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A comparative analysis of Japanese firm productivity: Solow residual and Malmquist productivity index

Masaru Ichihashi, Hidemichi Fujii

(Graduate School for International Development and Cooperation, Hiroshima University, Higashi-Hiroshima 739-8529, Japan)

Abstract: For some time, two major kinds of Total Factor Productivity (TFP) have existed independently of each other: the Solow residual and the Malmquist Productivity Index (MPI). The Solow residual was introduced in macro economic growth models, and the MPI has been used in micro economics and management studies. As both indices were developed independently, few studies utilize both together and compare the results. This paper uses the same data to compare the two productivity indices by setting to determine the economic implications of combining the two indices. We discovered that we could decompose TFP with each aspect of the Solow residual and MPI. We could then interpret their relationship in the business cycle. Our results indicated that the frontier shift in MPI of Japanese firms often occurred when the Solow residual increased, meaning that improving productivity with the Solow residual could be generated by a firm that could shift new production frontiers.

Key words: Total Factor Productivity; Solow residual; data envelopment analysis; Malmquist productivity index; Japanese manufacturing firms

1. Introduction

To discuss productivity, measuring and comparing production index efficiency is necessary. Productivity, or production per capita, is an often-used index. As this index measures only the production ratio to one input factor, we see only the proportion between two variables. Firm production simultaneously employs many input factors. Total Factor Productivity (TFP) is a production-measuring index that uses multiple inputs, including economics and business management.

Two major types of TFP are: the Solow residual and the Malmquist Productivity Index (MPI). The Solow residual was introduced in macro economic growth models, and the MPI has been used in micro economics and management studies. As both indices were developed independently, few studies utilize both together and compare the results.

This paper uses the same data set to compare the two productivity indices to determine the economic implications of combining the two indices. We discovered that we could decompose TFP via each aspect of the Solow residual and MPI. We could then interpret the relationship between the Solow residual and MPI in the business cycle.

In the following section, we will briefly introduce previous studies related to the productivity indices. In section 3, we will outline the theoretical framework of the Solow residual and MPI. Section 4 will discuss our data

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Masaru Ichihashi, Ph.D., Graduate School for International Development and Cooperation, Hiroshima University; research fields: economic development, technological change and growth.

Hidemichi Fujii , Ph.D., Graduate School for International Development and Cooperation, Hiroshima University; research fields: environmental economics and environmental management.

set and section 5 will show our results and their economic implications. Finally, we will provide a brief conclusion based upon the results from this paper and note the limitations of our analysis.

2. Literature review

TFP is the most popular index for measuring productivity. The Solow residual, introduced by Solow (1957) in his economic growth analysis, is a common measure of TFP. As Solow noted, this index does not necessarily show a precise degree of technical progress because the index is merely a residual of the macro economic growth rate rather than input factors, such as capital and labor. This residual index is useful for measuring productivity because it can use both macro and micro economic data. The Solow residual has been used to measure TFP for a long time, resulting in a large number of studies.

In recent years, this residual index has been frequently used in micro economic studies using company financial statements and industry data. For example, a controversial argument about if Japan's productivity declined in the 1990s following the economic boom produced many papers related to TFP using both macro and micro data, such as Hayashi and Prescott (2002), Iwata and Miyagawa (2003), Jorgenson and Motohashi (2003), Inui and Kwon (2004), Kawamoto (2004) and Ichihashi (2007). Many studies also used the JIP (Japan Industry Productivity) database, which was created by Keio University (Fukao, 2003). Based upon these papers, Japan's TFP fell during the 1990s, as compared to other economic periods.

Measurements of the Solow residual using cross-section or panel data from company financial statements are utilized in Good, et al (1997), Nakashima (2001), Miyagawa (2006) and Matsuura (2008). These studies provided revised indices of the Solow residual, which are comparable to cross-period and cross-section firms using a geometric TFP average. This application of the Solow residual enlarged the possibilities for its use.

Another measure of TFP, MPI, generally is applied for frontier inefficiency analysis. One of the major frontier analysis is Data Envelopment Analysis (DEA), which has been developed within industrial engineering and management studies. DEA is a non-parametric method that uses mathematical linear programming-based techniques to measure the relative performance of organizational units, termed Decision Making Units (DMUs). DEA can be applied to analyze multiple inputs and outputs without assuming production functional form. The technique was originally suggested by Charnes, et al (1978), and is built on the work of Farrel (1957). Since DEA was first introduced by Charnes, et al (1978), this methodology has been widely applied to the TFP change measurement of many organizations. These organizations include manufacturing units, the public sector, bank branches, hotels and power plants (Hwang & Chang, 2003; Barros & Alves, 2004; Estache, et al., 2008; Jamasb, et al., 2008; LIU & WANG, 2008; Odeck, 2008; Tortosa-Ausina, et al., 2008).

The MPI developed by Malmquist (1953), Caves, et al (1982) and Fare, et al (1994) proved that MPI can be decomposed into two parts: efficiency change (CU: Catching-Up) and technology change (FS: Frontier Shift). As noted, the Solow residual and MPI have been frequently used independently of each other and research involving combining the two indices is in its infant stage. This paper combines these productivity indices to discover the economic implications.

3. Methodology

3.1 Solow residual as TFP

Solow residual is defined as follows, assuming a Cobb-Douglas production function of *j* firm with homogenous type,

$$Y_j = F(K_j, wL_j, M_j, T_j) = T_j K_j^{\alpha} (wL)_j^{\beta} M_j^{1-\alpha-\beta} \tag{1}$$

where K is capital stock, wL is labor cost, M is intermediate material cost and T is the technical change term.

Transforming the right-hand side of this equation using logarithm,

$$\Delta tfp_j = \Delta y_j - c_{kj}\Delta k_j - c_{lj}\Delta wl_j - c_{mj}\Delta m_j \tag{2}$$

where lower-case letters of variables represent the logarithm of each variable and c_{kj}, c_{lj} and c_{mj} are consistent with distribution shares with cost base of each factor under the perfect competition condition. We can decompose TFP change of each factor using equation (2).

3.2 DEA method

In the DEA model, efficiency is defined as the ratio of the weighted sum of output to the weighted sum of input. Now we consider *N* samples with *P* input and *Q* output. In this case, the technological efficiency (*TE*) of DMU *k* is defined as the following:

Objective function $$TE_k = Max. \frac{\sum_{q=1}^{Q} v_q y_{k,q}}{\sum_{p=1}^{P} u_p x_{k,p}} \tag{3}$$

Subject to $$\frac{\sum_{q=1}^{Q} v_q y_{i,q}}{\sum_{p=1}^{P} u_p x_{i,p}} \le 1 \qquad \forall i,\ u^p \ge 0,\ v^q \ge 0,\ i = 1,2,\cdots,k,\cdots N$$

where, *i* is the sample name, *p* is the input variable name, such as labor and capital, and *q* is the output variable name, such as sales and products. y_k^p is the amount of output *p* produced by DMU *k*. x_k^q is the amount of input *q* produced by DMU *k*. y_k^p is the weight given to output *q* and u^p is the weight given to input *p*.

The fractional program in (3) is subsequently converted to a linear programming format, and a mathematical dual is employed as shown in (4), to solve the linear problem. In this regard, the value of TE_k is equal to $Min.\ \theta_k$ ($TE_k = Min.\theta_k$). The mathematical dual is necessary as it reduces the number of constraints in the computation (Charnes, et al., 1978). The dual DEA model can be stated as:

Objective function $$TE_k = Min.\ \theta_k \tag{4}$$

Subject to
$$\sum_{i=1}^{N} \lambda_i x_{i,p} \le \theta_k x_{k,p} \qquad \forall p$$
$$\sum_{i=1}^{N} \lambda_i y_{i,q} \ge y_{k,q} \qquad \forall q$$
$$\lambda_i \ge 0 \qquad \forall i$$

where θ_k is the efficiency score of DMU *k* and λ_i is the dual weighted variables (weight in the dual model for the inputs and outputs of DMU *k*). The solution to the above model gives a value θ_k, the efficiency of the unit being evaluated. If θ_k =1, then DMU *k* is efficiently relative to the others. If θ_k is less than 1, then some other DMUs are more efficient than DMU *k*. In this case, DMU *k* is evaluated as an inefficient unit.

3.3 Malmquist productivity index approach

The Malmquist productivity index calculates the TFP change by using the results of the DEA model (Caves, 1987). These indices can be decomposed into two components: one is the Catching-Up component (*CU*) and the other is the Frontier Shift component (*FS*). $CU_t^{t+1} \ge 1$ shows that the efficiency gap between efficient and inefficient DMUs becomes smaller from *t* year to *t+1* year. $FS_t^{t+1} \ge 1$ shows that frontier line shifts more efficient direction from t year to t+1 year. The calculation follows:

Malmquist productivity index $M_k\left(y_k^{t+1}, x_k^{t+1}, y_k^t, x_k^t\right)$ is expressed in equation (5).

$$M(y_{k,q}^{t+1}, x_{k,p}^{t+1}, y_{k,q}^{t}, x_{k,p}^{t}) = \underbrace{\frac{D^{t+1}(y_{k,q}^{t+1}, x_{k,p}^{t+1})}{D^{t}(y_{k,q}^{t}, x_{k,p}^{t})}}_{CU_t^{t+1}} \underbrace{\left[\frac{D^{t}(y_{k,q}^{t+1}, x_{k,p}^{t+1})}{D^{t+1}(y_{k,q}^{t+1}, x_{k,p}^{t+1})} \times \frac{D^{t}(y_{k,q}^{t}, x_{k,p}^{t})}{D^{t+1}(y_{k,q}^{t}, x_{k,p}^{t})}\right]^{\frac{1}{2}}}_{FS_t^{t+1}} \qquad (5)$$

This equation represents the TFP change of DMU *k* from *t* year to *t+1* year. The Malmquist productivity index in equation (5) is composed of two DEA results. One is evaluated by using the period *t* frontier line, such as $D^t(y_k^t, x_k^t)$, and the other is evaluated by using the period *t+1* frontier line, such as $D^{t+1}(y_k^t, x_k^t)$. These DEA calculations are given as the following equations:

Objective function $\quad D^t(y_k^t, x_k^t) = Min.\ \theta_k \qquad (6)$

Subject to

$$\sum_{i=1}^{N} \lambda_i x_{i,p}^t \le \theta_k x_{k,p}^t \qquad \forall p$$

$$\sum_{i=1}^{N} \lambda_i y_{i,q}^t \ge y_{k,q}^t \qquad \forall q$$

$$\lambda_i \ge 0 \qquad \forall i$$

Objective function $\quad D^{t+1}(y_k^t, x_k^t) = Min.\ \theta_k \qquad (7)$

Subject to

$$\sum_{i=1}^{N} \lambda_i x_{i,p}^{t+1} \le \theta_k x_{k,p}^t \qquad \forall p$$

$$\sum_{i=1}^{N} \lambda_i y_{i,q}^{t+1} \ge y_{k,q}^t \qquad \forall q$$

$$\lambda_i \ge 0 \qquad \forall i$$

4. Data

The main dataset we used is the Nikkei NEEDS financial database, which includes balance sheet items, profit and loss from each firm. The database includes 1,453 Japanese firms, covering all industries.

Variables for estimation include total sales of whole products, cost of sales of intermediate material costs, fixed asset and depreciation costs of capital stock, labor costs and other personnel costs of selling expenses of labor costs. Here, capital stock was calculated by aggregating fixed assets and depreciation costs for each year. We did not accept a constant discount rate for the capital like the perpetual inventory method because of the frequency of negative figures of capital stock, and we could not find an adequate method to solve this problem. Finding suitable discount rates that can be applied to every sector is difficult, another reason we did not use the perpetual inventory method.

The variables we employed were changed to real ones deflated by the Corporate Goods Price Index (CGPI) (2000 base), which is listed on the Nippon Bank site[1]. For the most precise deflation, finding price indicators for each sector is desirable, but such was not possible for our current analysis. We accepted the CGPI for our deflation because most variables, such as intermediate materials and capital, are treated in trade among firms and are not consumables.

The 1,453 Japanese firms in our data set can be categorized into 23 sectors. We then took the characteristics for each sector and compared the Solow residual and MPI.

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[1] http://www.boj.or.jp/en/type/stat/dlong/index.htm.

5. Results and discussion

Our TFP results are shown in Table 1, Table 2 and Fig. 1. In Table 1 and Table 2, we show average growth rates in five year increments for the two TFP measurements: Solow residual in the first row and MPI in the sixth row of each box for each of the 23 sectors. Other items in the boxes are decomposition factors of each TFP. Values SOLOW_L, M, K and Y represent the terms on the right-hand side of equation (2) and the values are determinants of the Solow residual level. The values of DEA_CU and DEA_FS are decomposition factors of MPI equation (5) for the growth rate of each term. “Type” in the last row of each box means the type of MPI change, either CU or FS. CU shows that the catching-up effect on MPI is stronger during the period, and FS shows that the frontier shift effect on MPI is stronger during the period. “Bad” indicates that the strength of the effects cannot be determined. The correlation coefficients are listed on the right side of each box, showing the relationship between the Solow residual and the MPI. Fig. 1 illustrates the data from these tables for several sectors.

According to these figures, we note several points. First, the Solow residual and MPI move closely together. The average correlation coefficient across all sectors is 0.75, but over one-half of all sectors have a correlation coefficient greater than 0.90, indicating that these two TFP measures are effective for measuring productivity.

Second, both TFP measures provide new insights into the decomposition of productivity changes. According to Table 1, for example, firms in the machinery sector saw TFP recover during two five-year intervals over the 25-year time period – from 1986-1990 and 2001-2005. The 1986-1990 interval was during the bubble economy in Japan, and the 2001-2005 interval was during a period of economic reform, the Structural Reform period (Kozo Kaikaku) initiated by Prime Minister Koizumi and his cabinet. Table 1 shows that the increase in machinery’s TFP from the Solow residual was caused by increasing total sales in both periods, but this increase resulted in a frontier shift in MPI. Also, MPI affected catch-up from 2001-2005 while the Solow residual was improved by reducing labor costs.

Third, we focus on the productivity change in the 115 (23×5) time period. According to the decomposition of the Solow residual, most improvements are accomplished by cutting labor costs and increasing sales. Table 1 and Table 2 show 23 types of businesses and five periods for each five years from 1980 to 2005. The 24 time periods show improving TFP (both Solow residual and MPI) in these tables.

Fourteen time periods are shown by the Solow residual rising due to labor cuts, including 9 time periods were the result of increasing sales simultaneously. Japanese firms have been improving production efficiency by reducing employees and increasing production during these 25 years.

Fourth, there is a close relationship between an increase in the Solow residual and the frontier shift of MPI. Twenty-one periods within the 24 time period in which both TFP improved in that show TFP improvements are due to the frontier shift of MPI. Five of these periods include not only the frontier shift, but also the catch-up, indicating that the most effective productivity increases in Japan are due to the frontier shifts of each industry rather than the catch-up aspect of MPI.

The average TFP tendency does not improve substantially in many sectors or over many periods. Japanese production efficiency was not good during the recession period, 1991-1995, or during the recovery period, 2001-2005. This tendency was affected by production factors such as intermediate materials and capital stock increasing over several periods. As previous studies have indicated, Japanese company TFP was low in the 1990s, but our results show that stagnant TFP growth is not confined to recessionary periods. Even in periods of economic boom, TFP growth in approximately half of the 23 sectors was not very high. As indicated, the Solow residual and MPI are similar indices for measuring productivity, but it is clearly beneficial to use both together, as well as independently of each other.

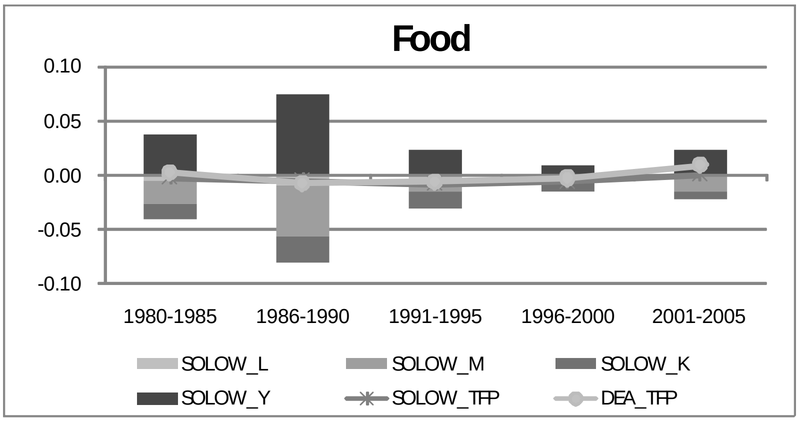
Table 1 Solow residual and DEA Malmquist index in industrial sector

		1980-1985	1986-1990	1991-1995	1996-2000	2001-2005	Correlation
Food	SOLOW_TFP	-0.002	-0.006	-0.008	-0.006	0.001	0.954
	SOLOW_L	-0.005	-0.010	-0.005	0.001	0.001	
	SOLOW_M	-0.021	-0.046	-0.011	-0.002	-0.015	
	SOLOW_K	-0.014	-0.025	-0.016	-0.012	-0.007	
	SOLOW_Y	0.038	0.075	0.023	0.008	0.022	
	DEA_MPI	0.003	-0.007	-0.006	-0.002	0.009	
	DEA_FS	0.003	0.001	0.002	-0.004	-0.007	
	DEA_CU	0.000	-0.008	-0.008	0.002	0.016	
	Type	CU	CU	CU	FS	FS	
Textile	SOLOW_TFP	-0.002	0.001	-0.012	0.002	0.009	0.867
	SOLOW_L	-0.005	-0.011	0.000	0.009	0.010	
	SOLOW_M	-0.016	-0.046	0.017	0.026	0.019	
	SOLOW_K	-0.005	-0.013	-0.005	-0.004	-0.004	
	SOLOW_Y	0.024	0.072	-0.025	-0.029	-0.016	
	DEA_MPI	-0.004	-0.006	-0.010	0.002	0.016	
	DEA_FS	-0.001	-0.005	-0.005	-0.031	-0.021	
	DEA_CU	-0.003	-0.001	-0.005	0.033	0.041	
	Type	bad	bad	bad	FS	FS	
Pulp	SOLOW_TFP	-0.002	-0.014	0.002	-0.004	-0.010	0.739
	SOLOW_L	-0.005	-0.012	-0.007	0.003	0.002	
	SOLOW_M	-0.012	-0.050	-0.021	-0.012	-0.024	
	SOLOW_K	-0.008	-0.026	-0.007	-0.008	-0.005	
	SOLOW_Y	0.023	0.074	0.036	0.013	0.017	
	DEA_MPI	0.008	-0.013	-0.001	-0.002	-0.002	
	DEA_FS	-0.002	0.000	-0.002	0.001	0.003	
	DEA_CU	0.010	-0.013	0.001	-0.002	-0.005	
	Type	FS	CU	FS	CU	CU	
Rubber	SOLOW_TFP	-0.005	-0.002	-0.001	-0.006	-0.004	0.131
	SOLOW_L	-0.011	-0.015	-0.010	0.003	0.006	
	SOLOW_M	-0.018	-0.045	-0.001	-0.004	-0.022	
	SOLOW_K	-0.009	-0.018	-0.005	-0.009	-0.006	
	SOLOW_Y	0.034	0.077	0.015	0.004	0.019	
	DEA_TFP	-0.008	0.002	-0.009	-0.005	0.001	
	DEA_EFFCH	0.006	0.004	-0.003	0.000	-0.003	
	DEA_TECHCH	-0.014	-0.002	-0.007	-0.005	0.004	
	Type	CU	CU	bad	bad	FS	
Chemistry	SOLOW_TFP	-0.001	-0.002	-0.001	-0.005	-0.003	-0.355
	SOLOW_L	-0.007	-0.011	-0.006	0.001	0.003	
	SOLOW_M	-0.031	-0.053	-0.008	-0.005	-0.009	
	SOLOW_K	-0.012	-0.022	-0.008	-0.008	-0.007	
	SOLOW_Y	0.049	0.084	0.020	0.006	0.011	
	DEA_MPI	-0.004	-0.009	-0.029	-0.005	0.001	
	DEA_FS	0.002	-0.001	-0.014	-0.010	0.000	
	DEA_CU	-0.005	-0.007	-0.015	0.005	0.002	
	Type	CU	bad	bad	FS	FS	
Medicine	SOLOW_TFP	-0.034	-0.001	-0.012	-0.014	-0.012	0.646
	SOLOW_L	-0.013	-0.023	-0.020	-0.002	0.002	
	SOLOW_M	-0.024	-0.032	-0.026	-0.019	-0.007	
	SOLOW_K	-0.058	-0.060	-0.048	-0.038	-0.028	
	SOLOW_Y	0.061	0.114	0.081	0.045	0.022	
	DEA_MPI	-0.010	-0.004	-0.011	-0.006	-0.006	
	DEA_FS	-0.004	-0.013	0.015	-0.003	0.000	
	DEA_CU	-0.006	0.008	-0.026	-0.003	-0.005	
	Type	bad	FS	CU	bad	bad	
Non ferrous metal	SOLOW_TFP	-0.005	0.004	-0.012	-0.005	0.005	0.950
	SOLOW_L	-0.006	-0.015	-0.006	0.002	0.002	
	SOLOW_M	-0.019	-0.083	-0.001	-0.005	-0.036	
	SOLOW_K	-0.008	-0.017	-0.008	-0.007	-0.002	
	SOLOW_Y	0.028	0.119	0.003	0.005	0.041	
	DEA_MPI	-0.004	0.007	-0.013	-0.002	0.003	
	DEA_FS	0.006	-0.003	0.003	0.005	-0.017	
	DEA_CU	-0.010	0.009	-0.015	-0.007	0.021	
	Type	CU	FS	CU	CU	FS	
Iron	SOLOW_TFP	-0.009	0.022	-0.025	-0.001	0.023	0.954
	SOLOW_L	-0.002	-0.010	-0.003	0.006	0.003	
	SOLOW_M	0.000	-0.063	0.008	0.008	-0.038	
	SOLOW_K	-0.004	-0.013	-0.010	-0.004	-0.002	
	SOLOW_Y	-0.003	0.107	-0.020	-0.012	0.061	
	DEA_MPI	-0.006	0.011	-0.020	0.000	0.028	
	DEA_FS	-0.002	-0.011	0.011	-0.001	-0.018	
	DEA_CU	-0.004	0.023	-0.030	0.001	0.048	
	Type	bad	FS	CU	FS	FS	

		1980-1985	1986-1990	1991-1995	1996-2000	2001-2005	Correlation
Petroleum	SOLOW_TFP	-0.009	0.005	-0.012	-0.010	0.000	0.599
	SOLOW_L	-0.002	-0.005	-0.003	-0.001	0.000	
	SOLOW_M	-0.032	-0.005	0.026	-0.075	-0.064	
	SOLOW_K	-0.005	-0.009	-0.011	-0.008	-0.002	
	SOLOW_Y	0.031	0.024	-0.023	0.074	0.066	
	DEA_MPI	-0.014	0.001	-0.020	0.001	0.033	
	DEA_FS	0.002	-0.003	0.002	-0.001	-0.004	
	DEA_CU	-0.016	0.003	-0.021	0.002	0.037	
	Type	CU	FS	CU	FS	FS	
Ceramic	SOLOW_TFP	-0.013	-0.001	-0.011	-0.006	-0.002	0.901
	SOLOW_L	-0.005	-0.012	-0.006	0.001	0.004	
	SOLOW_M	-0.019	-0.054	-0.019	-0.013	-0.006	
	SOLOW_K	-0.015	-0.022	-0.010	-0.010	-0.004	
	SOLOW_Y	0.026	0.088	0.023	0.015	0.005	
	DEA_MPI	-0.012	-0.005	-0.013	-0.006	0.000	
	DEA_FS	-0.003	-0.006	0.001	0.003	0.007	
	DEA_CU	-0.010	0.001	-0.014	-0.008	-0.007	
	Type	bad	FS	CU	CU	CU	
Machinery	SOLOW_TFP	-0.014	0.008	-0.017	-0.003	0.005	0.982
	SOLOW_L	-0.012	-0.016	-0.003	-0.001	0.001	
	SOLOW_M	-0.038	-0.079	-0.001	-0.013	-0.026	
	SOLOW_K	-0.019	-0.021	-0.010	-0.009	-0.007	
	SOLOW_Y	0.055	0.124	-0.004	0.019	0.036	
	DEA_TFP	-0.013	0.006	-0.014	-0.004	0.008	
	DEA_EFFCH	0.008	-0.003	0.006	-0.001	0.002	
	DEA_TECHCH	-0.021	0.009	-0.020	-0.002	0.006	
	Type	CU	FS	CU	bad	FS&CU	
Electrical machinery	SOLOW_TFP	-0.019	0.005	-0.007	0.000	0.015	0.935
	SOLOW_L	-0.015	-0.018	-0.004	-0.001	0.004	
	SOLOW_M	-0.073	-0.085	-0.010	-0.029	-0.010	
	SOLOW_K	-0.034	-0.018	-0.006	-0.009	0.010	
	SOLOW_Y	0.104	0.125	0.014	0.038	0.012	
	DEA_MPI	-0.015	-0.002	-0.007	-0.003	-0.001	
	DEA_FS	0.011	0.009	-0.006	-0.005	-0.023	
	DEA_CU	-0.026	-0.009	0.000	0.004	0.024	
	Type	CU	CU	bad	FS	FS	
Motor vehicles	SOLOW_TFP	-0.004	-0.003	-0.002	-0.002	0.004	0.935
	SOLOW_L	-0.011	-0.016	-0.004	-0.002	-0.005	
	SOLOW_M	-0.050	-0.076	0.005	-0.016	-0.060	
	SOLOW_K	-0.009	-0.011	-0.002	-0.006	-0.006	
	SOLOW_Y	0.066	0.099	-0.001	0.022	0.075	
	DEA_MPI	-0.004	-0.005	-0.001	-0.004	0.003	
	DEA_FS	0.007	-0.003	-0.001	-0.016	-0.004	
	DEA_CU	-0.011	-0.003	0.000	0.012	0.008	
	Type	CU	bad	FS	FS	FS	
Other transport equipment	SOLOW_TFP	0.001	0.009	-0.012	-0.005	0.003	0.832
	SOLOW_L	-0.007	-0.010	-0.004	0.004	0.001	
	SOLOW_M	-0.008	-0.080	0.002	0.009	-0.006	
	SOLOW_K	-0.004	-0.012	-0.006	-0.005	0.000	
	SOLOW_Y	0.019	0.112	-0.003	-0.013	0.007	
	DEA_MPI	-0.007	0.010	-0.011	-0.013	0.011	
	DEA_FS	0.006	0.000	0.006	-0.005	-0.007	
	DEA_CU	-0.013	0.010	-0.017	-0.007	0.018	
	Type	CU	FS&CU	CU	bad	FS	
Other industry	SOLOW_TFP	0.012	-0.005	-0.012	-0.004	0.001	0.441
	SOLOW_L	-0.024	-0.020	-0.006	0.001	0.004	
	SOLOW_M	-0.078	-0.096	-0.006	0.001	0.007	
	SOLOW_K	-0.021	-0.033	-0.010	-0.006	-0.002	
	SOLOW_Y	0.135	0.144	0.010	0.001	-0.008	
	DEA_MPI	-0.005	-0.002	-0.012	-0.004	0.004	
	DEA_FS	-0.001	0.001	0.001	0.001	-0.018	
	DEA_CU	-0.003	-0.003	-0.013	-0.005	0.022	
	Type	bad	CU	CU	CU	FS	

Table 2 Solow residual and DEA Malmquist index in service sector

		1980-1985	1986-1990	1991-1995	1996-2000	2001-2005	Correlation			1980-1985	1986-1990	1991-1995	1996-2000	2001-2005	Correlation
Mining	SOLOW_TFP	-0.011	-0.009	-0.010	0.007	-0.016	0.616	Precision instruments	SOLOW_TFP	-0.018	0.001	-0.008	0.002	-0.006	0.902
	SOLOW_L	-0.001	0.001	-0.003	0.001	0.005			SOLOW_L	-0.015	-0.018	-0.001	0.002	0.005	
	SOLOW_M	-0.042	-0.124	0.004	-0.042	0.006			SOLOW_M	-0.044	-0.078	0.009	-0.022	-0.016	
	SOLOW_K	-0.016	-0.017	-0.010	-0.010	-0.008			SOLOW_K	-0.028	-0.019	-0.005	-0.009	-0.014	
	SOLOW_Y	0.048	0.132	-0.002	0.059	-0.019			SOLOW_Y	0.069	0.117	-0.011	0.030	0.018	
	DEA_MPI	-0.006	0.004	-0.029	0.015	-0.006			DEA_MPI	-0.012	0.001	-0.010	0.007	-0.002	
	DEA_FS	-0.001	0.000	-0.005	0.005	-0.003			DEA_FS	0.007	0.005	-0.009	0.004	-0.004	
	DEA_CU	-0.005	0.004	-0.024	0.010	-0.003			DEA_CU	-0.017	-0.004	-0.001	0.003	0.001	
	Type	bad	FS&CU	bad	FS&CU	bad			Type	CU	CU	bad	FS&CU	FS	
Electricity and gas	SOLOW_TFP	0.005	-0.019	-0.008	-0.007	-0.003	0.882	Construction	SOLOW_TFP	-0.005	0.004	-0.008	-0.006	-0.002	0.904
	SOLOW_L	-0.006	-0.007	-0.007	-0.003	0.003			SOLOW_L	-0.006	-0.013	-0.009	0.000	0.004	
	SOLOW_M	-0.018	-0.003	-0.019	-0.017	-0.017			SOLOW_M	-0.025	-0.132	-0.043	0.006	0.017	
	SOLOW_K	-0.018	-0.027	-0.023	-0.011	-0.001			SOLOW_K	-0.005	-0.012	-0.010	-0.004	0.001	
	SOLOW_Y	0.046	0.018	0.041	0.024	0.012			SOLOW_Y	0.031	0.162	0.053	-0.008	-0.024	
	DEA_MPI	0.004	-0.015	0.000	-0.008	0.004			DEA_MPI	-0.006	0.002	-0.009	-0.007	0.002	
	DEA_FS	-0.003	-0.004	0.004	-0.002	-0.010			DEA_FS	-0.002	0.003	-0.001	0.004	-0.001	
	DEA_CU	0.007	-0.012	-0.004	-0.006	0.014			DEA_CU	-0.004	-0.001	-0.008	-0.012	0.003	
	Type	FS	bad	CU	bad	FS			Type	bad	CU	bad	CU	FS	
Transport	SOLOW_TFP	-0.007	0.003	-0.008	-0.003	0.004	0.978	Wholesale	SOLOW_TFP	-0.004	-0.004	-0.006	-0.002	0.002	0.969
	SOLOW_L	-0.009	-0.013	-0.007	-0.001	0.004			SOLOW_L	-0.006	-0.008	-0.003	0.001	0.003	
	SOLOW_M	-0.021	-0.067	-0.015	-0.018	-0.024			SOLOW_M	-0.045	-0.099	-0.007	0.010	0.000	
	SOLOW_K	-0.006	-0.012	-0.006	-0.004	-0.009			SOLOW_K	-0.011	-0.017	-0.006	-0.002	-0.001	
	SOLOW_Y	0.030	0.096	0.021	0.020	0.033			SOLOW_Y	0.058	0.119	0.010	-0.012	-0.001	
	DEA_MPI	-0.015	0.011	-0.019	-0.011	0.013			DEA_TFP	-0.003	-0.004	-0.007	-0.003	0.005	
	DEA_FS	-0.014	0.000	0.004	-0.051	0.046			DEA_EFFCH	-0.007	0.007	-0.004	-0.001	0.003	
	DEA_CU	0.001	0.014	-0.008	0.045	-0.008			DEA_TECHCH	0.004	-0.010	-0.003	-0.002	0.003	
	Type	FS	FS	CU	FS	CU			Type	FS	CU	bad	bad	FS&CU	
Other services	SOLOW_TFP	-0.017	-0.005	-0.018	-0.010	0.011	0.912	Retail trade	SOLOW_TFP	0.031	0.001	-0.007	-0.008	0.009	0.469
	SOLOW_L	-0.012	-0.015	-0.008	0.002	0.001			SOLOW_L	-0.024	-0.013	-0.005	0.000	-0.002	
	SOLOW_M	-0.053	-0.098	-0.029	-0.009	0.000			SOLOW_M	-0.158	-0.100	-0.028	-0.001	-0.024	
	SOLOW_K	-0.038	-0.048	-0.022	-0.014	-0.009			SOLOW_K	-0.021	-0.026	-0.016	-0.009	0.000	
	SOLOW_Y	0.087	0.156	0.041	0.011	0.018			SOLOW_Y	0.234	0.139	0.043	0.002	0.035	
	DEA_MPI	-0.002	0.009	-0.018	-0.002	0.020			DEA_MPI	-0.002	-0.005	-0.013	-0.003	0.007	
	DEA_FS	-0.004	0.012	0.003	0.003	-0.012			DEA_FS	-0.005	0.009	-0.023	0.011	-0.007	
	DEA_CU	0.005	-0.001	-0.020	-0.004	0.032			DEA_CU	0.003	-0.013	0.011	-0.014	0.014	
	Type	FS	CU	CU	CU	FS			Type	FS	CU	FS	CU	FS	



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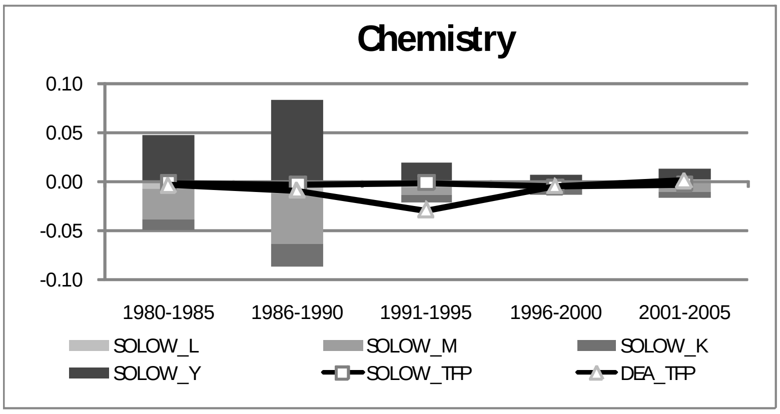

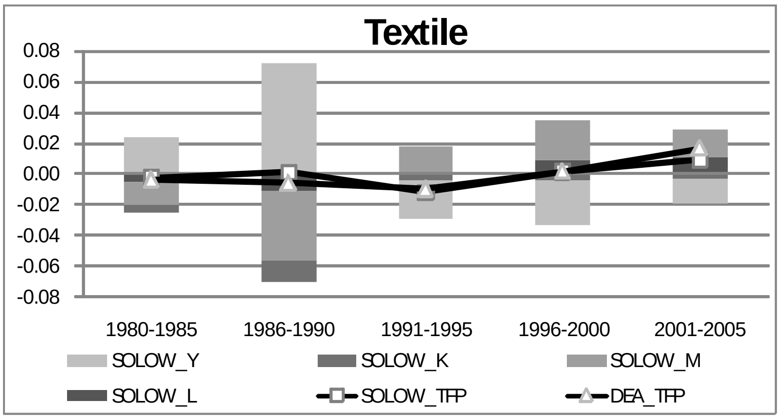

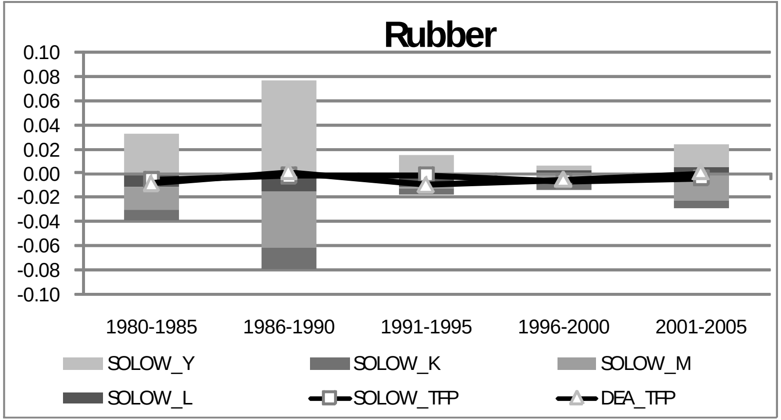

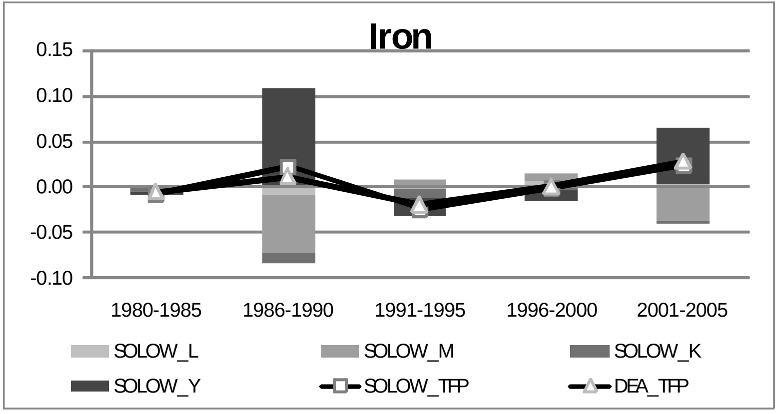

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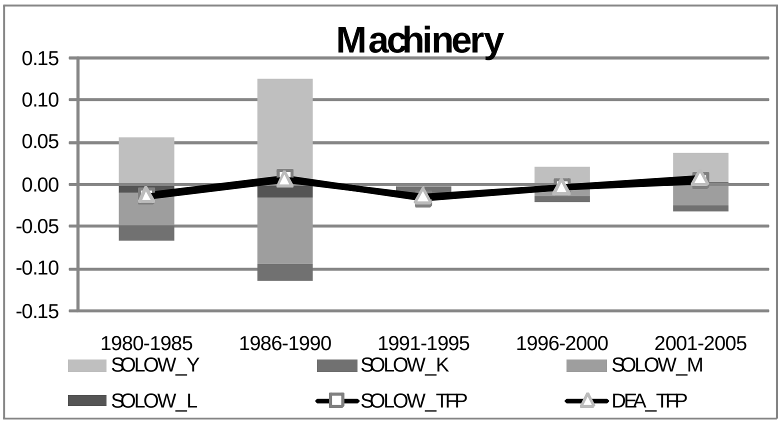

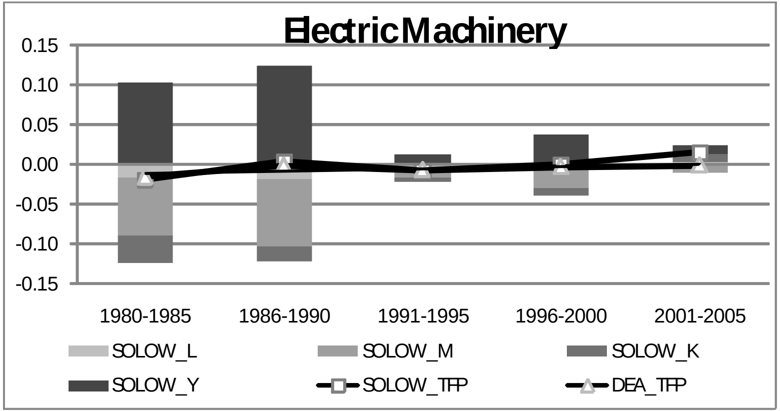

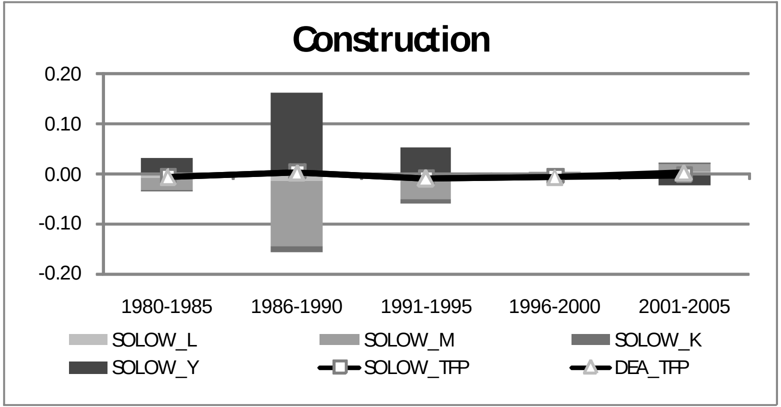

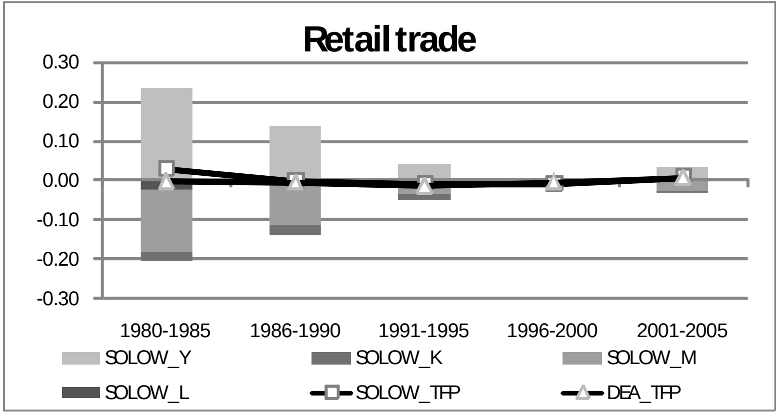

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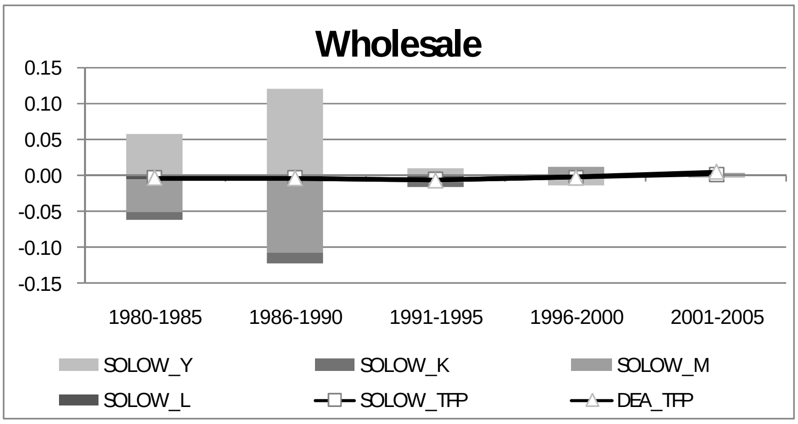

Fig. 1 Decomposition of TFP (Several sectors)

6. Conclusions

In this paper, we performed a comparative analysis of two kinds of TFP indices: the Solow residual and the MPI. Looking at these indices, we see that the decomposition of the TFP variation over periods is useful.

Our results indicate that the frontier shift in MPI for Japanese firms often occurred when the Solow residual increased. This indicates that improving productivity with the Solow residual may be generated by a firm that could reach new production frontiers. We have also shown that the Solow residual increases with a rise in total sales and a cut in labor costs. Cutting labor costs and expanding export production may contribute to an increase in TFP. We conclude that most Solow residual increases and frontier shifts of MPI have a strong positive relationship among Japanese firms in various industries over the 25 years studied.

The data we used in this paper have some limitations. First, capital stock was considered aggregate fixed assets and depreciation costs, not a constant discount rate in a perpetual inventory method. After reducing eliminating this limitation in the capital data, our comparison may be affected, but capital data processing might make measurement even more complicated. The second limitation concerns the deflator we accepted. We used only CGPI for the deflation of our data because we could not find a more desirable deflator for each sector.

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