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Decline in Productivity in Japan and Disparities Between Firms in the 1990s: An Empirical Approach Based on Data Envelopment Analysis

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Summary

1. The Japanese economy has suffered a low level of growth since the 1990s and the decline in productivity is often pointed out as the primary cause in growth accounting. Along with capital and labor input, productivity is another major factor that supports economic growth. However, since it can be calculated as the residual derived by subtracting growth in capital and labor input from the growth rate of the economy overall (the so-called Solow residual), increased productivity is not only the result of direct technological progress based on research and development and the like but also includes economies of scale, learning effect and various other elements. It is therefore difficult but important to clarify the factors that are involved in producing changes in productivity.

This study, based on individual corporate financial data, classifies changes in productivity as (1) technological progress of firms with the highest level of productivity within an industry and (2) improvements in productivity of other firms and conducts analyses focusing on the differences that are evident within major industries. Taking into account the intra-industry differences in productivity thus identified, possible directions of future policies are proposed.

2. First of all, in terms of changes in total factor productivity (TFP), although manufacturing industries suffered stagnant growth after the collapse of the bubble economy, they succeeded in maintaining positive growth due to expansion in electrical machinery and other IT-related industries. There was a broad decline in productivity in non-manufacturing industries, however, especially construction and other industries that were strongly impacted by the collapse of the bubble, and the TFP of non-manufacturing industries overall turned negative.

3. It is not possible to clarify the background causes of the slump in productivity by the TFP estimated based on aggregate data. The study therefore sought to verify whether or not disparities exist between firms by gauging disparities in productivity between firms within the same industry, using the Malmquist productivity index (MPI) calculated by data envelopment analysis (DEA). The MPI is divided into (1) changes (technical changes) in efficiency of firms that are making the most effective use of the input factors of capital, labor and so forth (i.e., that have the highest productivity) (technological frontier) and (2) improvements in efficiency (technical efficiency) of other less efficient companies. The amount of capital and labor input and value added of each firm are estimated using financial data of listed companies, then the MPI, technical change and technical efficiency in major industries are calculated.

4. The MPI of major manufacturing industries indicates growth in electrical machinery since the latter half of the 1990s while growth in chemicals, iron & steel, automobiles & components has been persistently low. There was a strong tendency toward continued positive growth in technical change throughout the 1990s, contributing considerably to improved corporate productivity. However, some firms were slow to introduce efficiency improvements.

5. The MPI of major non-manufacturing industries indicates a persistent overall decline in productivity in the construction, retail and services (excluding leasing and private sector broadcasting) industries. There was a broad expansion in productivity in the construction industry during the time of the bubble economy, but, after that, there has subsequently been a strong tendency toward negative growth in technical change. In the retail industry, there was a notable improvement in productivity in supermarkets, convenience stores and other re-

tail outlets from the 1980s through the early 1990s, though other industries failed to keep pace. But growth has remained low in recent years. While there has been modest change in productivity in the service industry, there is little prospect of an improvement in productivity due to economies of scale since the collapse of the bubble economy.

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Abstract

The Japanese economy has suffered a low level of growth since the 1990s and the decline in productivity is often pointed out as the primary cause. In regard to the characteristics of productivity at the corporate level in Japan, the analyses in this study focus on clarifying disparities between firms within the same industry. Specifically, the value added, labor productivity and capital productivity of each firm were measured using individual financial data of listed companies and the Malmquist productivity index (MPI) in eight major industries was calculated by data envelopment analysis (DEA). The results showed that the disparities between the two have been expanding, especially in manufacturing industries, since the latter half of the 1990s, through the decomposition of trends in productivity into (1) the technological progress of firms with the highest productivity in the industry and (2) the improvement of productivity in other firms.

I Introduction

1. Stagnation in Productivity in Japan from the Perspective of Total Factor Productivity

According to an estimate by the Cabinet Office (2001), the potential growth potential in Japan has been declining since the Heisei recession (Fig. 1-1). Besides a decline in capital and labor input reflecting restricted capital spending and a decline in working hours as well as stagnation in the growth in the number of employed persons, there has been notable stagnation in the growth of productivity (Fig. 1-2).

Productivity as calculated here is the total factor productivity (TFP). Essentially, TFP indicates total output per total input, that is, productivity in relation to the overall input; however, there is a problem with, the method of tabulating multiple inputs and outputs and gauging productivity. Here, assuming a production function with one output and two inputs, the growth of production volume and the growth of the two inputs of operating capital and labor were compared, and the portion that cannot be explained by growth in the two inputs was calculated as the TFP.

TFP trends by industry indicate that growth slumped in virtually all industries during the 1990s compared to the 1980s during the time of the bubble economy (Fig. 1-3). TFP in manufacturing industries maintained positive growth even during the 1990s due to technological progress in electrical machinery and other industries. In non-manufacturing industries, however, TFP growth was negative reflecting a decline in construction and other industries that were strongly impacted by the collapse of the bubble economy.

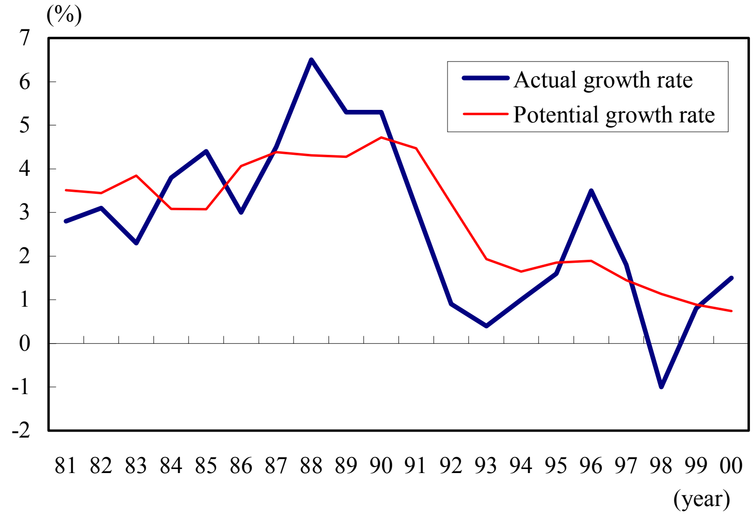


Fig. 1-1 Potential Growth Rate and Actual real GDP Growth Rate

Note: Productivity (TFP) is calculated from the disparity (so-called Solow residual) between the GDP growth rate and capital and labor input growth (multiplied by the allocation rate of each).

Source: Cabinet Office, "Fiscal 2001 Economic Outlook and Basic Stance for Macroeconomic & Fiscal Management."

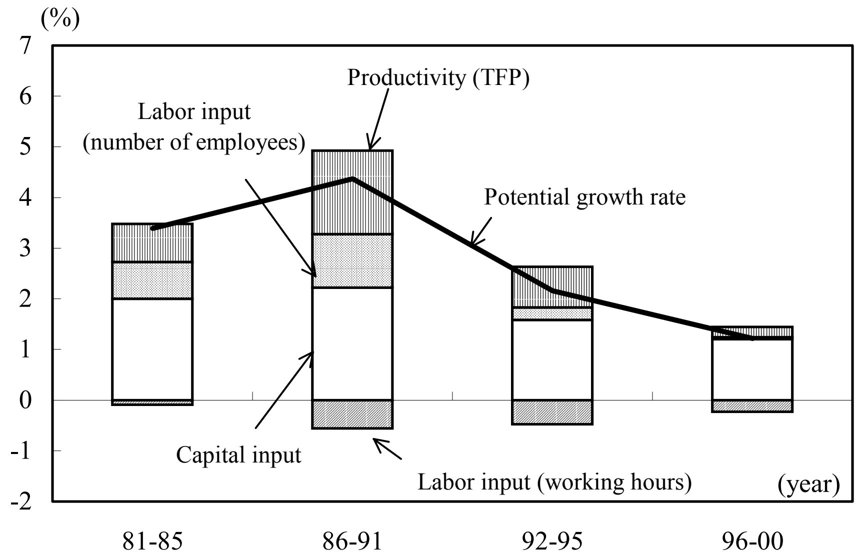


Fig. 1-2 Factors in the Decline of the Potential Growth Rate

Note: Productivity (TFP) is calculated from the disparity (so-called Solow residual) between the GDP growth rate and capital and labor input growth (multiplied by the allocation rate of each).

Source: Cabinet Office, "Fiscal 2001 Economic Outlook and Basic Stance for Macro-economic & Fiscal Management."

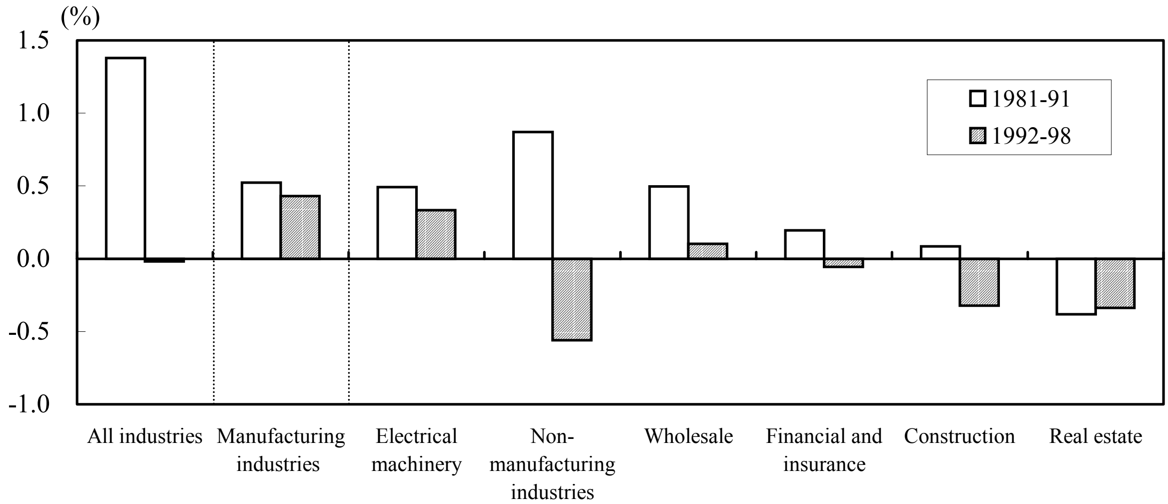


Fig. 1-3 Transition in TFP by Industry

Note: Productivity (TFP) is calculated from the disparity (so-called Solow residual) between the GDP growth rate and capital and labor input growth (multiplied by the allocation rate of each).

Source: Cabinet Office, "Fiscal 2001 Economic Outlook and Basic Stance for Macroeconomic & Fiscal Management."

2. Technological Efficiency and TFP

In terms of the efficient use of technology, it is possible to comprehend the rise in productivity, that is, technological progress, as the degree of efficiency with which companies use their production factors.

Technological progress can be summarized as the following two types. The first is the efficiency of technology consisting of whether or not a given level of technology is being used efficiently. The other is the change in the level of technology itself. Even if a certain level of sophisticated technology exists, when no entity is able to use it with full efficiency, there will be no improvement in technological progress overall. The extent of the technological progress of society as a whole is thought to consist of a combination of both efficiency and change in the technological level.

Can TFP thus be considered an appropriate index of technological progress? In order to clarify the efficiency of technology, it is necessary to compare the state in which certain technology is used to the maximum and the state in which it is not. In order to do this, it is necessary to establish an appropriate classification and tabulation of inputs such as value added, operating capital and labor input as well as outputs. Various problems have been pointed out in proving this, and the so-called productivity paradox occurs in which the calculated TFP moves differently from that expected. Nakajima (2001) points out the problem of the precision of the input and output data. Canter and Hanusch (1999) state that it is difficult to assume an appropriate production function for diverse technological progress. The TFP is calculated using outputs and inputs aggregated at the industry level. Due to the difficulty of incorporating all of the costs of all goods and qualitative changes, the TFP does not indicate content in detail. In addition, when clarifying changes in the technological level itself, similar problems arise when conducting analyses using aggregated values.

Therefore, this study sought to prove how efficiently firms within the same industry use production factors or if disparities in efficiency arise between firms by measuring the productivity at the level of each firm and using that to estimate the technological frontier (isoquant curve). Specifically, the disparities in productivity between firms within the same industry are clarified by calculating the Malmquist productivity index using data envelopment analysis procedures in estimating the technological frontier. The next chapter examines how productivity is comprehended by this approach.

II Technological Progress and Efficiency

1. Definition of Efficiency and Technological Progress

The definition of efficiency used in this paper is the extent to which output is generated by using production factors efficiently. Generally, when production factors are used most efficiently and it would be impossible to produce the same volume of output with fewer production factors, the isoquant curve (a curve indicating the combination of input volumes required to produce a given volume of output) can be expressed as the technological frontier. It furthermore indicates the degree of efficiency (or inefficiency) due to deviation from the technological frontier. For example, in Fig. 2-1, if the output is y and there are two inputs (production factors), x_1 and x_2, the isoquant curve is depicted as SS′. If we assume that it is not possible to produce the same volume of output with input less than SS′, SS′ then becomes the technological frontier. In the simplest case not taking the cost of production factors into account, Firm Q on curve SS′ is most efficient while Firm P, which deviates from SS′, is inefficient because it uses more production factors.

The above definition of efficiency is expressed by the technological frontier and deviation from it at that point in time and is comprehended statically. Technological progress, however, is subject to changes in the technological level with the passage of time. Technological progress is divided into technological efficiency at a given time and changes in the technological level that serves as the standard. Consequently, in order to express technological progress using the technological frontier, it is also necessary to consider changes in the technological frontier itself.

Section 2 below explains the means that are available for measuring the isoquant curve at a given time and the extent of the deviation from that, that is, the former point. Meanwhile, the latter, changes in the technological frontier itself, is considered from Section 3 onward.

2. Methods for Measuring Efficiency

There are two primary methods for measuring the technological frontier. The first uses parametric estimation methods, such as stochastic frontier analysis. This method considers the deviation from the technological frontier to be the distribution of stochastic variables, applies a function type to the frontier and econometrically estimates parameters. However, the number of parameters increases and multicollinearity readily occurs when formulating translog

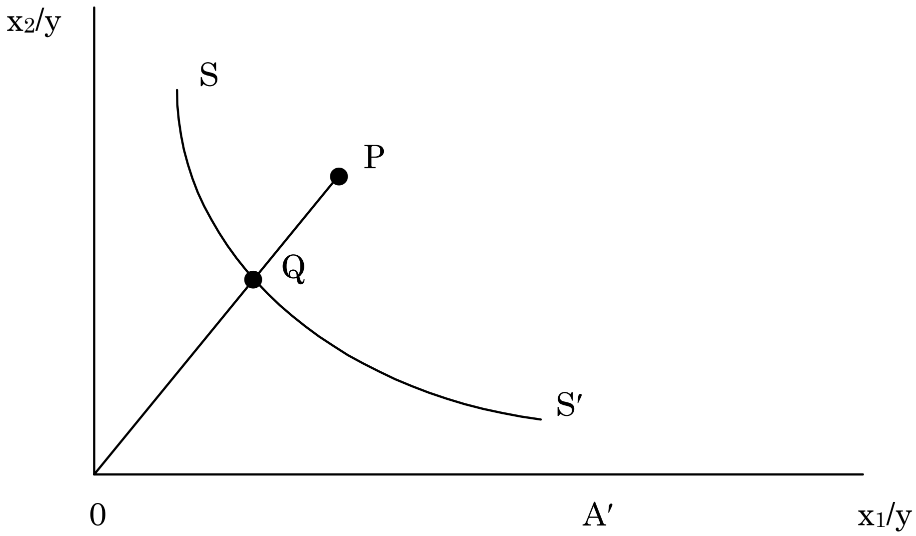


Fig. 2-1 Technological Frontier and Technological Efficiency

type or other functions.[1] Accordingly, this study uses a method that derives the technological frontier and the extent of deviation from observations without any parameter estimations. Data envelopment analysis (DEA) is a typical method of this type, and enables non-parametric estimates to be made.

When making parametric estimations, the TFP of a certain firm j, for example, would generally be defined as indicated below.

$$h_j = \frac{u^T y_j}{v^T x_j} \tag{2.1}$$

n : number of firms ($j = 1,\dots, n$)
h_j : TFP
y_j : output
x_j : input

When considering the production of s number of outputs from m number of inputs, y_j is the s-vector (r=1,…, s) and x_j is the m-vector (i=1,…, m); however, the weight of the outputs and inputs is exogenous and, in order to estimate the parameters, it is necessary to hypothesize certain special function types.

With a non-parametric approach such as the DEA method, however, it is possible to eliminate the restriction of applying such special function type to all and making the parameters the same. Since parameters are determined endogenously with the DEA method, individual observed objects have different parameters.

3. DEA Method and Technological Efficiency

The following is a simple outline of the DEA method. With the DEA method, the technological frontier envelope is estimated by applying a linear programming procedure such as that below.[2] Refer to Supplementary Note 2.1. for the calculation method using DEA.

Since the technological efficiency of firm j is expressed as $u'y_j/v'x_j$, the technological frontier maximizes this. Since technological efficiency is less than 1:

$$\begin{aligned} &\max_{u,v} \left(\frac{u'y_j}{v'x_j} \right), \\ &s.t. \\ &\frac{u'y_j}{v'x_j} \le 1, \\ &u, v \ge 0 \end{aligned} \tag{2.2}$$

The problem of maximization is thus resolved. This can be modified as indicated below.[3]

$$\begin{aligned} &\min_{\theta,\lambda} \theta_j, \\ &s.t. \\ &-y_j + X\lambda \ge 0, \\ &\theta_j x_j - X\lambda \ge 0, \\ &\lambda \ge 0 \end{aligned} \tag{2.3}$$

θ_j : technological efficiency of firm j (j=1,…, n)
λ : $n\times1$ absolute term vector
X : input vector of the industry overall
x_j : input vector of firm j
y_j : output vector of firm j

By implementing this linear programming problem repeatedly for n number of firms, it is possible to calculate the technological efficiency of each n firm. Since the technological frontier is estimated as an envelope, even if the number of observable firms is small, it is possible to specify the distance from observable objects and clarify the standards for promoting efficiency using production factors as long as it is possible to estimate the technological frontier.

The content covered thus far is summa-

[1] Nakajima (2001) points out that it is possible to avoid this problem by introducing a cost function; however, that requires input cost data. Estimations in this study were conducted using the DEA method described above due in part to the unavailability of input cost data of individual companies.

[2] This is the simplest case that does not take economies of scale into account. In the estimations in this study, calculations are carried out using a model that takes economies of scale into account. Refer to Supplementary Note 2.2.

[3] Based on Coelli (1996).

rized using Fig. 2-2. In Fig. 2-2, assuming a firm that produces one type of output using two types of inputs, the efficiency of the technology of that firm is clearly specified. The labor and capital productivity of various firms at a given point in time are calculated, the reciprocals of labor productivity and capital productivity are determined and plotted, respectively, on the vertical and horizontal axes. The bold line is the technological frontier. The technological frontier is the combination of capital productivity and labor productivity of a firm that produces the most outputs with the fewest production factors and is a line formed by connecting the observation points that are closest to the origin. Firms on the technological frontier are those that are capable of using technology the most efficiently.

Meanwhile, firms located above the technological frontier are technologically inefficient and the extent of deviation from the frontier is expressed by b. Consequently, to generally express the degree of efficiency, this b is relativized by the distance from the origin to the object. This represents the simplest case and the method of calculating efficiency differs depending on the configuration of the envelope, the existence of economies of scale and other factors.

4. Technological Change and the Malmquist Productivity Index

As seen thus far, technological efficiency indicates the degree of deviation from the most efficient technological frontier at a given point in time and is therefore static in nature. However, technological progress changes in time-series and, in order to comprehend it dynamically, changing the technological frontier itself must be considered.

In Fig. 2-2, looking first at changes in the technological frontier itself, the technological frontier of period t is the continuous bold line while the technological frontier of period t+1 moves on the dotted line. The shift width a from the continuous line to the dotted line is a time-series change in the technological frontier itself.

If the technological frontier shifts, the technological efficiency of the firms that deviate from that line also changes. The width of the deviation of the technological frontier at period t was b; however, it shifted to deviation width c due to the shift in the technological frontier. Since deviation widths b and c are relativized in actual measurements by the distance from the origin, the difference in the relative ratio expresses time-series change.

Changes in total dynamic technological progress include the two elements of the above changes in the technological frontier itself and changes in the technological efficiency of firms deviating from there. The Malmquist productiv-

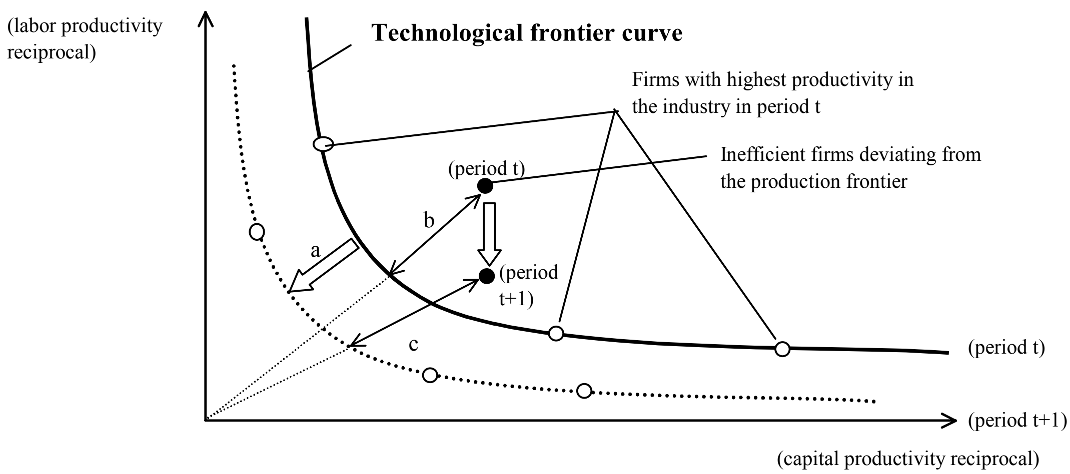


Fig. 2-2 Malmquist Productivity Index (MPI) Concept

ity index indicates changes in productivity by combining these two.

In Fig. 2-3, the technological frontier is expressed as F and a given firm located in a position deviating from that is expressed as A. The technological efficiency of A_t during period t is expressed as the ratio of $0A_t$ and 0B. If A_t shifts to A_{t+1} during period t+1, the changes in technological efficiency can be expressed as:

$$\frac{0B/0A_t}{0D/0A_{t+1}} \tag{2.4}$$

The technological efficiency of A in relation to technological frontier F_t rises if this is less than 1. However, since the technological frontier also shifts to F_{t+1} during period t+1, it is necessary to take into account the changes in technological efficiency of A in relation to technological frontier $F_{t+1,}$ that is,

$$\frac{0C/0A_t}{0E/0A_{t+1}} \tag{2.5}$$

If this is also less than 1, that indicates that there has been an improvement in technological efficiency.

The Malmquist productivity index determines the geometrical average of (2.4) and (2.5). That is,

$$MI_A^{t+1} = \sqrt{\frac{0B/0A_t}{0D/0A_{t+1}} \cdot \frac{0C/0A_t}{0E/0A_{t+1}}} \tag{2.6}$$

Equation (2.6) can be decomposed as indicated below.

$$MI_A^{t+1} = \left(\frac{0B/0A_t}{0E/0A_{t+1}}\right) \cdot \sqrt{\left(\frac{0E/0A_{t+!}}{0D/0A_{t+1}} \cdot \frac{0C/0A_t}{0B/0A_{t+1}}\right)}$$

$$= MC \cdot MT \tag{2.7}$$

Thus, the Malmquist productivity index can be decomposed to the product of MC, which expresses changes in technological efficiency, and MT, which expresses changes in the level of the technological frontier. If MC is more than 1, that indicates that it has approached the technological frontier and, if it is less than 1, it indicates that it lags behind the technological frontier. If MT is more than 1, the level of the technological frontier itself is rising and, if less than 1, it is declining.

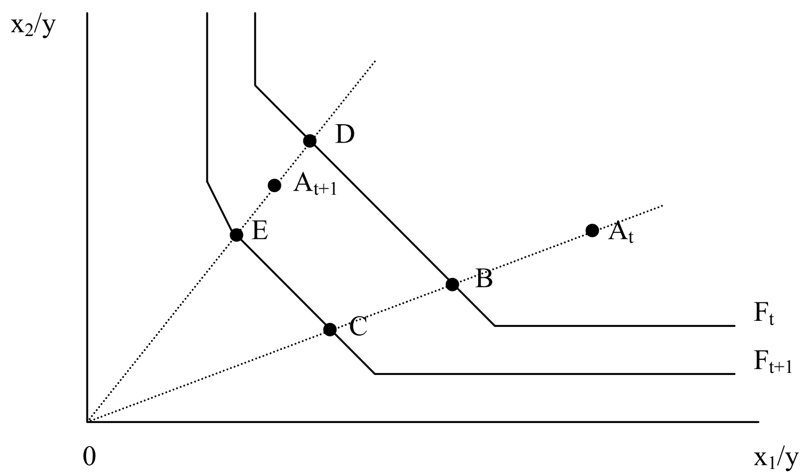


Fig. 2-3 Technological Efficiency, Technological Change and the Malmquist Productivity Index

5. Foregoing Research in the Analysis of Productivity Using the Malmquist Productivity Index

By using the Malmquist productivity index, it is possible to divide technological progress, the purpose of this study, that is, increased productivity, into changes in technology and changes in technological efficiency. The technological level of firms with the highest productivity within an industry, how that changes over time and to what extent firms with lower productivity are catching up with firms with the highest productivity are clarified by calculating the Malmquist productivity index for firms of a given industry as well as MC and MT. It is possible to pursue the substance of productivity increases by focusing on the nature of the changes within individual firms that result in changes in productivity in a given industry overall.

Malmquist (1953) and Solow (1957) presented the theoretical basis for the Malmquist productivity index and it was used by Caves, Christensen and Diewert (1982a, 1982b) as a method for measuring productivity. Canter and Hanusch (1999), in particular, attempted comprehensive calculations of the Malmquist productivity index by the DEA method at the national, industry and firm level.

However, the DEA method, which is the basis for calculating the Malmquist productivity index, has been frequently discussed in the field of operations research and has been used more frequently for analyzing the efficiency of firms in individual industries than for comprehensive empirical analysis. Berger and Humphrey (1999) refer to the use of the DEA method in analyzing management efficiency of financial institutions and later produced a number of empirical research studies relating to financial deregulation in South Asia and the management efficiency of financial institutions.

Empirical research in Japan has also focused on analyses of the management efficiency of firms in separate industries. These include Niimi (2000), who analyzed financial deregulation and the management efficiency of banks using the banking industry of Korea as a case study, and Kitamura and Tsutsui (1996), who measured and compared management efficiency in the electrical industry in Japan and the U.S. However, there have been few such studies. Much of the foregoing research has not gone beyond analyses of individual industries and, in addition, due in part to the short analysis periods, they have not calculated real operating capital stock, amount of labor input or real value added that would be frequently used in the field of empirical economic analysis using capital investment or productivity functions.

Consequently, compared to foregoing research, the analyses in this study are characterized by (1) using a comprehensive approach targeting the major industries of Japan and (2) being empirical analyses based on production functions after estimating real operating capital stock or the amount of labor input based on firms. It should therefore be possible to compare productivity trends between major industries and clarify the characteristics of their time-series changes.

The following chapter explains the development of data necessary before the Malmquist productivity index can be calculated at the firm level.

III Development of Data for Calculating the Malmquist Productivity Index

1. Labor and Capital Productivity at the Firm Level

A model with two inputs and one output is used in measuring the Malmquist productivity index at the firm level. The labor and capital productivity of each firm are calculated with labor and capital as the inputs and value added as the output.

The labor productivity and capital productivity of each firm are as indicated below.

Labor productivity =
real value added/amount of labor input (3.1)

Capital productivity =
real value added/amount of capital input (3.2)

The target firms are listed firms excluding the financial and insurance industries and the period of data acquisition is 1980-2000.[4] The sources of the data used are as indicated later and the corporate financial database of the Development Bank of Japan was used for the financial data of firms, the primary data.

All financial data used in this chapter was extracted from the corporate financial database of the Development Bank of Japan for 1980-2000 for the firms for which the Malmquist productivity index was actually measured. The number of firms involved is indicated in Figs. 4-1 to 4-8.

2. Value Added

The nominal value of value added, the denominator of labor and capital productivity, was calculated based on the definition in the Financial Data Handbook of the Development Bank of Japan.[5]

Nominal value added =
operating profit + labor expenses + rental expenses + taxes and public charges + patent license fees + depreciation expenses (3.3)

Nominal value added calculated in this manner is deflated by the commodity price index of the industry to which the firm belongs.[6]

3. Amount of Labor Input

The amount of labor input is calculated as number of workers multiplied by number of working hours. Number of workers is the aggregate total of the number of employees of each company at the end of the term, temporary and contract employees not included in the number of employees at the end of the term, employees on temporary transfer, on leave, etc. and company officers. The index of actual total working hours of the Monthly Labor Survey (Ministry of Health, Labor and Welfare) was used for working hours and, for industry, the intermediate sector classification was matched to the industry classification of the Monthly

[4] The settlement of firms with a settlement term extending from April of the relevant year through March of the following year was converted to settlement as of the end of the relevant year.

[5] The items are calculated based on the following data recorded in the corporate financial database of the Development Bank of Japan.

* Operating profit
* Labor expenses: officer compensation + employee salaries and allowances + welfare expense + transfer to reserve for retirement allowances + corporate pensions + cost of labor
* Rental expenses = rental expenses in the cost of goods manufactured + rental expenses in sales and management expenses
* Taxes and public charges: taxes and public charges in the cost of goods manufactured + taxes and public charges in sales and management expenses
* Patent license fees: patent license fees in the cost of goods manufactured + patent license fees in sales and management expenses
* Depreciation expenses: depreciation expenses in the cost of goods manufactured + depreciation expenses in sales and management expenses

[6] The intermediate sector classification of the Development Bank of Japan is used for industry classifications and the wholesale price index of the Bank of Japan is applied in principle for the price by goods as the corresponding price index. The corporate services price index (Bank of Japan), consumer price index (Ministry of Public Management, Home Affairs, Posts and Telecommunications) and construction price deflator (Ministry of Land, Infrastructure and Transport) are used for that portion of non-manufacturing industries to which the wholesale price index does not correspond (intermediate sector classification for construction, wholesale and retail, real estate, transportation and communications and service industries).

Labor Survey (mining, construction, manufacturing, electricity and gas, transportation and communications, wholesale and retail, real estate and service).

4. Amount of Capital Input

4.1 Depreciable Assets

When calculating the amount of capital input, assets are divided roughly into (1) depreciable assets, (2) real estate and (3) inventory assets. The amount of capital input of depreciable assets is calculated as indicated below.

Amount of capital input of depreciable assets = real capital stock of depreciable assets × capacity utilization rate (3.4)

Real capital stock of depreciable assets is calculated by the benchmark year method based on the relationship of:

$$K_t = (1-\sigma)K_{t-1} + I_t \tag{3.5}$$

K_t : real capital stock
I_t : read capital investment
σ : depreciation rate

Capital stock here is not gross capital stock as indicated in the Private Sector Corporate Capital Stock of the Cabinet Office but net capital stock. The former is a physical concept deducting asset retirement and so forth due to the sale or disposal of fixed assets while the latter takes into consideration real value in production activities that assumes capital wastage, also including the decline of production capacity due to asset superannuation or attrition.

a. Nominal Capital Investment
I_t is determined by deflating nominal capital investment by the price of capital goods. The acquisition price of new tangible fixed assets during the term is used in principle for nominal capital investment.[7]

[7] Refer to Supplementary Note 3.1 for details regarding the calculation method.

b. Calculation of the Price of Capital Goods by Industry and by Asset
The price of capital goods used in deflating is based on domestic wholesale prices. Tangible fixed assets are first divided into (1) non-residential construction, (2) structures, (3) machinery and equipment, (4) motor vehicles and transportation equipment and (5) tools, furniture and fixtures. The price of construction materials of the composite price index is used for items (1) and (2) and the price of transportation equipment of the domestic wholesale prices is used for (4). For (3) and (5), weight-averaged domestic wholesale prices using the weight for equipment and other investment goods in each industry given in the fixed capital matrix of the Input-Output Tables of the Ministry of Public Management, Home Affairs, Posts and Telecommunications are used for the price of capital goods.[8]

c. Preparation of Benchmarks for Real Capital stock
Real capital stock is calculated based on equation (3.5) using real capital investment deflated by the price of capital goods by asset, though it is necessary to estimate the initial value of benchmark *K*. Real capital stock by industry as of 1980, the benchmark, is thus estimated by determining the market value/book value ratio by industry as of 1980 and multiplying that by the book value in 1980. The market value/book value ratio is:

Market-to-book-value ratio =
real net capital stock/capital stock book value (3.6)

Real net capital stock by industry is estimated based on the National Accounts and Private Sector Corporate Capital Stock of the Cabinet Office.[9]

[8] If, for example, 70% of the machinery and equipment (excluding transportation equipment) included in the fixed assets of Industry Z in the fixed asset matrix for 1995 were general equipment, 20% were electrical equipment and 10% were precision equipment, the prices of machinery and equipment (excluding transportation equipment) capital goods of Industry Z in 1995 = domestic wholesale price of general equipment in 1995 x 0.7 + domestic wholesale price of electrical equipment in 1995 × 0.2 + domestic wholesale price of precision equipment in 1995 x 0.1.
[9] Refer to Supplementary Note 3.2 for details.

The book value of tangible fixed assets (excluding land and construction suspense accounts) of non-financial corporations from the Annual Report of Corporate Statistics (Ministry of Economy, Trade and Industry) is used for capital stock book value by industry.

Real (net) capital stock was estimated by determining the market value/book value ratio by industry in 1980 using the above data and multiplying that by the asset book price of each company in 1980.

d. Capital Fepreciation Rate

The capital depreciation rate differs from the asset retirement rate in the gross capital stock described above. The wastage rate by asset used in Hayashi and Inoue (1991) was used for this estimate.

e. Capacity Utilization Rate

It is possible to calculate the real capital stock of depreciable assets using a. to d. In order to determine the amount of capital input of depreciable assets, it is also necessary to multiply the utilization rate of depreciable assets by real capital stock. In regard to the utilization rate in manufacturing industries, capital stock based on utilization rate can be calculated by using the utilization rate indices by industry included in Indices of Industrial Production (Ministry of Economy, Trade and Industry) statistics.

Meanwhile, for non-manufacturing industries, the utilization rate was estimated by non-manufacturing industry capital investment judgment BSI and business-use electrical power consumption rate of the Business Outlook Survey (Ministry of Finance) based on the method of Kamada and Masuda (2000).[10]

4.2 Land

The market price of land was estimated by the method below by referring to the Economic Planning Agency (1997).

$$MV_1 = (BV_0 - L_d)\cdot(MV_0 / BV_0)\cdot P_1 / P_0 + L_a$$

When:

	Period t	Period t+1
Urban land price index (Real Estate Research Institute)	P_0	P_1
Increase during the term	-	L_a
Decrease during the term	-	L_d
Term-end book price	BV_0	$BV_1 = BV_0 + L_a - L_d$
Term-end market price	MV_0	MV_1

The market price in 1980, the benchmark, was determined by multiplying the market value/book value ratio derived from the non-financial corporation land asset value of the National Accounts (Cabinet Office) and land book value of the Annual Report of Corporate Statistics (Ministry of Economy, Trade and Industry) by the book value in 1980.

4.3 Inventory Assets

Inventory assets were divided into (a) products and manufactured goods, (b) sales-use real estate, (c) intermediate and partially-finished goods, (d) disbursements for work in progress and (e) raw materials. When deflating, the deflator used in section 2 was used for (a), the urban land price index was used for (b), the construction deflator was used for (d), the domestic wholesale price index was used for (e) and the average of (a) and (e) was used for (c).

Items 1. to 3. derived above were totaled and used as the amount of capital input. It is therefore possible to calculate value added and amount of labor input as well as the Malmquist productivity index using the DEA method.

[10] The business-use electrical power consumption rate was regressed by capital investment judgment BSI and time trends and the sum total of the absolute term and BSI term divided by their maximum value was set as the utilization rate for non-manufacturing industries.

IV Calculation of the Malmquist Productivity Index by Industry

The Malmquist productivity index was calculated using the value added, labor input and capital input for each company determined in the previous chapter. Though the DEA method with linear programming is used for the calculation, this study used DEAP Ver. 2.1, a data envelopment analysis (computer) program developed by Prof. Coelli of the University of New England, Australia.[11] The production function was an input-oriented model with two inputs (average labor input and capital input at the beginning and end of the term[12]) and one output (value added).

Based on this, the Malmquist productivity index, technological change and technological efficiency were calculated for eight major industries: chemicals, iron and steel, electrical machinery, automobiles and auto parts, construction, retail, real estate and services (excluding leasing and private sector broadcasting).

Figures 4-1 to 4-8 plot the calculated technological change and technological efficiency in 3-year central moving averages as well as the Malmquist productivity index. Graphs of the original figures are given in Supplementary Figs. 4-1 to 4-8.

1. Chemicals

It can be seen that the Malmquist productivity index (MPI) of chemicals stayed slightly above 1.0 during the 1980s until about FY1987 and that productivity rose gradually. Dividing the MPI between technological change and technological efficiency, technological change rose above 1.0 especially during the latter half of the 1980s while technological efficiency remained below 1.0. This indicates changes in the technological level of the group of companies with the highest productivity in this industry and an expansion in the gap due to other companies catching up.

Large-scale capital adjustments were made at this time, particularly among the leading petrochemical producers. Japanese petrochemical companies suffered from the structural chronic overcapacity stemming from continuous capital spending competition through the first half of the 1980s. In 1983, however, the Law Concerning Temporary Measures for the Structural Improvement of Specified Industries was enacted, promoting adjustments to

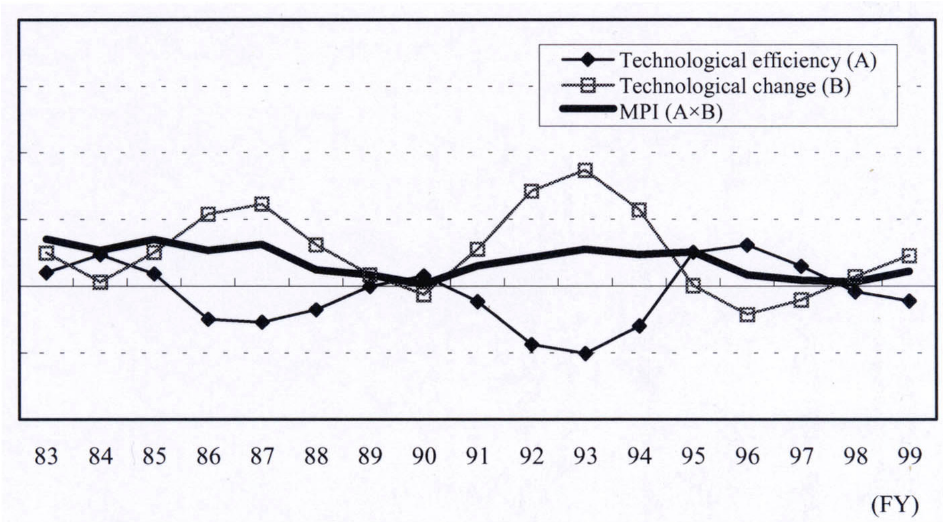


Fig. 4-1a Chemical Industry (135 firms) MPI (3-year moving average)

[11] Other computer programs include Warwick DEA, IDEAS and Frontier Analyst.

[12] In both cases, the beginning of the current term is deemed to be the same as the end of the previous term.

balance supply and demand through the large-scale disposal of facilities in 1984-85. As a result, the capacity utilization rate of ethylene plants improved and, with the rationalization of personnel and other measures, the leading ethylene centers improved revenues. However, pharmaceuticals and other business categories with higher productivity are also included in chemicals. Whereas the petrochemical companies improved their productivity through capital adjustments even if sales peaked, pharmaceuticals saw sluggish growth during the first half of the 1980s due to measures to restrain medical costs but midway through also managed to expand production and increase the utilization rate. Pharmaceuticals, etc. were thus largely responsible for stimulating the improvement in productivity in chemicals overall, especially in terms of technological change. The technological efficiency of the top petrochemical companies actually declined during this period while the technological efficiency of companies near the technological frontier of pharmaceuticals, etc. showed an improvement.

Technological change and technological efficiency both approached 1.0 in 1989-90 and MPI growth was no longer evident but, later, though growth was seen in technological change in 1993-94, technological efficiency dropped far below 1.0. This is the result of pressure on profits due to the increased burden of high-level investments made during the bubble period when the advent of the Heisei Recession brought a rapid drop in demand as well as a decline in productivity and other factors, even though (1) growth in pharmaceutical production, which had been stagnant until about 1990, started to rise due to the introduction of new drugs and other reasons while (2) the leading petrochemical companies enjoyed high profitability until 1989 due to the increased demand during the bubble economy.

In the latter half of the 1990s, technological change, which had grown until then at a level in excess of 1.0, dropped below 1.0. In the background, there was a series of NHI price revisions in the 1990s which had a considerable impact on pharmaceutical companies. The expansion of sales networks due to the development of new drugs and deregulation did not offset the negative factors and so productivity slumped. Meanwhile, productivity improved among petrochemical firms as demand recovered from about 1994. Since no rise in the level of the technological frontier centered on pharmaceuticals, etc. was evident, the slump in technological efficiency showed a relative improvement and a level above 1.0 was maintained for a time. In recent years, however, oversupply conditions due to the prolonged recession have persisted and the productivity of petrochemicals remains stagnant and the MPI for chemicals overall has remained at a low level. The transitions in the MPI of chemicals

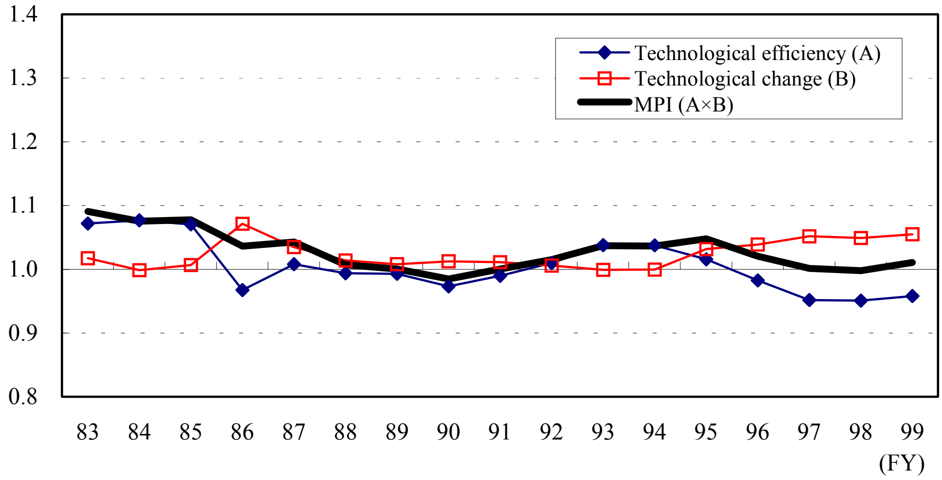


Fig. 4-1b Chemical Industry (excluding pharmaceuticals, 102 firms) MPI (3-year moving average)

excluding pharmaceuticals (Fig. 4-1b) during the 1990s indicate consistently low growth and, especially in recent years, the level has been about 1.0.

The difference in the growth of technological change and that of technological efficiency reflects the degree of expansion of disparities in technology within the industry. In chemicals overall, significant disparities occurred in the first half of the 1990s due to the growth of pharmaceuticals and the stagnation of petrochemicals, though the gap later narrowed. However, in chemicals excluding pharmaceuticals, the disparities instead were narrower during the early 1990s, expanding somewhat during the latter half of the decade. Thus, it is not only chemicals excluding pharmaceuticals that have demonstrated gradual inter-industry disparities in recent years but rather this characteristic can be seen in a number of industries as discussed below.

2. Iron and Steel

The MPI of iron and steel generally remained above 1.0 during the 1980s and productivity increased. Technological change showed considerable growth especially during the latter half of the 1980s and there was a boost in the technological level of firms on the technological frontier. There is a relatively large number of blast furnace producers among the firms that constitute the technological frontier and the revenues of those producers slowed during the early half of the 1980s and, in 1986, five producers posted broad losses in ordinary profit due to the downturn in exports as the yen appreciated. Later, while promoting restructuring measures, there was a broad expansion in domestic demand due to the bubble economy during the latter half of the 1980s, enhancing company revenues and significantly improving productivity.

In order to respond to the outlook for internal demand, firms began increasing capital spending again starting in 1989 and investments continued above the level of the previous year for four straight years through 1992. Actually, however, since internal demand reached a peak in about 1990, the burden of these investments and labor costs put pressure on revenues and company productivity began to slide in 1991. The revenues of steel producers other than blast furnace operations also deteriorated due to the effects of sagging internal demand following the collapse of the bubble economy. Since the drop in productivity was relatively smaller than that of blast furnace producers, however, their distance from the technological frontier shortened. Still, the MPI of the overall iron and steel industry remained consistently below 1.0 during the first half of the 1990s.

During the latter half, in spite of a certain degree of technological change, the MPI con-

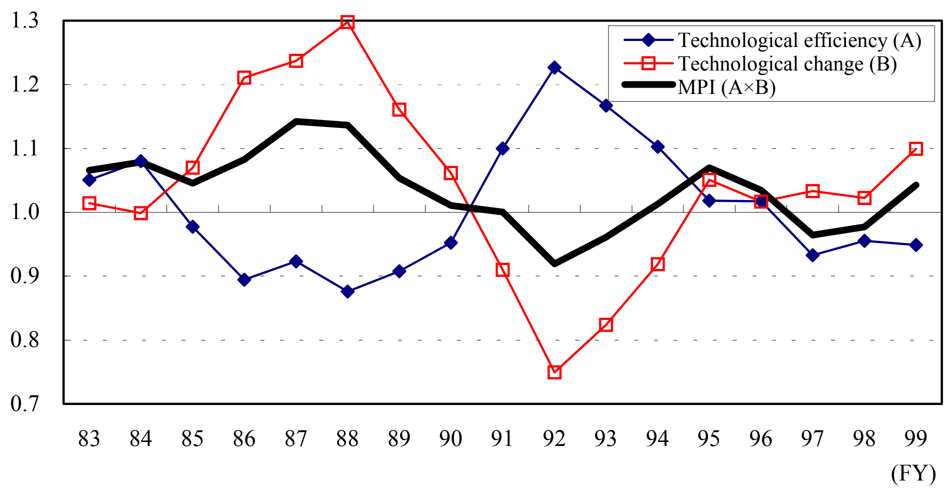


Fig. 4-2 Iron and Steel Industry (52 firms) MPI (3-year moving average)

tinued to expand above the 1.0 mark. This likely reflects the integration of production facilities or withdrawal from unprofitable operations by firms on the technological frontier or perhaps the implementation of employment adjustments or other management efforts. The overall MPI also rose to some degree in 2000, but technological efficiency dropped below 1.0 in 1997 and 1999 and the disparity between the two widened.

3. Electrical Machinery

The MPI of electrical machinery indicates that growth above 1.0 continued throughout the bubble economy from the latter half of the 1980s with a subsequent drop coinciding with the Heisei recession. In this respect, this industry demonstrates movements similar to chemicals and steel. One characteristic, however, is that the MPI remained relatively firm during the recovery from the Heisei recession.

The growth of technological change was especially strong from 1993 through 1996. The reason, however, was the improvement in productivity of companies on the technological frontier within the context of the broad rise in demand for IT-related goods in the 1990s. On the other hand, technological efficiency was below 1.0 and it is clear that the disparity between firms that are above and those that are below the technological frontier is now widening. In productivity analyses based on general TFP, it is frequently claimed that electrical machinery is one of the industries that have driven the rise in productivity in Japan in recent years and indeed, in the MPI-based analyses in this study, it was above 1.0 in most years during the 1990s and growth in productivity was confirmed to be higher than in other industries. The breakdown, however, suggests it was due to the continued technological progress of firms above the technological frontier and advancing disparities with technologically inefficient firms.

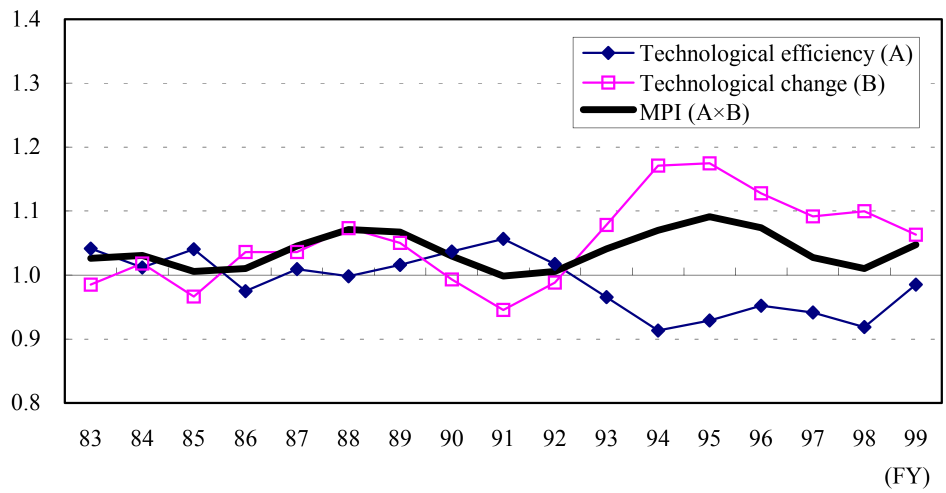


Fig. 4-3 Electrical Machinery and Equipment (123 firms) MPI (3-year moving average)

4. Automobiles and Auto Parts

Automobiles and auto parts also indicated the same tendencies as electrical machinery until the mid-1990s. Productivity rose strongly throughout the bubble period from the latter half of the 1980s, reflecting the favorable conditions of the industry at that time. Since the latter half of the 1990s, the MPI has weakened while productivity has slumped. Entering the Heisei recession, technological change dropped below 1.0 and the productivity of firms above the technological frontier diminished, restraining the overall MPI. Along with the recovery in demand in the mid-1990s, the restructuring of operations was promoted, especially by finished automobile manufacturers, stimulating another increase in technological change. On the other hand, auto parts producers positioned away from the technological frontier experienced depressed profits and technological efficiency declined. Both have suffered in recent years and the growth of the overall MPI has been minimal.

5. Construction

After rising sharply during the latter half of the 1980s, the MPI of the construction industry has been held in check since the Heisei recession. During the bubble period from the latter half of the 1980s, there was a notable rise in technological change, which is thought to be due to an upswing in productivity supported by expansion primarily on the demand side, such as robust growth in private-sector demand for both residential and non-residential construction.

However, as the Heisei recession deepened in the 1990s, technological change dropped sharply, lowering the MPI. Firms with high productivity on the technological frontier, greatly burdened by capital and labor accumulated during the bubble, were compelled to restructure: the number of employees of listed construction companies declined from 337,000 in FY1990 to 313,000 by FY2000, while fixed assets increased from 19% of total assets in FY1990 to 35% in FY2000[13], indicating increased burden in terms of capital. In single years, though technological change was above 1.0 in 1996 and 1999, it has generally been below 1.0, dragging down productivity overall.

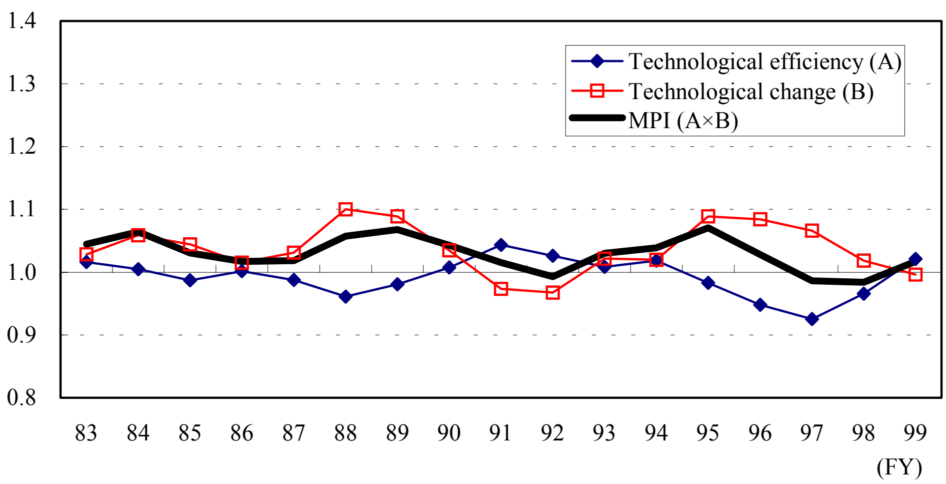


Fig. 4-4 Automobile and Auto Parts Industry (73 firms) MPI (3-year moving average)

[13] Source: Research Institute of Capital Formation, Development Bank of Japan (2002)

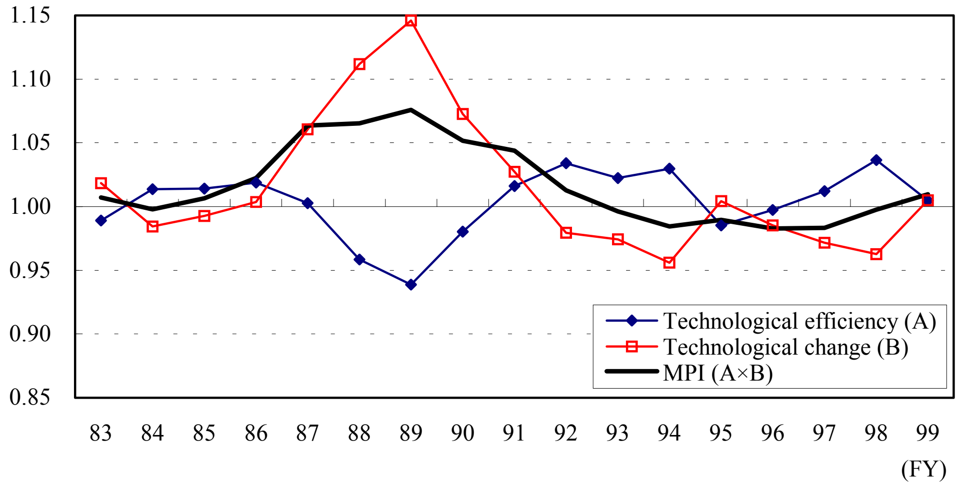


Fig. 4-5 Construction Industry (117 firms) MPI (3-year moving average)

6. Retail

The MPI of retail showed growth exceeding 1.0 during the 1980s until about 1987, followed by a slowdown that continued until about 1992. Though growth resumed in 1993-95, it is noteworthy that technological change consistently exceeded 1.0 from the latter half of the 1980s until the mid-1990s, whereas technological efficiency dropped far below 1.0.

Growth in technological change at this time was primarily due to supermarkets and convenience stores. The technological frontier improved due to the emergence of new business categories different from department stores. This deviation between technological change and technological efficiency persisted throughout the bubble period, which was due to the fact that the productivity of department stores that were not on the technological frontier not only deteriorated but also some department stores that had been on the technological frontier during the 1980s later fell below as the result of investment failures during the bubble period.

MPI growth remained low from the latter half of the 1990s onward. Technological change by year indicates that, in spite of growth in 1999, growth was depressed in the other years and technological efficiency stayed below 1.0. Thus, growth in the productivity of supermarkets, convenience stores and other businesses on the technological frontier was restrained amidst the prolonged stagnation in personal consumption while the productivity of other companies, which never caught up, was even lower.

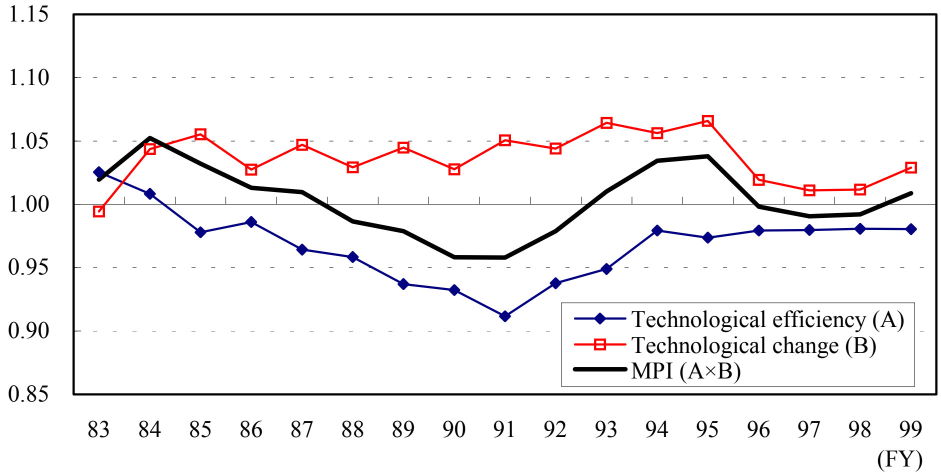


Fig. 4-6 Retail Industry (51 firms) MPI (3-year moving average)

7. Real Estate

In regard to the real estate industry, the burden of investments of some companies on the technological frontier became heavier as office floor space increased in the mid to late 1980s and technological change dropped below 1.0. There was an improvement in technological efficiency, however, and overall the MPI remained above 1.0. However, technological efficiency plunged when office floor space dropped below the level of the previous year after entering the Heisei recession and firms not on the technological frontier suffered from a decline in productivity. The productivity of firms on the technological frontier, though in excess of 1.0, showed slower growth and the MPI experienced a considerable slump in the first half of the 1990s. Due to differences in type of operation, the range of the fluctuation in productivity of mainstay real estate firms with fewer leased properties was greater than that of the large general real estate companies with many leased properties and the degree of decline was especially great during this period.

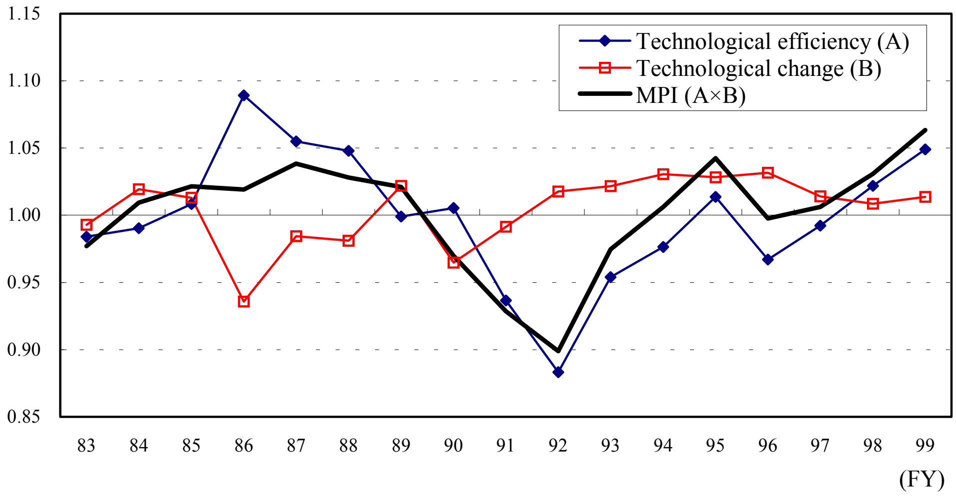


Fig. 4-7 Real Estate Industry (18 firms) MPI (3-year moving average)

In the latter half of the 1990s, all of the firms undertook restructuring measures such as asset and staffing reductions to improve productivity, which had worsened. From about 1999, both technological change and technological efficiency improved and recovery in the MPI is also apparent.[14]

8. Services (excluding leasing and private sector broadcasting)

For services, the MPI was calculated with the exclusion of leasing and private sector broadcasting. There was not much fluctuation in the MPI compared to the other industries described above and, overall, it remained near 1.0. In the post-bubble period, however, the tendency to drop below 1.0 become stronger and companies on the technological frontier have data, engineering and many other business services; however, productivity declined due to constrained demand during the recession in the 1990s. Meantime, the productivity of companies not on the technological frontier, particularly hotels and inns, cinema and entertainment and other industries, was no longer evident due to the prolonged slump in personal consumption. The drop in technological efficiency was especially notable in 2000 and a glance at the breakdown shows that this is due largely to a decline in economies of scale. Although firms made efforts to reduce assets and rationalize staffing, such measures did not lead to any notable recovery in profitability which remains depressed.

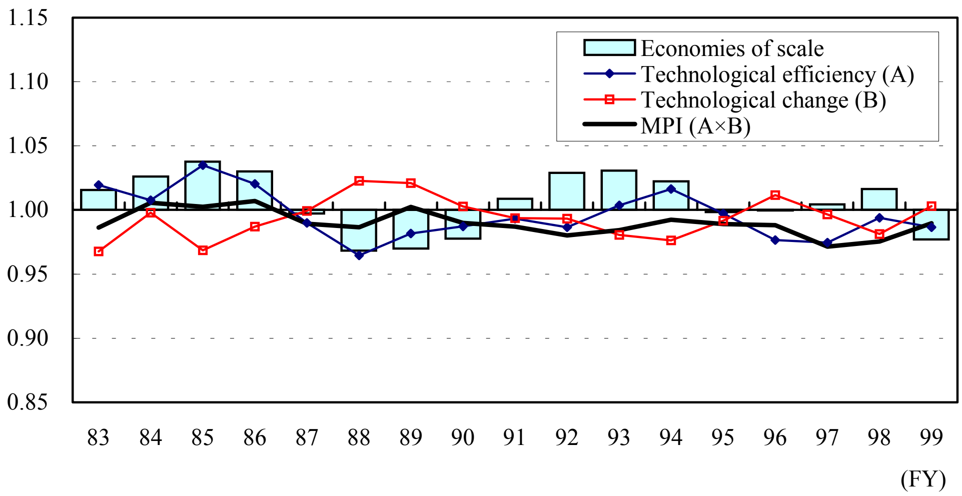


Fig. 4-8 Service Industry (excluding leasing and private sector broadcasting, 35 firms) MPI (3-year moving average)

[14] According to the Research Institute of Capital Formation of the Development Bank of Japan, the rate of return on assets of listed firms in the real estate industry was 1.8% in 1996, which rose to 2.5% in 1999 and 2.9% in 2000.

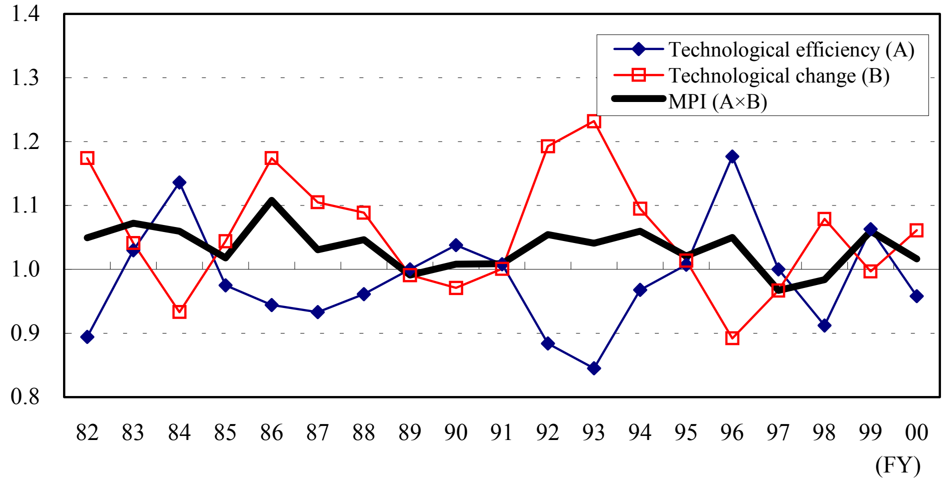
V Conclusion

The MPI trends in the eight industries described above are summarized below.

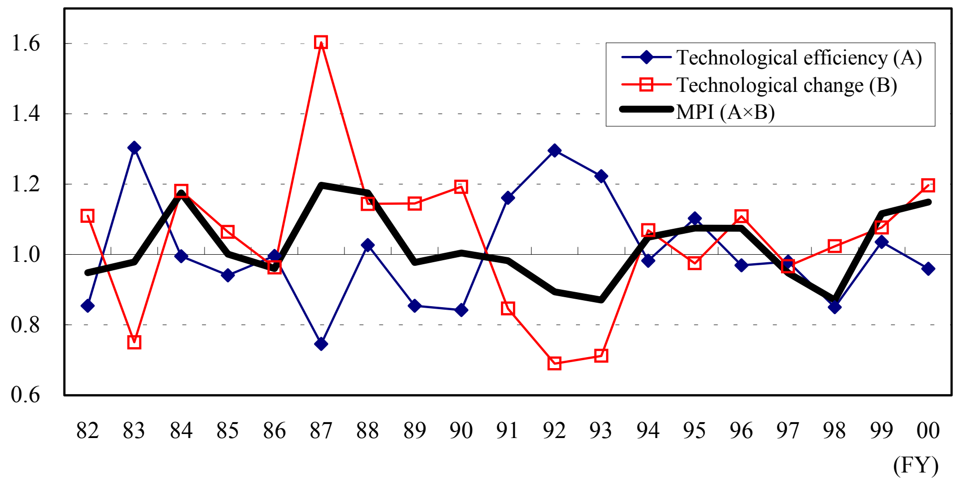
- The MPI of both manufacturing and non-manufacturing industries increased throughout the bubble period from the latter half of the 1980s and declined after the bubble burst. However, disparities are evident depending on the industry in the degree of the decline and moves toward recovery during the economic rebound in the latter half of the 1990s.
- Disparities in productivity emerged between firms on the technological frontier and other firms in most manufacturing industries from the latter half of the 1990s, which continued to expand.
- In non-manufacturing industries, disparities in productivity between firms are not as apparent as in manufacturing industries but there was an overall downturn in the MPI in most industries.

It is necessary to take into account various problems relating to the estimates in these results. For example, the effects of economic fluctuations on the changes in productivity must be excluded from those changes. To do this, capital and labor input calculated in this study are based on actual utilization, but they are strictly industry-specific data and not individual firm data. This means that the effects of economic fluctuations are not entirely removed. Consequently, there are probably areas in which economic fluctuations greatly affect productivity trends. However, since the relationship between value added, capital input and labor input of individual firms is taken into consideration, such effects are perhaps less than, for example, TFP calculated using capital and labor input aggregated the macro-level.[15]

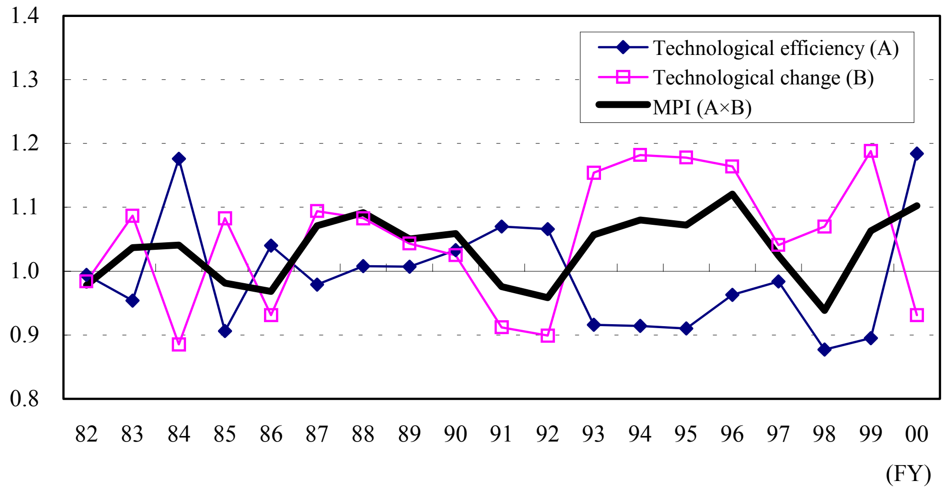
[15] It is possible to cite cases in which favorable business conditions only affect some firms and not others for one reason or another. For example, even if growth in value added evidently exceeds the growth of some firms as the result of large-scale capital input by those firms and aggregate-measured TFP also increases during an economic boom, technological efficiency could decline and growth of the MPI could be hindered if there are a considerable number of other firms that are not able to catch up with them.



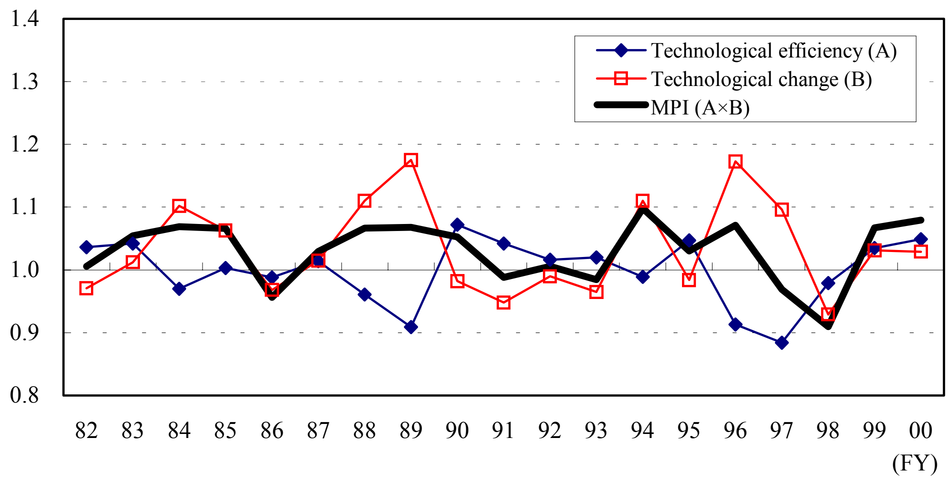
Supplementary Fig. 4-1 MPI of the Chemical Industry (135 firms)



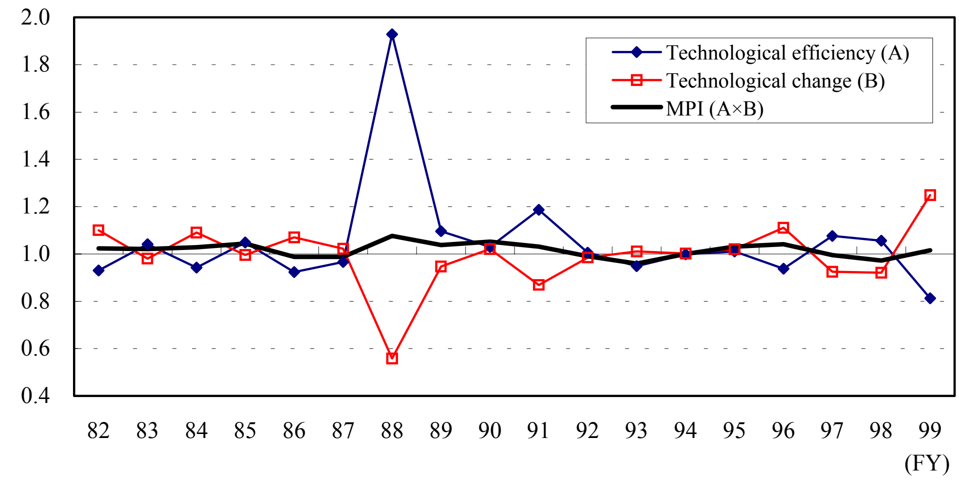
Supplementary Fig. 4-2 MPI of the Iron and Steel Industry (52 firms)



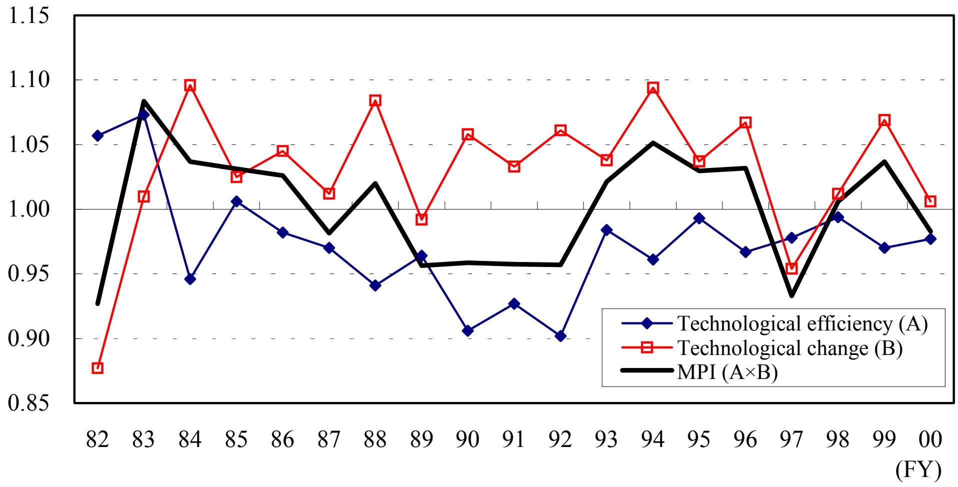
Supplementary Fig. 4-3 MPI of the Electrical Machinery and Equipment Industry (123 firms)



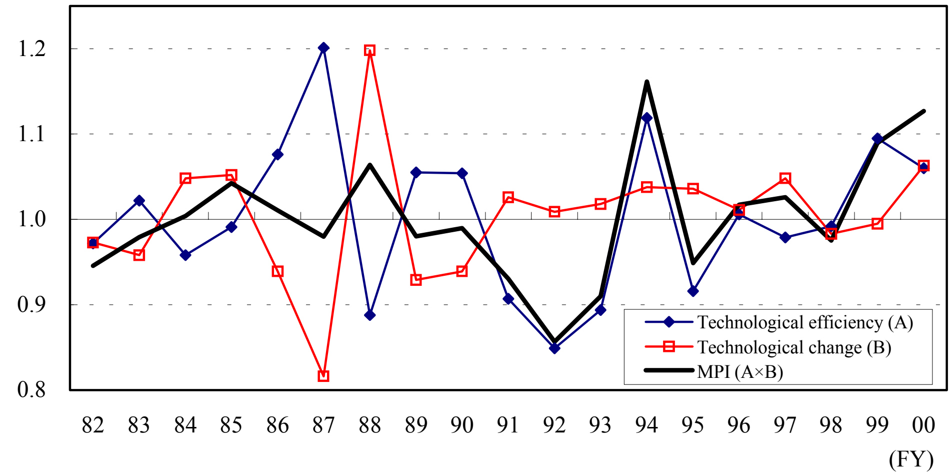
Supplementary Fig. 4-4 MPI of the Automobile and Auto Parts Industry (73 firms)



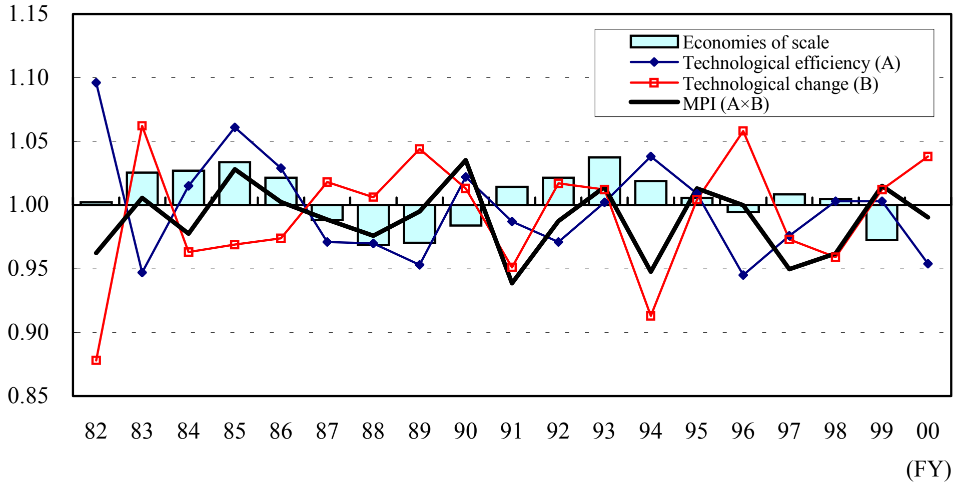
Supplementary Fig. 4-5 MPI of the Construction Industry (117 firms)



Supplementary Fig. 4-6 MPI of the Retail Industry (51 firms)



Supplementary Fig. 4-7 MPI of the Real Estate Industry (18 firms)



Supplementary Fig. 4-8 MPI of the Service Industry
(excluding leasing and private sector broadcasting, 35 firms)

Supplementary Table 4-1 Inter-industry Disparities in Technological Efficiency (manufacturing industries)

	Chemicals			Chemicals (excluding pharmaceuticals)			Iron & steel		
	Technological change	Technological efficiency	Disparity	Technological change	Technological efficiency	Disparity	Technological change	Technological efficiency	Disparity
FY81-85	1.05	1.01	0.04	1.04	1.04	0.00	1.03	1.02	0.00
FY86-90	1.07	0.98	0.09	1.03	0.99	0.04	1.21	0.89	0.32
FY91-95	1.11	0.94	0.16	1.00	1.02	-0.02	0.86	1.15	-0.29
FY96-00	1.00	1.02	-0.02	1.05	0.96	0.09	1.07	0.96	0.12

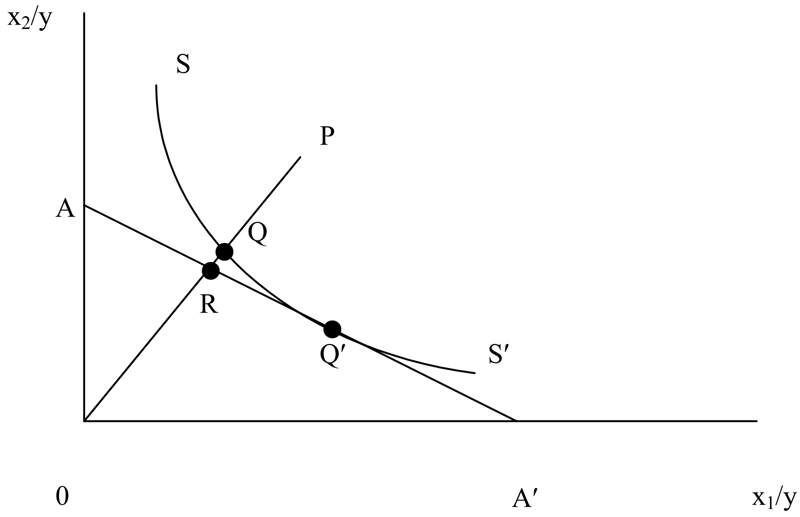
	Electrical machinery			Automobiles and auto parts		
	Technological change	Technological efficiency	Disparity	Technological change	Technological efficiency	Disparity
FY81-85	1.01	1.01	0.00	1.04	1.01	0.02
FY86-90	1.04	1.01	0.02	1.05	0.99	0.06
FY91-95	1.07	0.98	0.09	1.00	1.02	-0.02
FY96-00	1.08	0.98	0.10	1.05	0.97	0.08

Supplementary Table 4-2 Inter-industry Disparities in Technological Efficiency (non-manufacturing industries)

	Construction			Retail			Real estate		
	Technological change	Technological efficiency	Disparity	Technological change	Technological efficiency	Disparity	Technological change	Technological efficiency	Disparity
FY81-85	1.02	0.99	0.03	1.00	1.02	-0.02	1.01	0.99	0.02
FY86-90	1.09	0.98	0.11	1.04	0.95	0.09	0.96	1.05	-0.09
FY91-95	0.97	1.03	-0.06	1.05	0.95	0.10	1.03	0.94	0.09
FY96-00	1.00	1.00	0.01	1.02	0.98	0.04	1.02	1.03	-0.01

	Service (excluding leasing and private sector broadcasting)		
	Technological change	Technological efficiency	Disparity
FY81-85	0.97	1.03	-0.06
FY86-90	1.01	0.99	0.02
FY91-95	0.98	1.00	-0.02
FY96-00	1.01	0.98	0.03

Supplementary Note 2.1 Technological Efficiency, Allocative Efficiency and Economic Efficiency



where, y is output, x_1 and x_2 are inputs, SS′ is technological frontier and the deviation of P from SS′, that is, technological efficiency, is expressed as:

$$TE = 0Q/0P = 1-(QP/0P)$$

TE is a value between 0 and 1. If *TE*=1, P is above SS′, which is the level of greatest efficiency.

Furthermore, considering the price of the inputs, if the input price ratio is expressed as AA′, the allocative efficiency of the input of Firm P is expressed as:

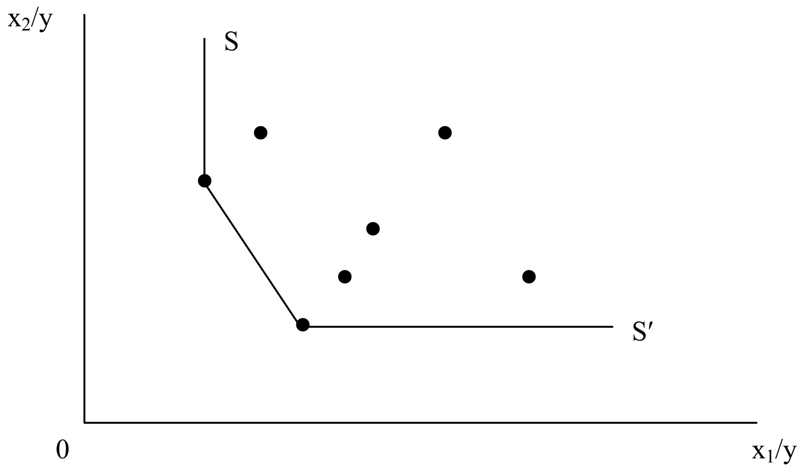
$$AE = 0R/0Q$$

Economic efficiency taking both *TE* and *AE* into account is expressed as:

$$EE = TE \cdot AE = (0Q/0P)\cdot(0R/0Q) = 0R/0P$$

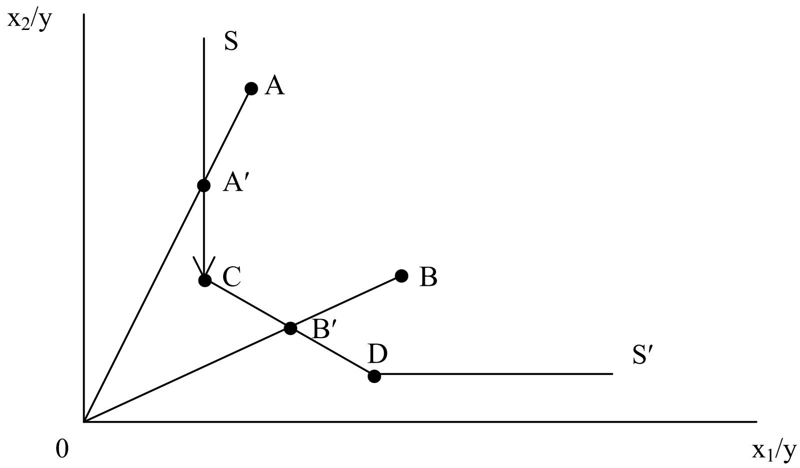
EE is a value between 0 and 1.

Supplementary Note 2.2   DEA Method Approach and Numerical Sequence



With the DEA method, the technological frontier SS′ is estimated from actual plotted company data. In the case above, SS′ is determined by linking to the point where there are no more observable objects on either the x axis (left) or y axis (bottom). This line is referred to as a piecewise linear convex iso-quant.

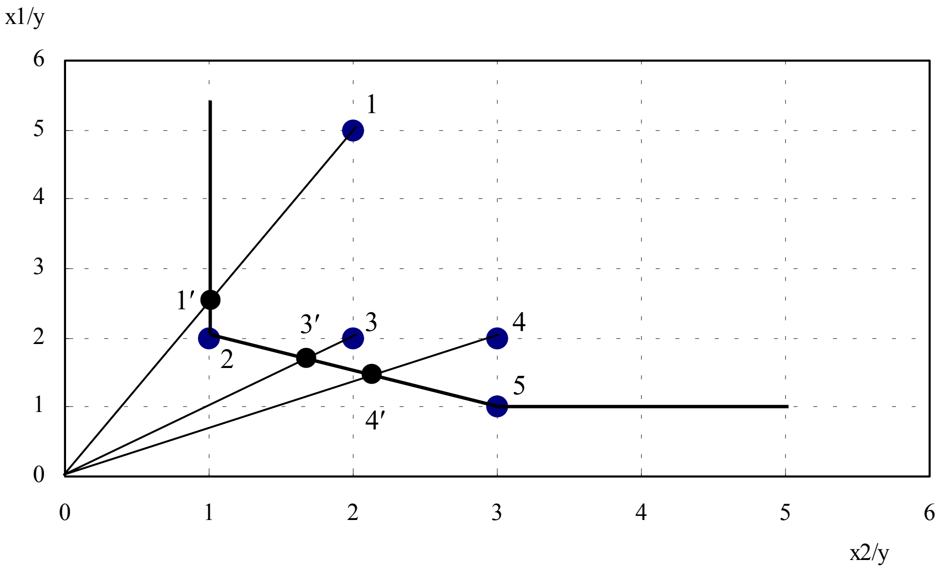
A number of problems arise, however, when estimating this piecewise linear convex isoquant. For example, let us consider the example below.



The efficiency of Firm A is expressed as OA/OA[1] if A′ of SS′, which has the greatest efficiency, is the standard. However, since it is possible to shift A′ to point C by decreasing the amount of input x_2 without changing the output, it is not necessarily an efficient point. A′C is referred to as input slack and, in order to resolve this problem of slack with DEAP used for calculation in this study, the peers of B (C and D) are determined by repeating linear programming problems a number of times, and the distance between B′, where CD and OB intersect, and B is measured and efficiency is measured using that weight.

The following is an attempt to express the numerical sequence.[1] The assumption is that Firms 1-5 produce y using inputs x_1 and x_2, as described below.

Firm	y	x_1	x_2	x_1/y	x_2/y
1	1	2	5	2	5
2	2	2	4	1	2
3	3	6	6	2	2
4	1	3	2	3	2
5	2	6	2	3	1



Linear programming problems are resolved for each firm based on this data. The linear programming problem in the case of Firm 3 is solved as indicated below based on Equation (4.3) of the main text.

$$
\begin{aligned}
&\min_{\theta,\lambda} \theta_3 \\
&s.t. \\
&-y_j + (y_1\lambda_1 + y_2\lambda_2 + y_3\lambda_3 + y_4\lambda_4 + y_5\lambda_5) \geq 0, \\
&\theta_3\, x_{13} - (x_{11}\lambda_1 + x_{12}\lambda_2 + x_{13}\lambda_3 + x_{14}\lambda_4 + x_{15}\lambda_5) \geq 0, \\
&\lambda \geq 0, \\
&\lambda = (\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5)'
\end{aligned}
$$

1 Based on Coelli (1996)

The results are indicated in the table below.

Firm	θ	λ_1	λ_2	λ_3	λ_4	λ_5	IS_1	IS_2
1	0.5	-	0.5	-	-	-	-	0.5
2	1.0	-	1.0	-	-	-	-	-
3	0.833	-	1.0	-	-	0.5	-	-
4	0.714	-	0.214	-	-	0.286	-	-
5	1.0	-	-	-	-	1.0	-	-

It can be seen that the technological efficiency (θ) of Firms 2 and 5 is 1.0 and that they are on the technological frontier. θ of Firm 3 is 0.833. Firms 2 and 5 are peers of 3 and 3′ is the point on the frontier that is the standard when measuring the efficiency of 3. As indicated on the graph, the weight of 2 and 5 at that time is $\lambda_2(1.0)$ and $\lambda_5(0.5)$, respectively.

In addition, since 2 has higher efficiency than 1′, an input slack (IS_2) of only 0.5, the difference between the two, is generated.

Supplementary Note 2.3 Technological Efficiency Taking Economies of Scale into Account

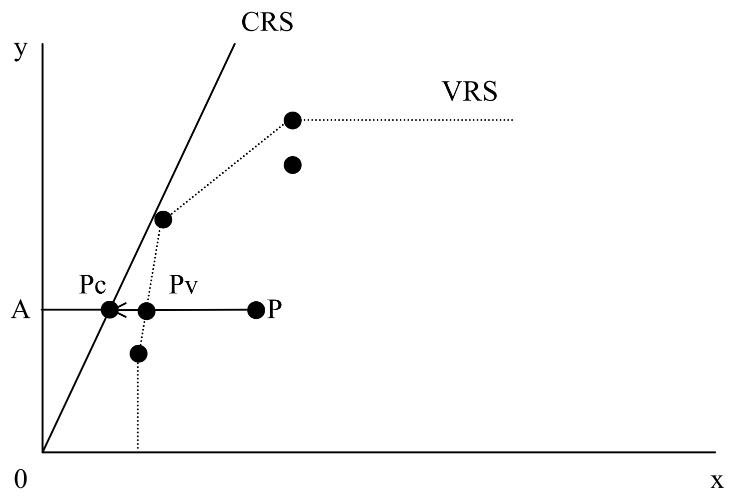
Technological efficiency has been defined based on the assumption of constant returns to scale in the model used in Supplementary Notes 2.1 and 2.2. Banker, Charnes and Cooper expanded the model of constant returns and have presented a model that incorporates the increase in technological efficiency due to economies of scale.[2]

A linear programming problem incorporating economies of scale is derived by adding the condition below to Equation (2.3) of the main text.

$$n1'\lambda = 1$$

where, $n1'$ is the $n\times 1$ vector.

The diagram below shows the technological frontier with one input and one output.



[2] Based on Coelli (1996)

CRS is the technological frontier with constant returns to scale. Technological efficiency *TE* at this time is:

$$TE_{CRS} = AP_c / AP$$

Meanwhile, if there are economies of scale, the technological frontier is VRS and *TE* is:

$$TE_{VRS} = AP_v / AP$$

It is possible to express economies of scale *SE* as:

$$SE = AP_c / AP_v$$

That is:

$$TE_{CRS} = TE_{VRS} \cdot SE$$

Supplementary Note 3.1 Method of Calculating Nominal Capital Investment

If nominal capital investment is *NOMI* and the newly acquired amount is *ACQ*, assuming that asset sales and other reductions in tangible fixed assets are not considered:

$$NOMI = ACQ$$

However, here, if there are asset sales, etc., the relevant amount must be deducted from *ACQ* and that must be considered as *NOMI.* The amount deducted is not the balance of the book value (*NR*) of the sold asset but rather the cost of re-procurement (*CNR*). *CNR* is calculated by the following method. P_K is cost of capital goods, *K* is real capital stock and *KNB* is the book value of the stock.

$$CNR = NR \cdot (P_K \cdot K / KNB)$$

That is, *CNR* is estimated by multiplying the ratio of re-procurement cost/book value by *NR*. *NR* thereby becomes:

$$NOMI = ACQ - NR \cdot P_K \cdot K / KNB$$

However, since *K* and *KNB* during the current term are not known, the ratio derived from the value of each from the previous term is used.

Supplementary Note 3.2 Calculation of Net Capital Stock by Industry[3]

In order to determine net capital stock by industry, net capital stock by industry in 1970 indicated in the National Wealth Survey of the Cabinet Office is converted to a deflation standard and the benchmark is produced.

New capital investments indicated in the private sector capital stock statistics of the Cabinet Office are used for capital investments in each year.

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[3] With reference to Miyagawa (1996)

Capital depreciation rate is calculated by building, structure, means of transportation, equipment and other assets from net fixed assets and gross fixed asset formation of the national economic accounting. The capital depreciation rate is weight averaged by the weight of each asset in each industry using the National Wealth Survey.

Net capital stock by industry is estimated by the benchmark year method from the benchmark, capital investments and capital depreciation rates derived above.

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