represented by the "implicit" Törnqvist index number obtained by the difference between production (or cost) variations and the aggregating Törnqvist index numbers of differences in input quantities (or prices) [3].

The novelty of this paper is the extension of the above-mentioned methodology to the input-output framework, which permits us to analyze, not only the *direct*, but also the *indirect* input components of costs of production which are incorporated in the intermediate inputs. More specifically, whereas the studies mentioned above have left the costs of intermediate inputs "unexplained," the techniques of input-output analysis permits us to decompose these costs into indirect input price and technological components. The distinction of the analyses based on direct costs of production from those based on direct *and* indirect costs is related, respectively, to the concepts of "industry" and the so-called "vertically integrated sector". As we shall see, both concepts are familiar in I-O analysis and have always been employed in the economic literature, although their definition has seldom been explicitly established[4].

Moreover, by adopting the approximating Translog functional form of sectorial cost functions, we are able to consider a modified Leontief price equation system, where the physical input-output coefficients may vary according to this particular functional form. Since the Translog cost function includes the Cobb-Douglas cost function as a special case, our input-output equations represent a generalization of Klein's (1952-53) reformulation of Leontief's input-output system.

The comparative study of cost structure was carried out on the input-output tables for Japan and the U.S., which were harmonized by adopting the same sectorial classification.

In the following section we present the methodology of decomposing differences in costs of production in the intertemporal and interspacial comparisons within the input-output framework. In section 3, we present the application of the decomposition based on the Translog-Törnqvist representation of the technology of sectorial price differences between Japan and the U.S. in the year 1985. Section 4 provides the concluding remarks.

2. Accounting for Cost Differences in the Intertemporal and Interspacial Comparisons

The international and interspacial comparisons of cost structure can be based on accounting methods which are basically the same as those developed for intertemporal comparisons. Let's start by considering the decomposition of the time-change of an aggregate value as follows:

$$\frac{\partial V_t}{\partial t} = \sum_{i=1}^{N} \frac{\partial w_{it}}{\partial t} x_{it} + \sum_{i=1}^{N} w_{it} \frac{\partial x_{it}}{\partial t} \tag{1}$$

where $V_t \equiv \sum_{i=1}^{N} w_{it} \cdot x_{it} = \mathbf{w}_t' \cdot \mathbf{x}_t$ is the sum of values obtained by multiplying the prices w_{it} by the quantities x_{it}, for $i = 1, ..., N$, and t means that they are considered as functions of time ($\mathbf{w}_t$

[3] Denny and Fuss (1983), however, have shown that the direct application of econometrically estimated Translog production (or cost) functions is not always equivalent to the application of Törnqvist index numbers. In fact, the Törnqvist index numbers of productivity difference correspond *exactly* (in Diewert's sense) to the measure obtained using the underlying Translog functions only if these differ in their "first-order" parameters.

[4] See Pasinetti (1973) for an extensive discussion of the concept of vertical integration in economic analysis.

and $\mathbf{x}_t$ represent column vectors of prices and quantities at time t, respectively, and $'$ denotes transposition). Two main accounting methods for intertemporal comparisons can be devised starting from equation (1) and following the so-called Bennet (1920) decomposition procedure and the Divisia (1925) index number approach. Denny and Fuss (1983b) provided a justification for extending these methods to interspacial comparisons.

2.1. The Bennet decomposition procedure in the I-O accounting for cost changes

Integrating both sides of (1) from period 0 to period 1 yields:

$$\begin{aligned} V_1 - V_0 &= \int_0^1 \tfrac{\partial V_t}{\partial t} \cdot dt \\ &= \sum_{i=1}^N \int_0^1 \tfrac{\partial w_{it}}{\partial t} x_{it} \cdot dt + \sum_{i=1}^N \int_0^1 w_{it} \tfrac{\partial x_{it}}{\partial t} \cdot dt \\ &= \int_0^1 \tfrac{\partial \mathbf{w}_t'}{\partial t} \mathbf{x}_t \cdot dt + \int_0^1 \mathbf{w}_t' \tfrac{\partial \mathbf{x}_t}{\partial t} \cdot dt \end{aligned} \tag{2}$$

Bennet (1920; p.457) discrete-time approximations to the two sums of integrals in decomposition (2) are given by

$$\begin{aligned} \Delta W &\equiv (\mathbf{w}_1' - \mathbf{w}_0')\tfrac{1}{2}(\mathbf{x}_1 + \mathbf{x}_0) \sim \int_0^1 \tfrac{\partial \mathbf{w}_t'}{\partial t} \mathbf{x}_t \cdot dt \\ \Delta X &\equiv \tfrac{1}{2}(\mathbf{w}_0' + \mathbf{w}_1')(\mathbf{x}_1 - \mathbf{x}_0) \sim \int_0^1 \mathbf{w}_t' \tfrac{\partial \mathbf{x}_t}{\partial t} \cdot dt \end{aligned} \tag{3}$$

Bennet also showed that the sum of the two approximating variables ΔW and ΔX is exactly equal to the difference in the aggregate value in the two periods, that is:

$$V_1 - V_0 = \Delta W + \Delta X \tag{4}$$

This result can be justified also on the ground of Diewert's (1976, p.118) *Quadratic lemma.* This states that, for any quadratic function $y = f(z_1, z_2, ..., z_r)$ such that

$$f(z_1, z_2, ..., z_r) \equiv a_0 + \sum_m^r a_m z_m + \sum_m^r \sum_n^r a_{mn} z_m z_n \tag{5}$$

where a_m and a_{mn} are constants and $a_{mn} = a_{nm}$ for all m, n, then

$$y_1 - y_0 = \sum_m^r \tfrac{1}{2} \left[\tfrac{\partial f(\mathbf{z}^0)}{\partial z_m^0} + \tfrac{\partial f(\mathbf{z}^1)}{\partial z_m^1} \right] \cdot (z_m^1 - z_m^0) \tag{6}$$

Since $V_t = \mathbf{w}_t' \cdot \mathbf{x}_t$ is a special case of (5), the corresponding accounting equation for cost differences between period 1 and period 0 can be written as (4).

In the input-output framework, V_t can be assigned the meaning of a sectorial cost of production and $\mathbf{w}_t$ and $\mathbf{x}_t$ assume the meaning of vectors of input prices and input quantities, respectively. Fujikawa, Izumi, and Milana (1993a)(1993b)(1995) applied the decomposition formula (4) to the changes observed in the accounting Leontief price system, which is expressed in "reduced" form as follows:

$$\mathbf{p}_t = \mathbf{v}_t \mathbf{F}_t (\mathbf{I} - \mathbf{A}_t)^{-1} \tag{7}$$

If, for each *ith* output price p_{it}, we replace the vector $\mathbf{w}_t'$ with the row vector of primary input prices $\mathbf{v}_t \equiv [v_{1t} v_{2t} ... v_{Mt}]$ of order M, and the vector $\mathbf{x}_t$ with *ith* column of the matrix of order $M \times N$ given by $\mathbf{F}_t(\mathbf{I} - \mathbf{A}_t)^{-1}$, where the matrices $\mathbf{F}_t$ and $\mathbf{A}_t$ are the Leontief's matrices of direct input-output coefficients at period t, and apply repeatedly at various stages the same decomposition procedure described above, we have:

$$\begin{aligned}(\mathbf{p}_1 - \mathbf{p}_0) &= \mathbf{\Delta FIM1{+}\Delta FIM2{+}\Delta FIM3} \\ &= \mathbf{\Delta FIM1A{+}\Delta FIM1B{+}\Delta FIM2A{+}\Delta FIM2B{+}\Delta FIM3A{+}\Delta FIM3B} \\ &= \mathbf{\Delta FIM1A{+}\Delta FIM1B{+}\Delta FIMT1{+}\Delta FIMT2}\end{aligned} \tag{8}$$

where

$\mathbf{\Delta FIM1} \equiv (\mathbf{v}_1 - \mathbf{v}_0)\frac{1}{2}[\mathbf{F}_0(\mathbf{I}-\mathbf{A}_0)^{-1} + \mathbf{F}_1(\mathbf{I}-\mathbf{A}_1)^{-1}]$: Total primary input price component;

$\mathbf{\Delta FIM2} \equiv \frac{1}{2}(\mathbf{v}_1 + \mathbf{v}_0)(\mathbf{F}_1 - \mathbf{F}_0)\frac{1}{2}[(\mathbf{I}-\mathbf{A}_0)^{-1} + (\mathbf{I}-\mathbf{A}_1)^{-1}]$: Total primary input technological component;

$\mathbf{\Delta FIM3} \equiv \frac{1}{2}(\mathbf{v}_1 + \mathbf{v}_0)\frac{1}{2}(\mathbf{F}_1 + \mathbf{F}_0)[(\mathbf{I}-\mathbf{A}_1)^{-1} - (\mathbf{I}-\mathbf{A}_0)^{-1}]$: Total intermediate input technological component.

These can, respectively, be further decomposed as follows:

$\mathbf{\Delta FIM1} = \mathbf{\Delta FIM1A{+}\Delta FIM1B}$:

$\mathbf{\Delta FIM2} = \mathbf{\Delta FIM2A{+}\Delta FIM2B}$

$\mathbf{\Delta FIM3} = \mathbf{\Delta FIM3A{+}\Delta FIM3B}$

where

$\mathbf{\Delta FIM1A} \equiv (\mathbf{v}_1 - \mathbf{v}_0)\frac{1}{2}(\mathbf{F}_0 + \mathbf{F}_1)$: Direct primary input price component;

$\mathbf{\Delta FIM1B} \equiv (\mathbf{v}_1 - \mathbf{v}_0)\frac{1}{2}[\mathbf{F}_0\mathbf{A}_0(\mathbf{I}-\mathbf{A}_0)^{-1} + \mathbf{F}_1\mathbf{A}_1(\mathbf{I}-\mathbf{A}_1)^{-1}]$: Indirect primary input price component;

$\mathbf{\Delta FIM2A} \equiv \frac{1}{2}(\mathbf{v}_1 + \mathbf{v}_0)(\mathbf{F}_1 - \mathbf{F}_0)$: Direct primary input technological component;

$\mathbf{\Delta FIM2B} \equiv \frac{1}{2}(\mathbf{v}_1 + \mathbf{v}_0)(\mathbf{F}_1 - \mathbf{F}_0)\frac{1}{2}[\mathbf{A}_0(\mathbf{I}-\mathbf{A}_0)^{-1} + \mathbf{A}_1(\mathbf{I}-\mathbf{A}_1)^{-1}]$: Indirect primary input technological component;

$\mathbf{\Delta FIM3A} \equiv \frac{1}{2}(\mathbf{v}_1 + \mathbf{v}_0)\frac{1}{2}(\mathbf{F}_1 + \mathbf{F}_0)\frac{1}{2}[(\mathbf{I}-\mathbf{A}_0)^{-1} + (\mathbf{I}-\mathbf{A}_1)^{-1}](\mathbf{A}_1 - \mathbf{A}_0)$: Direct intermediate input technological component;

$\mathbf{\Delta FIM3B} \equiv \frac{1}{2}(\mathbf{v}_1 + \mathbf{v}_0)\frac{1}{2}(\mathbf{F}_1 + \mathbf{F}_0)\frac{1}{2}[(\mathbf{I}-\mathbf{A}_0)^{-1} + (\mathbf{I}-\mathbf{A}_1)^{-1}](\mathbf{A}_1 - \mathbf{A}_0)\frac{1}{2}(\mathbf{A}_0 + \mathbf{A}_1)$ $\cdot\frac{1}{2}[(\mathbf{I}-\mathbf{A}_0)^{-1} + (\mathbf{I}-\mathbf{A}_1)^{-1}]$: Indirect intermediate input technological component;

and obtaining also

$\mathbf{\Delta FIMT1} \equiv \mathbf{\Delta FIM2A} + \mathbf{\Delta FIM3A}$: Direct total input technological component;

$\mathbf{\Delta FIMT2} \equiv \mathbf{\Delta FIM2B{+}\Delta FIM3B}$: Indirect total input technological component.

It can be noted that the term ($\mathbf{\Delta FIM2{+}\Delta FIM3}$) can be defined as the difference in the unit costs of production after accounting for differences in input prices. By normalizing output and input prices, so that $\mathbf{p}_0 = [11...1]$ and $\mathbf{v}_0 = [11...1]$, and redefining consistently the matrices $\mathbf{F}_0$, $\mathbf{F}_1$, $\mathbf{A}_0$, and $\mathbf{A}_1$, the cost efficiency (defined as cost ratio) of the vertically integrated sectors in 1 with respect to the same sectors in 0 is given by

$$\gamma_{VIS} = [\iota + \mathbf{\Delta FIM2{+}\Delta FIM3}] \tag{9}$$

where ι is the unit vector [1 1 ... 1].

The cost efficiency of industries in 1 with respect to the respective industries in 0 can be calculated by taking into account the "direct" technological components, that is

$$\gamma_{IND} = [\iota + \mathbf{\Delta FIM2A{+}\Delta FIM3A}] \tag{10}$$

The effect on cost efficiency of vertically integrated sectors arising from the relative productivity incorporated directly and indirectly into intermediate inputs is given by the ratio

$$\gamma_{INTP} = \gamma_{VIS} \cdot \widehat{\gamma}_{IND}^{-1} \tag{11}$$

where ^ denotes a transformation of a vector into a diagonal matrix.

The relative total factor productivity of the vertically integrated sectors in 1 with respect to those in 0 are expressed as

$$\pi_{VIS} = [11...1] \cdot \widehat{\gamma}_{VIS}^{-1} \tag{12}$$

The total factor productivity of industries in 1 relative to that of industries in 0 is given by

$$\pi_{IND} = [11...1] \cdot \widehat{\gamma}_{IND}^{-1} \tag{13}$$

Therefore, the relative level of total factor productivity of 1 with respect to 0 can be decomposed as follows:

$$\pi_{VIS} = \pi_{IND} \cdot \widehat{\pi}_{INTP} \tag{14}$$

where $\widehat{\pi}_{INTP} = \widehat{\gamma}_{INTP}^{-1}$.

A slightly different procedure can be set up starting from the traditional input-output price system that is expressed in "structural" form as follows:

$$\mathbf{p}_t = \mathbf{p}_t \mathbf{A}_t + \mathbf{v}_t \mathbf{F}_t \tag{15}$$

Adopting Bennet's discrete-time approximation given by (4) to the decomposition of time-change of the output prices in each sector yields:

$$(\mathbf{p}_1 - \mathbf{p}_0) = (\mathbf{p}_1 - \mathbf{p}_0)\tfrac{1}{2}(\mathbf{A}_0 + \mathbf{A}_1) + (\mathbf{v}_1 - \mathbf{v}_0)\tfrac{1}{2}(\mathbf{F}_0 + \mathbf{F}_1) + \Delta\mathbf{\Upsilon} \tag{16}$$

where $\Delta\mathbf{\Upsilon} = \frac{1}{2}(\mathbf{p}_0 + \mathbf{p}_1)(\mathbf{A}_1 - \mathbf{A}_0) + \frac{1}{2}(\mathbf{v}_0 + \mathbf{v}_1)(\mathbf{F}_1 - \mathbf{F}_0)$ is the industry "direct" technological component.

Expressing the system (16) in "reduced" form by solving it with respect to $(\mathbf{p}_1 - \mathbf{p}_0)$, through a simple further manipulation, gives:

$$\begin{aligned}(\mathbf{p}_1 - \mathbf{p}_0) &= \Delta\mathbf{V1} + \Delta\mathbf{V2} + \Delta\mathbf{F1} + \Delta\mathbf{F2} + \Delta\mathbf{A1} + \Delta\mathbf{A2} \\ &= \Delta\mathbf{V1} + \Delta\mathbf{V2} + \Delta\mathbf{T1} + \Delta\mathbf{T2}\end{aligned} \tag{17}$$

where

$\Delta\mathbf{V1} \equiv (\mathbf{v}_1 - \mathbf{v}_0)\frac{1}{2}(\mathbf{F}_0 + \mathbf{F}_1)$: Direct primary input price component;

$\Delta\mathbf{V2} \equiv (\mathbf{v}_1 - \mathbf{v}_0)\frac{1}{2}(\mathbf{F}_0 + \mathbf{F}_1)\frac{1}{2}(\mathbf{A}_0 + \mathbf{A}_1)\left[\mathbf{I} - \frac{1}{2}(\mathbf{A}_0 + \mathbf{A}_1)\right]^{-1}$: Indirect primary input price component;

$\Delta\mathbf{F1} \equiv \frac{1}{2}(\mathbf{v}_0 + \mathbf{v}_1)(\mathbf{F}_1 - \mathbf{F}_0)$: Direct primary input technological component;

$\Delta\mathbf{F2} \equiv \frac{1}{2}(\mathbf{v}_0 + \mathbf{v}_1)(\mathbf{F}_1 - \mathbf{F}_0)\frac{1}{2}(\mathbf{A}_0 + \mathbf{A}_1)\left[\mathbf{I} - \frac{1}{2}(\mathbf{A}_0 + \mathbf{A}_1)\right]^{-1}$: Indirect primary input technological component;

$\Delta\mathbf{A1} \equiv \frac{1}{2}(\mathbf{p}_0 + \mathbf{p}_1)(\mathbf{A}_1 - \mathbf{A}_0)$: Direct intermediate input technological component;

$\Delta\mathbf{A2} \equiv \frac{1}{2}(\mathbf{p}_0 + \mathbf{p}_1)(\mathbf{A}_1 - \mathbf{A}_0)\frac{1}{2}(\mathbf{A}_0 + \mathbf{A}_1)\left[\mathbf{I} - \frac{1}{2}(\mathbf{A}_0 + \mathbf{A}_1)\right]^{-1}$: Indirect intermediate input technological component;

and

$\Delta\mathbf{T1} \equiv \Delta\mathbf{F1} + \Delta\mathbf{A1} = \Delta\mathbf{\Upsilon}$: Direct total input technological component;

$\Delta\mathbf{T2} \equiv \Delta\mathbf{F2} + \Delta\mathbf{A2}$: Indirect total input technological component.

We note that the decomposition (17) approximates the decomposition given by (8), since

$\Delta\mathbf{V1} = \Delta\mathbf{FIM1A}$

$\Delta\mathbf{V2} \neq \Delta\mathbf{FIM1B}$

$\Delta\mathbf{F1} = \Delta\mathbf{FIM2A}$

$\Delta\mathbf{F2} \neq \Delta\mathbf{FIM2B}$
$\Delta\mathbf{A1} \neq \Delta\mathbf{FIM3A}$
$\Delta\mathbf{A2} \neq \Delta\mathbf{FIM3B}$
and
$\Delta\mathbf{T1} \neq \Delta\mathbf{FIM2A}+\Delta\mathbf{FIM3A}$
$\Delta\mathbf{T2} \neq \Delta\mathbf{FIM2B}+\Delta\mathbf{FIM3B}$

Moreover, the intermediate input price component in (16) can be reconstructed by using the indirect input price and technological components in (17), that is $(\mathbf{p}_1 - \mathbf{p}_0)\frac{1}{2}(\mathbf{A}_0 + \mathbf{A}_1) = \Delta\mathbf{V2} + \Delta\mathbf{T2} = \Delta\mathbf{V2} + \Delta\mathbf{F2} + \Delta\mathbf{A2}$. This can be approximated by using the corresponding elements in (8), that is $(\mathbf{p}_1 - \mathbf{p}_0)\frac{1}{2}(\mathbf{A}_0 + \mathbf{A}_1) \sim \Delta\mathbf{FIM1B} + \Delta\mathbf{FIM2B} + \Delta\mathbf{FIM3B}$[5].

The two decomposition procedures (8) and (11) are not, however, equivalent. The decomposition (8) starts from the reduced form of the accounting price equation system given by (7), whereas the decomposition (17) calculates the reduced form of the decomposition of price changes after the decomposition procedure has been applied to the "structural" form of the accounting equation system. Moreover, we note that the decomposition (8) has the advantage of avoiding the use of the weights $\frac{1}{2}(\mathbf{p}_0+\mathbf{p}_1)$, which are evidently constructed by using the same prices that are under examination.

Finally, under the normalization of output and input prices, so that $\mathbf{p}_0= [11...1]$ and $\mathbf{v}_0= [11...1]$, and consistent definition of the matrices $\mathbf{F}_0$, $\mathbf{F}_1$, $\mathbf{A}_0$, and $\mathbf{A}_1$, relative cost efficiencies of vertically integrated sectors and industries are, respectively:

$$\begin{aligned} \gamma_{VIS} &\equiv [\iota + (\Delta\mathbf{F1}+\Delta\mathbf{F2})+(\Delta\mathbf{A1}+\Delta\mathbf{A2})] \\ &= [\iota + \Delta\mathbf{T1}+\Delta\mathbf{T2}] \end{aligned} \tag{18}$$

and

$$\begin{aligned} \gamma_{IND} &\equiv [\iota + \Delta\mathbf{F1}+\Delta\mathbf{A1}] \\ &= [\iota + \Delta\mathbf{T1}] \end{aligned} \tag{19}$$

The relative total factor productivity measures for the vertically integrated sectors and industries can be calculated, respectively, by using the above cost efficiency measures in the definitions (12) and (13).

2.2. The Divisia index number approach in the I-O decomposition of cost changes

The second alternative decomposition method can be derived from the Divisia (1925) index number approach. Starting from (1) and dividing through by V_t we obtain:

$$\begin{aligned} \frac{\partial V_t}{\partial t}\frac{1}{V_t} = \frac{\partial \ln V_t}{\partial t} &= \sum_{i=1}^{N} \frac{\partial w_{it}}{\partial t} \cdot \frac{1}{w_{it}} \cdot \frac{w_{it}x_{it}}{\sum_{j=1}^{N} w_{jt}x_{jt}} + \sum_{i=1}^{N} \frac{w_{it}x_{it}}{\sum_{j=1}^{N} w_{jt}x_{jt}} \cdot \frac{1}{x_{it}} \cdot \frac{\partial x_{it}}{\partial t} \\ &= \sum_{i=1}^{N} \frac{\partial \ln w_{it}}{\partial t} \cdot s_{it} + \sum_{i=1}^{N} \frac{\partial \ln x_{it}}{\partial t} \cdot s_{it} \end{aligned} \tag{20}$$

where $s_{it} \equiv \frac{w_{it}x_{it}}{\sum_{j=1}^{N} w_{jt}x_{jt}}$ is the cost share of the *ith* input at time *t*. Integrating both sides of (20) from period 0 to period 1 yields:

[5] Commenting on the decomposition procedure (8) proposed in a former version of the paper written by Fujikawa, Izumi, and Milana (1993a) and presented at the 1993 PAPAIOS Annual Conference, Mitsuo Ezaki suggested an alternative procedure, which consists of calculating components equivalent to $(\Delta\mathbf{V1} + \Delta\mathbf{V2})$, $(\Delta\mathbf{F1} + \Delta\mathbf{F2})$, and $(\Delta\mathbf{A1} + \Delta\mathbf{A2})$.

$$\begin{aligned}\ln V_1 - \ln V_0 &= \int_0^1 \tfrac{\partial \ln V_t}{\partial t} \cdot dt \\ &= \sum_{i=1}^N \int_0^1 \tfrac{\partial \ln w_{it}}{\partial t} \cdot s_{it} \cdot dt + \sum_{i=1}^N \int_0^1 \tfrac{\partial \ln x_{it}}{\partial t} \cdot s_{it} \cdot dt \\ &= \int_0^1 \tfrac{\partial \ln \mathbf{w}_t'}{\partial t} \cdot \mathbf{s}_t \cdot dt + \int_0^1 \mathbf{s}_t' \cdot \tfrac{\partial \ln \mathbf{x}_t}{\partial t} \cdot dt\end{aligned} \tag{21}$$

Good discrete-time approximations to the two sums of integrals in (21) are given by the Törnqvist indices

$$\begin{aligned}\Delta \ln W &\equiv (\ln \mathbf{w}_1' - \ln \mathbf{w}_0')\tfrac{1}{2}(\mathbf{s}_1 + \mathbf{s}_0) \sim \int_0^1 \tfrac{\partial \ln \mathbf{w}_t'}{\partial t} \cdot \mathbf{s}_t \cdot dt \\ \Delta \ln X &\equiv \tfrac{1}{2}(\mathbf{s}_0' + \mathbf{s}_1')(\ln \mathbf{x}_1 - \ln \mathbf{x}_0) \sim \int_0^1 \mathbf{s}_t' \cdot \tfrac{\partial \ln \mathbf{x}_t}{\partial t} \cdot dt\end{aligned} \tag{22}$$

We note, however, that unlike Bennet's discrete-time approximations these two Törnqvist indices *do not necessarily sum up exactly* to the change of the aggregate value, so that in general $(\ln V_1 - \ln V_0) \neq \Delta \ln W + \Delta \ln X$. Therefore, if we want to guarantee the exact summing up of the decomposition procedure and we are approximating, for example, the first sum of integrals referring to the price components with the Törnqvist price index we must approximate the second integral by using the so-called *implicit* Törnqvist quantity index[6] given by

$$\Delta \widetilde{\ln X} \equiv (\ln V_1 - \ln V_0) - (\ln \mathbf{w}_1' - \ln \mathbf{w}_0')\frac{1}{2}(\mathbf{s}_1 + \mathbf{s}_0) \sim \int_0^1 \mathbf{s}_t' \cdot \frac{\partial \ln \mathbf{x}_t}{\partial t} \cdot dt \tag{23}$$

where the superscript ~ means that the index number is constructed *implicitly* by deriving it from the difference in the log-change of the aggregate value *direct* index number and the (weighted) log-changes of *direct* price indices.

Since the "direct" Törnqvist price index and the "implicit" Törnqvist quantity index always sum up exactly to the change of aggregate value, we can write

$$\ln V_1 - \ln V_0 = \Delta \ln W + \Delta \widetilde{\ln X} \tag{24}$$

In the framework of the I-O price model in reduced form given by (7), this approach gives rise to the following approximating decomposition procedure:

$$\begin{aligned}(\ln \mathbf{p}_1 - \ln \mathbf{p}_0) &= (\ln \mathbf{v}_1 - \ln \mathbf{v}_0)\tfrac{1}{2}\left[\overline{\mathbf{F}}_0(\mathbf{I} - \overline{\mathbf{A}}_0)^{-1} + \overline{\mathbf{F}}_1(\mathbf{I} - \overline{\mathbf{A}}_1)^{-1}\right] \\ &\quad + \Delta \ln \widetilde{\mathbf{FIMT}} \\ &= \Delta \ln \mathbf{FIM1A} + \Delta \ln \mathbf{FIM1B} + \Delta \ln \widetilde{\mathbf{FIMT}}\end{aligned} \tag{25}$$

where $\overline{\mathbf{A}}_t \equiv \widehat{\mathbf{p}}_t \mathbf{A}_t \widehat{\mathbf{p}}_t^{-1}$ and $\overline{\mathbf{F}}_t \equiv \widehat{\mathbf{v}}_t \mathbf{F}_t \widehat{\mathbf{p}}_t^{-1}$ (for t=0,1) are the Leontief's direct I-O matrices, which are expressed in nominal shares valued at current prices and

$\Delta \ln \mathbf{FIM1A} \equiv (\ln \mathbf{v}_1 - \ln \mathbf{v}_0)\frac{1}{2}(\overline{\mathbf{F}}_0 + \overline{\mathbf{F}}_1)$: Direct primary input price component;

$\Delta \ln \mathbf{FIM1B} \equiv (\ln \mathbf{v}_1 - \ln \mathbf{v}_0)\frac{1}{2}\left[\overline{\mathbf{F}}_0\overline{\mathbf{A}}_0(\mathbf{I} - \overline{\mathbf{A}}_0)^{-1} + \overline{\mathbf{F}}_1\overline{\mathbf{A}}_1(\mathbf{I} - \overline{\mathbf{A}}_1)^{-1}\right]$: Indirect primary input price component;

$\Delta \ln \widetilde{\mathbf{FIMT}} \equiv (\ln \mathbf{p}_1 - \ln \mathbf{p}_0) - (\ln \mathbf{v}_1 - \ln \mathbf{v}_0)\frac{1}{2}[\overline{\mathbf{F}}_0(\mathbf{I} - \overline{\mathbf{A}}_0)^{-1} + \overline{\mathbf{F}}_1(\mathbf{I} - \overline{\mathbf{A}}_1)^{-1}]$: implicit (direct and indirect) Törnqvist-type technological component.

We note that the term $\Delta \ln \widetilde{\mathbf{FIMT}}$ can be defined as the logarithmic difference in the unit costs of production of the vertically integrated sectors, after accounting for differences in input

[6] See, for example, Allen and Diewert (1981) for the concept of implicit index numbers.

prices. The relative cost efficiency of sectors in 1 with respect to sectors in 0 are defined as the ratio of costs that would be obtained after correcting for the effects of differing input prices, that is:

$$\tilde{\gamma}_{VIS} = \exp(\Delta \ln \widetilde{\mathbf{FIMT}}) \tag{26}$$

where $\tilde{}$ means that this measure is calculated implicitly by using the implicit index $\Delta \ln \widetilde{\mathbf{FIMT}}$. The levels of relative total factor productivity of the vertically integrated sectors in 1 with respect to those in 0 are given by:

$$\begin{aligned} \tilde{\pi}_{VIS} &\equiv [11...1] \cdot \hat{\tilde{\gamma}}_{VIS}^{-1} \\ &= \exp(-\Delta \ln \widetilde{\mathbf{FIMT}}) \end{aligned} \tag{27}$$

In the framework of the I-O price model in "structural" form given by (15), the same approach gives rise to the following approximating decomposition procedure:

$$\begin{aligned} (\ln \mathbf{p}_1 - \ln \mathbf{p}_0) = (\ln \mathbf{p}_1 - \ln \mathbf{p}_0)\tfrac{1}{2}(\overline{\mathbf{A}}_0 + \overline{\mathbf{A}}_1) + (\ln \mathbf{v}_1 - \ln \mathbf{v}_0)\tfrac{1}{2}(\overline{\mathbf{F}}_0 + \overline{\mathbf{F}}_1) \\ + \Delta \widetilde{\ln \boldsymbol{\Upsilon}} \end{aligned} \tag{28}$$

where $\Delta \widetilde{\ln \boldsymbol{\Upsilon}}$ is the implicit Törnqvist index of (direct) technological component.

Solving (28) with respect to $(\ln \mathbf{p}_1 - \ln \mathbf{p}_0)$, through a further manipulation, yields:

$$\begin{aligned} (\ln \mathbf{p}_1 - \ln \mathbf{p}_0) &= (\ln \mathbf{v}_1 - \ln \mathbf{v}_0)\tfrac{1}{2}(\overline{\mathbf{F}}_0 + \overline{\mathbf{F}}_1)\left[\mathbf{I} - \tfrac{1}{2}(\overline{\mathbf{A}}_0 + \overline{\mathbf{A}}_1)\right]^{-1} \\ &+ \Delta \widetilde{\ln \boldsymbol{\Upsilon}} \cdot \left[\mathbf{I} - \tfrac{1}{2}(\overline{\mathbf{A}}_0 + \overline{\mathbf{A}}_1)\right]^{-1} \\ &= \Delta \ln \mathbf{V1} + \Delta \ln \mathbf{V2} + \Delta \widetilde{\ln \mathbf{T1}} + \Delta \widetilde{\ln \mathbf{T2}} \end{aligned} \tag{29}$$

where

$\Delta \ln \mathbf{V1} \equiv (\ln \mathbf{v}_1 - \ln \mathbf{v}_0)\tfrac{1}{2}(\overline{\mathbf{F}}_0 + \overline{\mathbf{F}}_1)$: Direct primary input price component;

$\Delta \ln \mathbf{V2} \equiv (\ln \mathbf{v}_1 - \ln \mathbf{v}_0)\tfrac{1}{2}(\overline{\mathbf{F}}_0 + \overline{\mathbf{F}}_1)\tfrac{1}{2}(\overline{\mathbf{A}}_0 + \overline{\mathbf{A}}_1)\left[\mathbf{I} - \tfrac{1}{2}(\overline{\mathbf{A}}_0 + \overline{\mathbf{A}}_1)\right]^{-1}$: Indirect primary input price component;

$\Delta \widetilde{\ln \mathbf{T1}} = \boldsymbol{\Delta} \widetilde{\ln \boldsymbol{\Upsilon}} \equiv (\ln \mathbf{p}_1 - \ln \mathbf{p}_0) - (\ln \mathbf{p}_1 - \ln \mathbf{p}_0)\tfrac{1}{2}(\overline{\mathbf{A}}_0 + \overline{\mathbf{A}}_1)$

$-(\ln \mathbf{v}_1 - \ln \mathbf{v}_0)\tfrac{1}{2}(\overline{\mathbf{F}}_0 + \overline{\mathbf{F}}_1)$: Direct total input technological component;

$\Delta \widetilde{\ln \mathbf{T2}} \equiv \Delta \widetilde{\ln \mathbf{T1}} \cdot \tfrac{1}{2}(\overline{\mathbf{A}}_0 + \overline{\mathbf{A}}_1)\left[\mathbf{I} - \tfrac{1}{2}(\overline{\mathbf{A}}_0 + \overline{\mathbf{A}}_1)\right]^{-1}$: Indirect total input technological component.

We note that the decomposition (29) approximates the decomposition given by (25), since

$\Delta \ln \mathbf{V1} = \Delta \ln \mathbf{FIM1A}$

$\Delta \ln \mathbf{V2} \neq \Delta \ln \mathbf{FIM1B}$

$\Delta \widetilde{\ln \mathbf{T1}} + \Delta \widetilde{\ln \mathbf{T2}} \neq \Delta \ln \widetilde{\mathbf{FIMT}}$..

Moreover, the intermediate input price component in (28) can be reconstructed by using the indirect input price and technological components in (29), that is $(\ln \mathbf{p}_1 - \ln \mathbf{p}_0)\tfrac{1}{2}(\overline{\mathbf{A}}_0 + \overline{\mathbf{A}}_1) = \Delta \ln \mathbf{V2} + \Delta \widetilde{\ln \mathbf{T2}}$.

The implicit measures of relative cost efficiencies of vertically integrated sectors and industries are, respectively, redefined as follows:

$$\tilde{\gamma}_{VIS} = \exp(\Delta \widetilde{\ln \mathbf{T1}} + \Delta \widetilde{\ln \mathbf{T2}}) \tag{30}$$

$$\widetilde{\gamma}_{IND} = \exp(\Delta \widetilde{\ln \mathbf{T1}}) \tag{31}$$

and, following definition (12), the implicit measure of technological component of intermediate input prices is given by

$$\widetilde{\gamma}_{INTP} = \exp(\Delta \widetilde{\ln \mathbf{T2}}) \tag{32}$$

The corresponding implicit measure of relative total factor productivity in vertically integrated sectors and industries can be calculated, respectively, by using the above cost efficiencies. Recalling definitions (10) and (13), we have:

$$\begin{aligned} \widetilde{\pi}_{VIS} &= [11...1] \cdot \widehat{\widetilde{\gamma}}_{VIS}^{-1} = \exp(-\Delta \widetilde{\ln \mathbf{T1}} - \Delta \widetilde{\ln \mathbf{T2}}) \\ &= \widetilde{\pi}_{IND} \cdot \widehat{\widetilde{\pi}}_{INTP} \end{aligned} \tag{33}$$

where

$$\widetilde{\pi}_{IND} = [11...1] \cdot \widehat{\widetilde{\gamma}}_{IND}^{-1} = \exp(-\Delta \widetilde{\ln \mathbf{T1}}) \tag{34}$$

and

$$\widetilde{\pi}_{INTP} = [11...1] \cdot \widehat{\widetilde{\gamma}}_{INTP}^{-1} = \exp(-\Delta \widetilde{\ln \mathbf{T2}}) \tag{35}$$

In order to clarify some aspects of the methodology described above, we recall some theoretical foundations from which this stems form. By establishing the *Quadratic lemma*, Diewert(1976) showed that if the underlying "aggregator" function $V_t = V(\mathbf{w}_t, \boldsymbol{\theta})$ (which is numerically equal to $\mathbf{w}_t' \cdot \mathbf{x}_t$, since it is assumed that $\mathbf{x}_t = \partial V_t / \partial \mathbf{w}_t$ and $V_t = \mathbf{w}_t' \cdot (\partial V_t / \partial \mathbf{w}_t)$), with $\boldsymbol{\theta} \equiv [\alpha_0 \alpha_1 \alpha_2 ... \alpha_N \gamma_{11} \gamma_{12} ... \gamma_{NN}]'$ being a vector of parameters which remain constant over time) has a homogeneous Translog functional form, so that

$$\ln V(\mathbf{w}_t, \boldsymbol{\theta}) = \alpha_0 + \sum_{i=1}^{N} \alpha_i \ln w_{it} + \frac{1}{2} \sum_{j=1}^{N} \sum_{k=1}^{N} \gamma_{jk} \ln w_{jt} w_{kt} \tag{36}$$

then $\ln V_1 - \ln V_0 = (\ln \mathbf{w}_1' - \ln \mathbf{w}_0') \frac{1}{2}(\mathbf{s}_0 + \mathbf{s}_1)$, that is $(\ln V_1 - \ln V_0)$ can be *exactly* reconstructed by an aggregating Törnqvist index number of prices. In the notation of the I-O price model the function (36) can be re-expressed, for each sector, as $p_i = \exp c_i(\ln \mathbf{p}_t, \ln \mathbf{v}_t; \boldsymbol{\theta})$, where $c_i(\cdot)$ has the value of the logarithm of a unit cost function. Therefore, if $\boldsymbol{\theta}$ does not change over time, the log-change of output prices can be exactly decomposed as follows: $(\ln \mathbf{p}_1 - \ln \mathbf{p}_0) = (\ln \mathbf{p}_1 - \ln \mathbf{p}_0) \frac{1}{2}(\overline{\mathbf{A}}_0 + \overline{\mathbf{A}}_1) + (\ln \mathbf{v}_1 - \ln \mathbf{v}_0) \frac{1}{2}(\overline{\mathbf{F}}_0 + \overline{\mathbf{F}}_1)$, that is the log-change of output prices can be accounted for only by a weighted sum of log-change of input prices, since no technological change has taken place.

Technological changes are reflected by variations over time of the functional form or the technological parameters of the "true" unknown function $c_{it}(\ln \mathbf{p}_t \ \ln \mathbf{v}_t; \boldsymbol{\theta}_t)$. As Denny, Fuss, and May (1981) have suggested, this function can be approximated by a function $c_i(\ln \mathbf{p}_t, \ln \mathbf{v}_t, t; \boldsymbol{\theta})$, which is quadratic in all the explanatory variables, including the technology index t. The function $c_{it}(\cdot)$ is therefore replaced by $c_i(\cdot)$, which is characterized by a Translog functional form with constant parameters $\boldsymbol{\theta}$ and the additional explanatory variable t. We also note that only in the case where $c_{it}(\ln \mathbf{p}_t, \ln \mathbf{v}_t; \boldsymbol{\theta}_t)$ is identically equal to $c_i(\ln \mathbf{p}_t, \ln \mathbf{v}_t, t; \boldsymbol{\theta})$ for all t's, will $\Delta \widetilde{\ln \boldsymbol{\Upsilon}} \equiv (\ln \mathbf{p}_1 - \ln \mathbf{p}_0)$ - $(\ln \mathbf{p}_1 - \ln \mathbf{p}_0) \frac{1}{2}(\overline{\mathbf{A}}_0 + \overline{\mathbf{A}}_1)$ - $(\ln \mathbf{v}_1 - \ln \mathbf{v}_0) \frac{1}{2}(\overline{\mathbf{F}}_0 + \overline{\mathbf{F}}_1)$ be exactly equal to the "true" technological component, otherwise it will only approximate this last component[7]. However, even if it is only approximating the "true" unknown technological component, this *implicit* measure of magnitude always sum up exactly to the log-change of output prices, by construction, along with the *direct* measure of the input-price component.

Moreover, since the Translog function includes the Cobb-Douglas function as a special case, the use of Törnqvist-type formulas in input-output analysis brings about a generalization of Klein's (1952-53)(1956) and Morishima's (1956)(1957) reformulation of Leontief's equation system[8]. They used, in fact, constant input-output coefficients expressed as unit cost shares valued at current prices, rather than technical coefficients valued at constant prices or expressed in physical units, as in Leontief's system. More specifically, the inverse matrix $\left[\mathbf{I} - \frac{1}{2}(\overline{\mathbf{A}}_0 + \overline{\mathbf{A}}_1)\right]^{-1}$ is our Törnqvist-type reformulation of Leontief's and Klein-Morishima's inverse matrices, where the technology is described by an underlying Translog cost function. This reformulation permits us to be consistent with recent applications of studies in the field of intertemporal and interspacial comparison of cost structure. As we mentioned above, these studies were all concerned with the "direct" costs of production at the industry level, whereas we take into account, not only the industries and their "direct" costs, but also the so-called "vertically integrated sectors," with their "direct" *and* "indirect" costs of production.

The concepts of "industry" corresponds to the I-O equation system (15), which is expressed in "structural" form using only direct I-O coefficients, whereas the concept of "vertically integrated sector" corresponds to the I-O equation system (7), which is expressed in "reduced" form using direct and indirect I-O coefficients. A domestic industry can be defined as an aggregate of "observed" production units which produce homogeneous goods by using primary inputs (human and non human capital, labor, imported intermediate inputs, land and natural resources) as well as domestically produced intermediate inputs, which are originated by other industries producing *different types* of goods. On the other hand, a "vertically integrated sector" is an accounting concept defined as an aggregate of "unobservable" production units which produce homogeneous goods as final output as well as *all* the necessary domestically originated intermediate inputs of various kind by using *only* primary inputs[9]. Whilst the costs of production in each industry and the corresponding vertically integrated sector are the same, their inputs are different: the industry has to buy from other domestic industries some of the inputs of production (the so-called domestically produced intermediate inputs), whereas the theoretically defined vertically integrated sector is completely autonomous and therefore produces itself all the intermediate inputs that are needed directly and indirectly as well as the final output by using all the necessary primary inputs. Both concepts are useful for a complete accounting analysis of the structure of costs of production.

The distinction between industries and vertically integrated sectors also makes clear the different implications of the alternative formulas (8), (16), (25), and (29). The functional forms of the underlying production or cost function that are implied by the particular index number formulas used in the above four alternative cases refer to different technological hypotheses. More specifically, in (8) and (25) the index number formulas correspond to a particular functional form of cost functions in the vertically integrated sectors, whereas in (16) and (29) they correspond to a particular functional form of cost functions in the "observed" industries. These different

[7] Since Diewert's *Quadratic lemma* involves derivatives of cost function with respect to its variables, a problem may arise from the discontinuity of the technology index t between the countries examined in interspacial comparisons. However, Denny and Fuss (1983b) provided a justification for the application of the *Quadratic lemma* in this context.

[8] See Saito (1972), among others, for the empirical application of this reformulation of Leontief's system.

[9] The notion of vertically integrated sector is implicit in various definitions of macroeconomic aggregates and in many analyses of classical and neoclassical economists. Walras (1874,1877), for example, eliminated intermediate inputs from his theoretical model by adopting the device of vertical integration. In I-O analysis, Leontief (1953)(1956) applied empirically this concept for the first time by using his inverse I-O matrix (which was previously defined in Leontief, 1941-1951). For an example of more recent applications see Heimler (1991).

hypotheses on sectorial technology give rise to different results in the alternative decomposition procedures.

Jorgenson and Kuroda (1990), Fuss and Waverman (1991), Nakamura (1991), Kuroda (1992), and Denny, Bernstein, Fuss, Nakamura, and Waverman (1992) applied a formula equivalent to (28) to account for sectorial cost differences between Japan and the U.S., by aggregating the inputs at the so-called *KLEM* level (Capital, Labor, Energy, and Intermediate inputs). They decomposed the sectorial cost differences into direct input price component, which in our notation is given by $(\ln \mathbf{p}_1 - \ln \mathbf{p}_0)\frac{1}{2}(\overline{\mathbf{A}}_0 + \overline{\mathbf{A}}_1) + (\ln \mathbf{v}_1 - \ln \mathbf{v}_0)\frac{1}{2}(\overline{\mathbf{F}}_0 + \overline{\mathbf{F}}_1) = (\Delta \ln \mathbf{V1} + \Delta \ln \mathbf{V2} + \Delta \widetilde{\ln \mathbf{T2}})$, and direct technological difference, which is given by $\Delta \widetilde{\ln \mathbf{T1}} = \Delta \widetilde{\ln \boldsymbol{\Upsilon}}$. Our proposed method based on (29) decomposes the direct intermediate input price component given by $(\ln \mathbf{p}_1 - \ln \mathbf{p}_0)\frac{1}{2}(\overline{\mathbf{A}}_0 + \overline{\mathbf{A}}_1)$ into the incorporated primary input price component, which is given by $\Delta \ln \mathbf{V2}$, and the incorporated total input technological component, which is given by $\Delta \widetilde{\ln \mathbf{T2}}$. At the sectorial disaggregation level of the above-mentioned studies, it is important to decompose the direct intermediate input price component, as this often amounts to more than 60 per cent of the unit cost of production.

3. Empirical Results

In the preceding section we proposed four alternative methods which can be used to account for differences in sectorial costs of production between two countries. These methods are given by the formulas (8), (17), (25), and (29) which can lead to slightly different empirical results. Since we intend to compare our results with those obtained by previous studies in the field, which were based on the analysis of "direct" input costs by using a formula corresponding to (28), we shall concentrate mainly on formula (29), which can be derived from (28) as its "reduced" form and can be brought back to "direct" accounting components.

3.1. Data

The Japanese and U.S. I-O tables for the year 1985, which were used in the empirical application, were harmonized according to the same industrial classification. The sectorial output and primary input prices of Japan are relative to the respective U.S. prices. The output price ratios are calculated by using Purchasing Power Parity (PPP) data supplied by OECD for 187 commodities for the year 1985. The PPP data were aggregated to be consistent with the industrial classification by using the averages of share weights in the final consumption in the U.S. and Japan. The PPP data were corrected in order to compare producer prices rather than consumer prices. Therefore, they were adjusted by excluding transportation costs and commercial margins per unit of output. The levels of producer prices relative to the corresponding U.S. prices (with all prices expressed in a common currency) were actually obtained by dividing the corrected sectorial PPP data by the observed nominal exchange rate of Japanese Yen against 1 U.S. dollar[10]. The annual average of the nominal exchange rate in 1985 was 238.54 Yen per U.S. dollar. Moreover, the original OECD PPP data should refer, ideally, to commodities that have the same characteristics and quality standards, so that by deflating the current-price sectorial values of production by means of the obtained corresponding producer prices, we would end up with quantities and input-output coefficients that include quality differences between the two countries. In practice, however, we cannot control if quality differences are completely netted out from those computed producer prices and therefore our empirical results could be affected by some residual errors in the data[11]. As for the sectorial labor prices, the ratios between the Japanese hourly wages expressed in Yens and the U.S. hourly wages expressed in U.S. dollars

[10] For an analytical description of this calculation of price ratios, see Fujikawa, Izumi, and Milana (1995)

[11] We are grateful to an anonymous referee for having reminded us about this point.

(which give us implicitly the sectorial PPP for labor prices) were divided by the nominal exchange rate in order to obtain the Japanese labor prices relative to the corresponding U.S. labor prices. The ratios between the sectorial Japanese capital prices relative to the corresponding U.S. capital prices were derived by those used by Jorgenson and Kuroda (1990) and Kuroda (1992). The Japanese relative prices of outputs and primary inputs in 1985 are shown in Table 1, where the corresponding sectorial U.S. prices are normalized to 1.

Table 1: Japanese Sectoral Price Index Transformed by Purchasing Power Parities, 1985
(United States Price = 1.000)

Industry		Output Price	Labor Input Price	Capital Input Price
01	Agriculture	1.8586	1.0869	1.6070
02	Mining	2.1645	0.4289	0.7400
03	Oil & Natural Gas	1.1716	0.7144	0.7400
04	Food Products	1.4856	0.3994	1.0260
05	Textiles & Clothing	1.0056	0.5181	0.6120
06	Paper and Wooden Products	2.5262	0.5038	0.7590
07	Chemical Products	0.7413	0.5971	1.1880
08	Coal and Petroleum Products	1.7544	0.4732	0.9620
09	Non-metal Ores & Products	1.9711	0.7307	0.2480
10	Primary Metal	0.7891	0.5592	3.3950
11	Metal Products	0.7560	0.4833	0.8870
12	General Machinery	1.3553	0.5235	1.9710
13	Electric Machinery	1.0615	0.4936	1.4190
14	Automobiles	0.7984	0.3840	5.0150
15	Transport Equipment	1.0773	0.5515	2.5910
16	Precision Apparatus	1.2866	0.4842	0.3510
17	Other Manufactures	1.2910	0.5731	0.9170
18	Building & Construction	1.3668	0.4910	0.7690
19	Electricity, Gas, & Water	1.4482	0.6363	0.7860
20	Wholesale & Retail Services	0.9304	0.7300	0.8940
21	Finance and Insurance	0.9304	0.7105	0.8000
22	Real Estate Services	1.1867	0.7522	0.8000
23	Transport Services	0.9816	0.5421	2.3640
24	Communications	0.5901	1.6183	2.3640
25	Education & Medical Services	1.9840	0.8583	0.4820
26	Other Services	1.7954	0.4906	0.6860
27	Not Elsewhere Classified	0.7926	0.8955	0.6860

Source: Output Price: our computations based on OECD PPP data and nominal exchange rates
Labour Input Price: our computations based on national statistics
Capital Input Price: data made available by Masahiro Kuroda

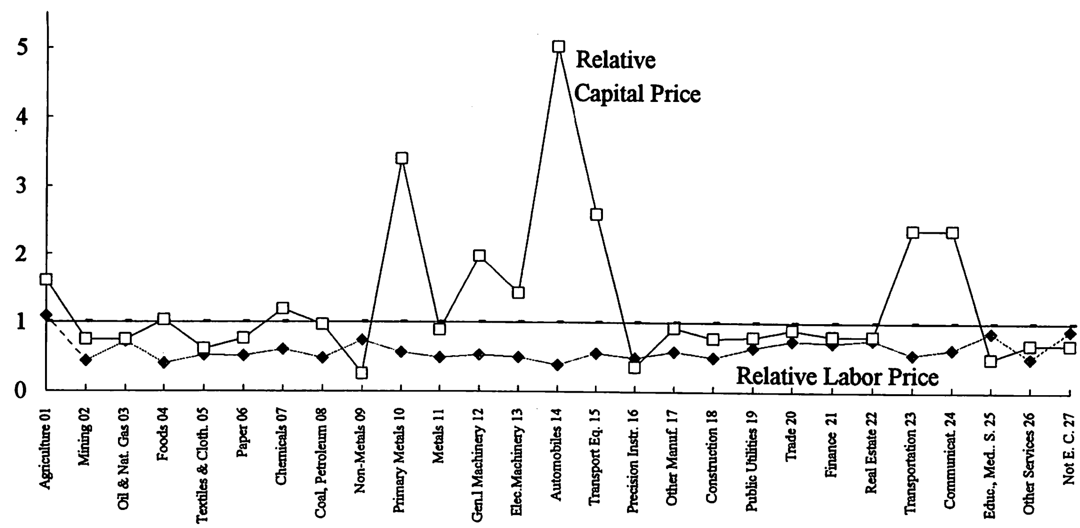

Figure 1: Relative Capital and Labor Prices in Japan, 1985 (U.S. = 1.00)

3.2. Output and input prices

Proportional gaps of sectorial costs of production has been found very similar to those obtained by Jorgenson and Kuroda (1992), Denny *et al.*(1992), Kuroda (1994). In the first column of Table 1, Japan appears to have substantial absolute advantages over the U.S. in the industries *Chemical Products, Primary Metals, Metal Products, Automobiles,* and *Communications.* On the other hand, it has absolute disadvantages in *Agriculture, Mining, Food Products, Paper and Wooden Products, Coal and Petroleum Products, Non-Metal Ores and Products, General Machinery, Building and Construction, Electricity, Gas and Water Supply, Education and Medical Services,* and *Other Services.*

The second column in Table 1 and Figure 1 reveal that labor input price is substantially lower in Japan than in the U.S. in all sectors, except *Agriculture.* This lower labor input price is, however, partially compensated by a capital input price, which in some industries turns out to be much higher than that in the U.S. (see the third column in Table 1 and Figure 1).

3.3. Sources of output price gaps

The price competitiveness indicated above is decomposed into input price and productivity components. The alternative four methods of decomposition of price differences led to slightly different results, as expected. Limited space prevents us to show the results obtained by applying all these alternative methods. Therefore, we shall present only those produced by the application of (29), which is consistent with the methodology used by Jorgenson and Kuroda (1990, 1992) and Denny *et al.*(1992) (see Table 2 and Figures 2, 4, and 5). In all sectors, except *Agriculture,* wages of laborers directly employed were lower than U.S. wages. The relatively low wages are the main factor of competitiveness of Japanese products and in some sectors offset the relatively low total factor productivity, as in *Metal Products, Wholesale and Retail Services, Finance and Insurance Services,* and *Transport Services.* The cost of capital services is less uniform than wages across the sectors. The cost of direct capital inputs is lower in Japan, except in the industries *Automobiles, Transport Equipments, General Machinery, Transport Services,* and

Communications, where it is substantially higher, and in *Food Products, Primary metals, Metal Products,* and *Electric Machinery,* where it is approximately at the same level as in the U.S.

The relative productivity at industry level is similar to that found in the other studies in almost all sectors (see Table 3 and Figure 3). However, our estimates for *Paper and Wooden Products, Electric Machinery, Transportation Equipment,* and *Precision Apparatus* are rather different from those of Jorgenson and Kuroda (1990, 1992) and Denny *et al.* (1992). In general, according to our results, total factor productivity is lower in Japan than in the U.S. in the majority of industries, but it is substantially higher in *Chemical Products, Automobiles,* and *Communications.* In the *Automobiles* industry, however, the relatively high level of productivity is almost offset by a relatively high cost of capital. The strong competitiveness of Japan in this industry is therefore mainly due to wages which are lower than that in the U.S.

In almost all sectors, the intermediate input price component is higher in Japan than in the U.S., thus partially offsetting the primary input price component in many sectors. The breakdown of the intermediate input price component into primary input price and productivity components reveals that the productivity incorporated in intermediate inputs used by Japanese industries is much lower than that in the U.S. In no industry, at the level of aggregation of our analysis, has this component turned out to be higher in Japan than in the U.S. It is worth noting that in some industries, like *Chemical Products, Primary Metals, Transport Equipment,* and *Other Industries (n.e.c.),* the direct productivity component is higher in Japan than in the U.S., but is completely offset by the lower indirect productivity component. In *Primary Metals* and *Transport Equipment* the indirect productivity component more than offsets the direct productivity component, thus leading to an unfavorable total productivity component. In these cases, the vertically integrated sector presents an overall productivity, which is opposite to the direct productivity component that is observed superficially at the industry level. Therefore, with the results reported above, the taxonomy in terms of technological gaps of Japan with respect to the U.S., as defined at the industrial level by Jorgenson and Kuroda (1992, pp. 44-45, Table 5), should be revised substantially if we consider it at the level of the so-called "vertically integrated sectors".

Table 2 as well as Figures 4 and 5 show that the relative cost efficiency of industries is apparently higher than vertically integrated sectors. Relatively low levels of productivity and inexpensive primary input prices characterize the production conditions in Japan that are "behind the scenes" of the single industries. As Figures 6 and 7 show, productivity in Japan relative to the U.S. can turn out to be very different if we measure it at the level of vertically integrated sectors instead of at the industry level. For example, it is 80 per cent higher at the industry level than at the level of vertically integrated sector in the case of *Paper and Wooden Products.* In 17 industries out of 27, relative productivity at the industry level is equal or greater than 30 per cent of productivity measured at level of the corresponding vertically integrated sectors. This means that international as well as intertemporal comparisons of cost efficiency or relative productivity levels cannot be complete if they remain confined at the "superficial" analysis of direct "industrial" costs.

In summary, our results indicate that only in a few manufacturing industries is the "direct" productivity level higher in Japan than in the U.S. However, in these industries the "indirect" productivity component is significantly lower than that in the U.S., thus bringing the Japanese technical performance observed in most sectors during 1985 at a lower level than that in the U.S.

Table 2: Decomposition of Logarithmic Differences of Costs of Production between Japan and The U.S. in 1985 (EQ.(29))

	Sector	Log Difference of Cost	Direct Labor Price Effect	Direct Capital Price Effect	Intermediate Input Price Effect				Direct Technolog. Effect
					Interm. Input Price Effect	Indirect Labor Price Effect	Indirect Capital Price Effect	Indirect Technolog. Effect	
		(1)=(2)+(3) +(4)+(8)	(2)	(3)	(4)=(5) +(6)+(7)	(5)	(6)	(7)	(8)
01	Agriculture	0.6198	0.0441	-0.0274	0.1680	-0.1116	-0.0250	0.3046	0.4352
02	Mining	0.7722	-0.2384	-0.0531	0.1275	-0.1828	-0.0115	0.3218	0.9362
03	Oil& Natural Gas	0.1584	-0.0674	-0.1491	0.0654	-0.0802	-0.0259	0.1715	0.3096
04	Food Products	0.3958	-0.1200	0.0040	0.3054	-0.1561	-0.0299	0.4914	0.2064
05	Textiles & Clothing	0.0056	-0.1779	-0.0135	0.0358	-0.2514	-0.0268	0.3140	0.1611
06	Paper and Wooden Products	0.9267	-0.1617	-0.0262	0.3286	-0.2209	-0.0306	0.5801	0.7860
07	Chemical Products	-0.2993	-0.0815	0.0241	0.0478	-0.2102	-0.0302	0.2882	-0.2897
08	Coal and Petroleum	0.5621	-0.0293	-0.0070	0.1627	-0.1540	-0.1074	0.4241	0.4357
09	Non-metal Ores & Products	0.6786	-0.1802	-0.2052	0.2165	-0.2031	-0.0500	0.4696	0.8475
10	Primary Metal	-0.2369	-0.1679	0.0350	0.0153	-0.2599	-0.0077	0.2829	-0.1193
11	Metal Products	-0.2797	-0.3952	0.0239	0.0299	-0.2866	-0.0059	0.2626	0.1214
12	General Machinery	0.3040	-0.1955	0.0758	0.0450	-0.2411	0.0046	0.2815	0.3787
13	Electric Machinery	0.0597	-0.2964	0.0030	0.0512	-0.2479	-0.0040	0.3040	0.3019
14	Automobiles	-0.2252	-0.1555	0.2429	0.0125	-0.2772	0.0915	0.1732	-0.3000
15	Transport Equipment	0.0745	-0.1116	0.1676	0.0432	-0.2445	0.0492	0.2385	-0.0246
16	Precision Apparatus	0.2520	-0.2480	-0.1114	0.0887	-0.2172	-0.0151	0.3210	0.5226
17	Other Manufactures	0.2554	-0.1646	-0.0100	0.1289	-0.2011	-0.0212	0.3512	0.3011
18	Building & Constr.	0.3125	-0.2351	-0.0264	0.1553	-0.2267	-0.0189	0.4009	0.4188
19	Electricity, Gas, & Water	0.3703	-0.1020	-0.0771	0.1401	-0.1179	-0.0457	0.3037	0.4092
20	Wholesale & Retail Serv.	-0.0721	-0.1639	-0.0140	0.0962	-0.1096	-0.0201	0.2259	0.0096
21	Finance and Insurance	-0.0721	-0.1649	-0.0320	0.0613	-0.1137	-0.0196	0.1946	0.0635
22	Real Estate Services	0.1712	-0.0120	-0.1783	0.0388	-0.0471	-0.0141	0.1000	0.3226
23	Transport Services	-0.0186	-0.2877	0.0778	0.0880	-0.1440	-0.0037	0.2357	0.1034
24	Communications	-0.5274	-0.1713	0.3086	0.0677	-0.0961	-0.0060	0.1698	-0.7324
25	Education & Medical Serv.	0.6851	-0.0743	-0.1054	0.0692	-0.1052	-0.0228	0.1972	0.7957
26	Other Services	0.5852	-0.2713	-0.0589	0.1493	-0.1522	-0.0196	0.3211	0.7662
27	Not Elsewhere Classified	-0.2324	-0.0663	-0.0445	0.0746	-0.0952	-0.0079	0.1777	-0.1962

Table 3: Relative Productivity of Japanese Industries and Vertically Integrated Sectors (U.S. = 1.00)

	Industry or Vertically Intergrated Sector	Relative Productivity at Industry Level, EQ.(34)				Indirect Productivity	Direct and Indirect Productivity	Percentage Difference in Productivity Measurement
		J. -K. 1985 (1)	Kuroda 1985 (2)	Denny et al. 1984-6 (3)	Our Results 1985 (4)	EQ.(35) (5)	EQ.(33) (6)=(4)*(5)	(7) ={[(4)-(6)]/(6)} *100
01	Agriculture	0.597	0.582	-	0.647	0.737	0.477	35.6
02	Mining	2.540	2.471	-	0.392	0.725	0.284	38.0
03	Oil& Natural Gas	-	-	-	0.734	0.842	0.618	18.7
04	Food Products	0.836	0.785	0.622	0.814	0.612	0.498	63.5
05	Textiles & Clothing	0.886	0.912	0.824	0.851	0.731	0.622	36.9
06	Paper and Wooden Products	0.981	0.977	0.982	0.456	0.560	0.255	78.6
07	Chemical Products	1.275	1.221	1.115	1.336	0.750	1.002	33.4
08	Coal and Petroleum	0.412	0.405	0.407	0.647	0.654	0.423	52.8
09	Non-metal Ores & Products	0.695	0.651	0.755	0.428	0.625	0.268	59.9
10	Primary Metal	0.970	0.926	1.219	1.127	0.754	0.849	32.7
11	Metal Products	0.731	0.720	0.672	0.886	0.769	0.681	30.0
12	General Machinery	0.746	0.745	0.842	0.685	0.755	0.517	32.5
13	Electric Machinery	1.173	1.191	1.329	0.739	0.738	0.546	35.5
14	Automobiles	0.949	0.975	-	1.350	0.841	1.135	18.9
15	Transport Equipment	0.647	0.559	0.735	1.025	0.788	0.807	26.9
16	Precision Apparatus	1.061	0.862	0.883	0.593	0.725	0.430	37.9
17	Other Manufactures	1.046	1.646	0.690	0.740	0.704	0.521	42.1
18	Building & Constr.	0.508	1.523	-	0.658	0.670	0.441	49.3
19	Electricity, Gas, & Water	1.028	1.281	-	0.664	0.738	0.490	35.5
20	Wholesale & Retail Serv.	0.791	0.839	-	0.990	0.798	0.790	25.3
21	Finance and Insurance	0.589	0.585	-	0.938	0.823	0.773	21.5
22	Real Estate Services	-	-	-	0.724	0.905	0.655	10.5
23	Transport Services	-	-	-	0.902	0.790	0.712	26.6
24	Communications	1.047	0.800	-	2.080	0.844	1.755	18.5
25	Education & Medical Serv.	-	-	-	0.451	0.821	0.371	21.8
26	Other Services	0.566	0.563	-	0.465	0.725	0.337	37.9
27	Not Elsewhere Classified	-	-	-	1.217	0.837	1.019	19.4

J. -K.: Derived from Jorgenson and Kuroda (1992, Table 5, pp.44-45) data on log differences in total factor productivity.
Kuroda: Derived from Kuroda's (1994, Table 3, p.17) data on log differences in total factor productivity.
Denny et al.: Denny, Bernstein, Fuss, Nakamura, Waverman (1992, Table 6, p.599).

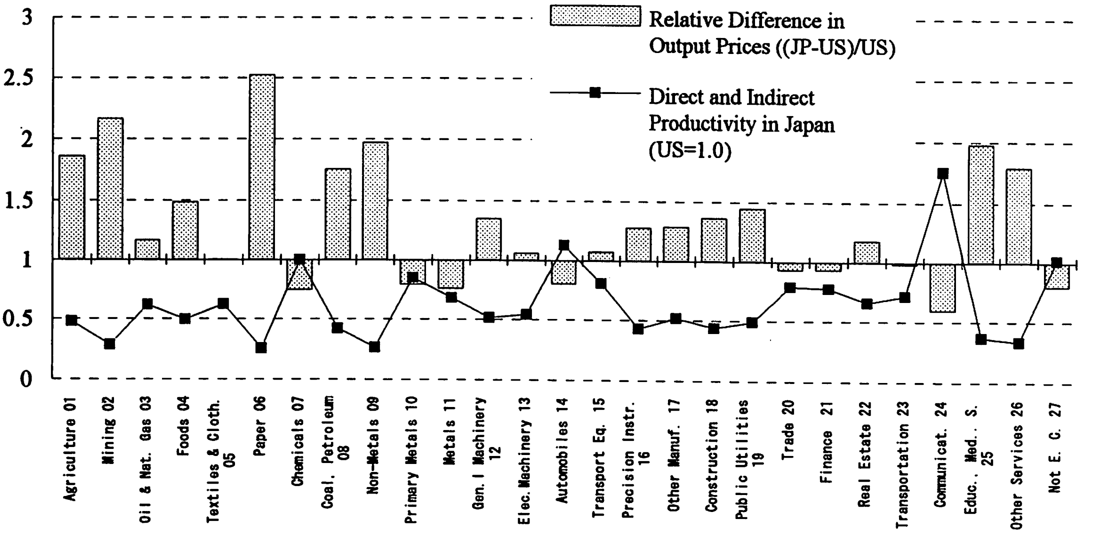

Figure 2: Difference in Output Prices and Productivity

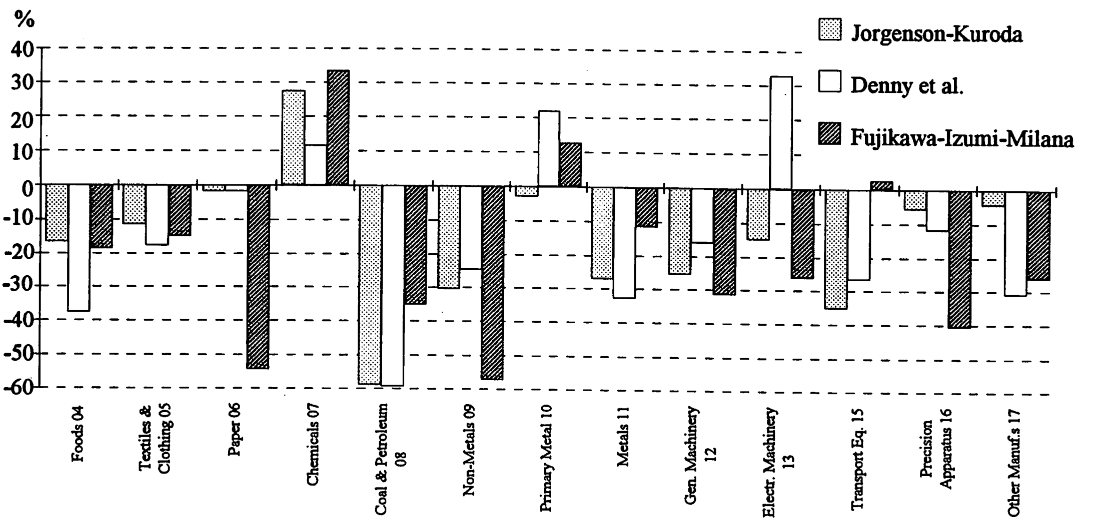

Figure 3: Comparison of Estimations of Relative Difference in Productivity between Japan and the U.S. ((JP-US)/US)

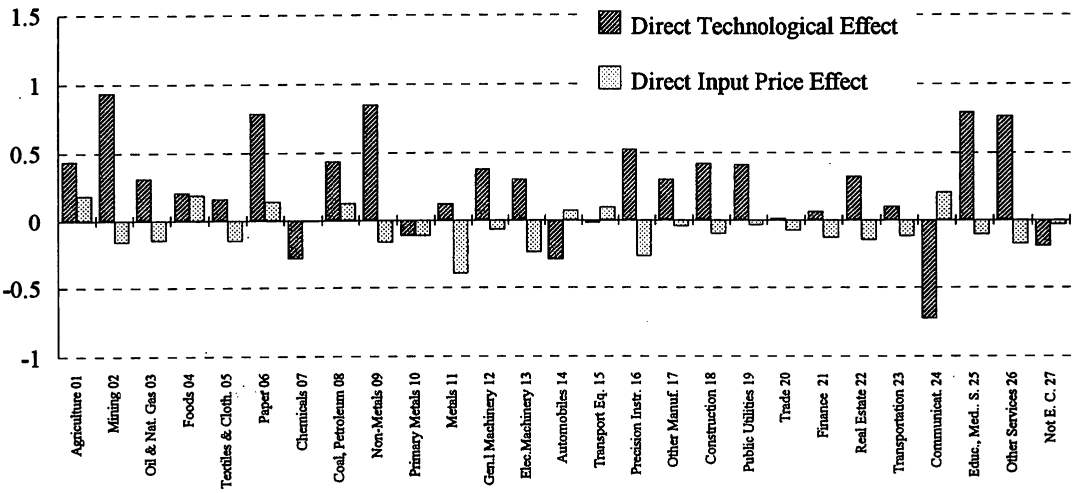

Figure 4: Components of Log-Difference of Production Costs between Japan and the U.S. in 1985: Direct Effects at Industry Level

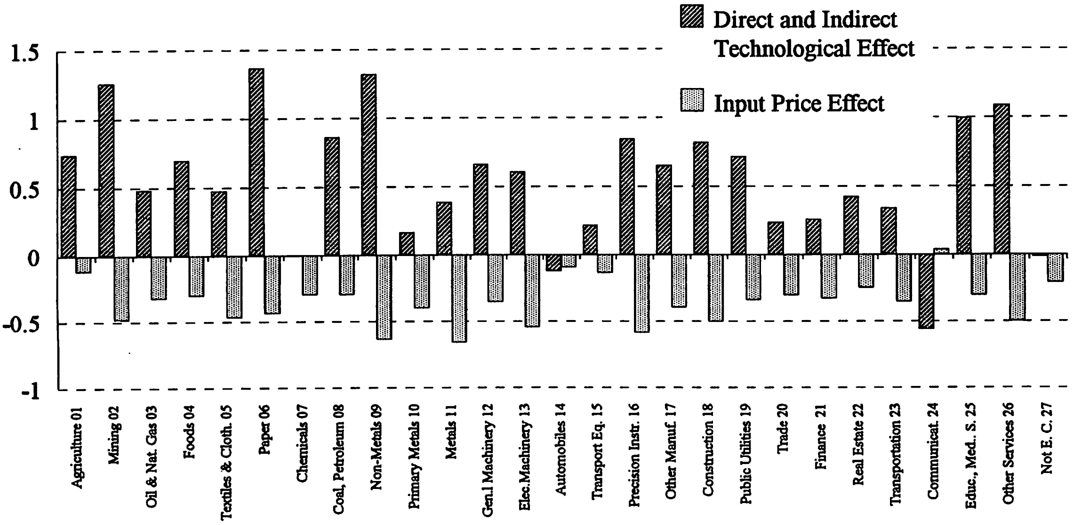

Figure 5: Components of Log-Difference of Production Costs between Japan and the U.S. in 1985: Vertically Integrated Sectors

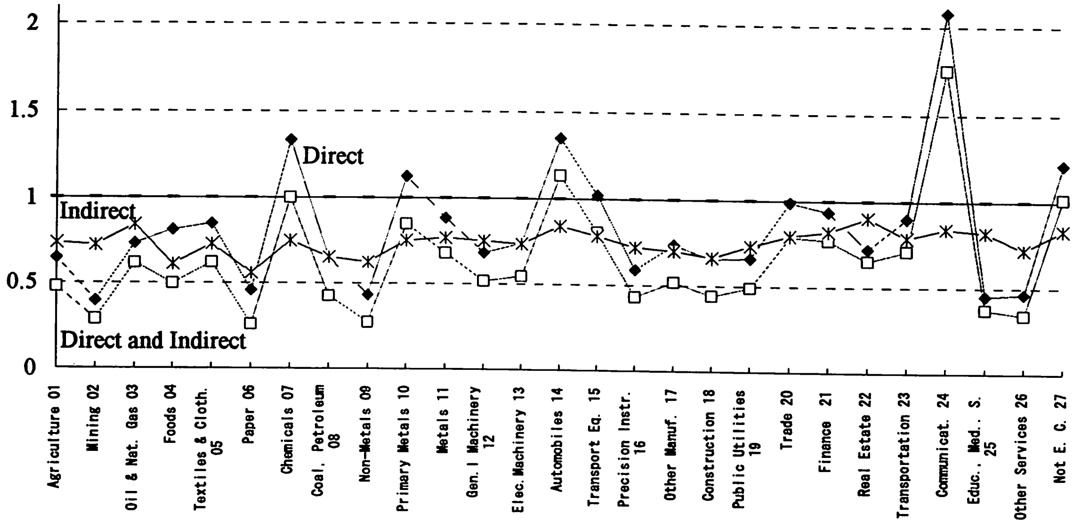

Figure 6: Relative Direct and Indirect Productivity in Japan, 1985 (U.S. = 1.00)

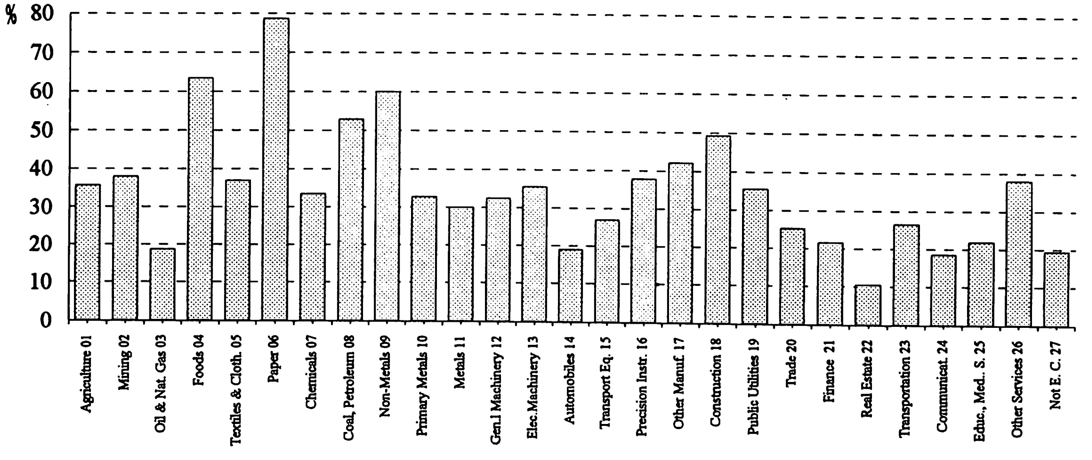

Figure 7: Difference in Measurement of Relative Productivity Levels between Japan and the U.S. in 1985
(Percentage Difference of Productivity between Industries and Vertically Integrated Sectors)

4. Conclusion

The bilateral comparison between Japan and the United States of relative levels of sectorial unit production costs and their components has been carried out for the year 1985 by using harmonized input-output tables and Purchasing Power Parities. The analysis aimed at finding additional results that would complement those of previous studies in this field. It examined, not only the *direct* costs of production at the industry level, but also the indirect costs that are incorporated in the intermediate inputs. Input-output analysis permits us to decompose intermediate input costs into primary input price and technological components, thus giving a further insight into the structure of costs of production. By using an input-output inverse matrix, which is defined in such a way that it is exactly consistent with the technological assumptions of the previous studies, we were able to replicate the results of these studies and extend them to the so-called "vertically integrated sectors". The relative productivity gap between Japan and the U.S. in 1985 turns out to be much higher if we consider the whole economic system that is behind the production of the single goods rather than that observable at the industry level.

In particular, Japan seems to have been more competitive than the U.S. in 1985 in few sectors (*Chemicals, Primary Metals, Metals, Automobiles, Trade, Finance, Transport Services, Communications*, and *Others not elsewhere classified*). This higher competitiveness was mainly due to lower labor input prices in Japan than in the U.S. This result is more evident in the analysis carried out on the vertically integrated sectors, where both the input prices and cost efficiency are much lower that those found at the industry level.

A natural possible extension of this study is in the direction of intertemporal bilateral and multilateral comparisons of relative cost and productivity levels. The availability of harmonized input-output tables of Japan, the U.S. and the major European countries for different years starting from 1970 makes it possible to apply the methodology established in this paper to the comparison of cost structures of single pairs of countries in different periods of time. Multilateral comparisons can be made by using appropriate weighted averages of the results obtained in these bilateral comparisons.

Appendix

Data sources

The list of data sources for the comparison of cost structures in the I-O tables of Japan and the U.S. is the following:

A. Prices by commodity

OECD, "Purchasing Power Parities and Real Expenditures 1985," Paris, (less than 60 items, aggregates and sub-aggregates);

OECD, *PPP data 1985,* Paris, on diskettes (187 commodities).

Except the sectors mentioned below, the PPP data were aggregated into the 27 sectors of the input-output tables by using geometric weighted formulae. Since the PPP data are purchaser prices, they should be adjusted to the level of producer prices in order to be used to deflate the input-output table of each country. The data on prices of steal products of Japan and the U.S. were taken from *World Steel Intelligence,* 1992 (price of cold-reduced coil at April 1985). More specifically, for Japan the weighted average of Big Buyer Price (40% weight) and Dealer Price (60% weight) has been used. PPP data for the whole GDP were used as proxies for prices of *Trade* and *Finance* sectors.

B. Nominal exchange rate between Japan and the U.S. for the year 1985

International Monetary Fund, *International Financial Statistics,* Washington, D.C.

C. Input-Output tables

USA: Department of Commerce, "Annual Input-Output Accounts of the U.S. Economy," *Survey of Current Business,* January 1990.

Japan: Management and Coordination Agency, *Input-Output Table 1985,* Tokyo, 1990.

The sectorial classifications of the Japanese and U.S. I-O tables were harmonized according to the same sectorial classification.

D. Wages by industry

USA: Department of Commerce, "National Income and Product Accounts," *Survey of Current Business,* July 1987.

Japan: Management and Coordination Agency, *1985 Input-Output Tables,* Tokyo, 1989.

Wages were calculated dividing the value of compensation of employees by the number of employees.

E. Persons in production activities

Japan: Management and Coordination Agency, *Input-Output Tables, 1985 (*Employment table), Tokyo, 1989.

USA: Department of Labor, *Time Series Data for Input-Output Industries*, Washington, D.C., 1989.

F. Average annual working hours

Japan: (*i)* Ministry of Labour, *Monthly Labour Survey,* Tokyo, 1985; (*ii*) Management and Coordination Agency, *Labour Force Survey,* Tokyo, 1985. If the sectorial data were available in source (*i),* the average annual working hours of employee were obtained by multiplying them by 12. Otherwise, the average weekly working hours published in source (*ii)* have been multiplied by 52.1.

USA: Department of Labor, *Time Series Data for Input-Output Industries*, Washington, D.C., 1989.

G. Capital input prices

Japan: Capital input prices at the industry level relative to those of the U.S. in 1985 are those used by Jorgenson and Kuroda (1990) and Kuroda (1994).

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