Productivity Growth, Technological Progress and Efficiency Change in Chinese Manufacturing Industry: A DEA Approach*

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This study employs a data envelopment analysis (DEA) approach to analyze total factor productivity (TFP), technological progress and efficiency change in Chinese manufacturing production from 1993 to 2002. The Malmquist (1953) productivity index measures are decomposed into technical change index and efficiency change index. This Malmquist productivity index can help us to identify the contribution of the improved efficiency or the technological progress to Chinese manufacturing productivity growth. The results show that the TFP in Chinese manufacturing sector annually rose 2.4 percent on average during the 1994-2002 period. The average annual change rate of technical progress was 2.4 percent while that of technical efficiency was 0.3 percent. It indicates that the TFP growth in Chinese manufacturing sector is mostly attributable to the technological progress although the efficiency improved during this period.

I. Introduction

Rapid economic growth in China has attracted worldwide attention, with an average annual GDP growth rate of about 10 percent in the past two decades (World Bank, 2003). Usually, it is considered that the growth in an economy has been due to the growth of inputs and the productivity improvement in use of those inputs. Those factors that affect the productivity growth will influence on wealth creation as well as the ability of the economy to maintain wealth levels. It has become very important to investigate whether the productivity growth has contributed to the high growth of China. Therefore, the research on Chinese productivity growth has been paid much attention.

Many previous studies on Chinese productivity growth measurement have been based on the standard calculation of total factor productivity (TFP) shaped by Solow (1957) (see McMillan et al., 1989; Chen et al., 1988). These studies interpreted the TFP as a measure of technical change. This way of interpretation incorporates a restrictive assumption into the analysis of TFP, that is, assume that each producer is completely efficient in the production process. However, this assumption is limited because there exists technical inefficiency in the actual production process. In order to overcome this shortcoming and identify the

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Ecomponents of TFP change, two major methods were developed based on the decomposition of the standard productivity index. One is the parametric approach that calculates the Chinese TFP by estimating an aggregate production function, a cost function, or a profit function. This method has been employed in the analysis of TFP in China (see Lau et al. 1990; Xu, 1999; Zhang et al., 2004). The other is the nonparametric approach, i. e. data envelopment analysis (DEA). It does not require specification of the underlying technology and production function. Furthermore, it has an advantage in dealing with disaggregated inputs and multiple outputs technologies. Few study on Chinese manufacturing industry used the DEA approach for the analysis of productivity, especially in the provincial level.

The objective of this study is three-fold: 1) to investigate whether high economic growth was achieved by productivity lifting in Chinese manufacturing sector using the nonparametric DEA approach; 2) to find which factors contributed to the productivity growth in Chinese manufacturing; 3) to observe how TFP change of each region was during the 1993-2002 period.

This study applies the DEA approach to analyze the TFP growth in manufacturing sectors of three regions including twenty-five provinces in China from 1993 to 2002. Using the Malmquist productivity index developed by Fare et al. (1994), we decompose the TFP growth of Chinese manufacturing into technical change and efficiency change. This productivity index can help us to identify the contributions of the improved efficiency and the technological progress to Chinese manufacturing productivity growth.

This paper is organized as follows: Section 2 presents a discussion of the Malmquist productivity index and the distance functions. How to calculate them also is introduced in this section. Section 3 contains a brief description of the data and a discussion of the empirical results. Section 4 is the summary of this paper.

Ⅱ. The Models

The Malmquist (1953) productivity index was first proposed by Malmquist and developed by Cave et al. (1982) later. Fare et al. (1994) decomposed the TFP growth index into technical change index and efficiency change index.

In order to discuss the Malmquist productivity indices, we denote $x^t (x^t \in R^+)$ as inputs, $y^t (y^t \in R^+)$ as outputs, and then define the production technology P^t in terms of output set at each period $t=1 \ldots T$ as:

$$P^t(x^t)=\{y^t : x^t \text{ can produce } y^t\} \quad (1)$$

Where P^t is output set.

We follow Shephard et al. (1970) to define the output distance function in period t as:

$$D_0^t(x^t, y^t)=\min\{\lambda : (x^t, y^t/\lambda) \in P^t\} \quad (2)$$

The output distance function is defined

as the inverse of the maximal proportional increase of the desirable output vector y^t under the given inputs x^t. It is also equivalent to the reciprocal of Farrell's (1957) output efficiency, which measures the level of "catching-up" of an observation to the best-practice frontier. In this study, the production on the best-practice frontier is the highest productivity observed in all the observations with the same technology. If $D_o^t(x^t, y^t)=1$, the production is technically efficient. If $D_o^t(x^t, y^t)<1$, the proudction is not technically efficient. Thus, the output distance function also can measure the degree of technical inefficiency. The output distance function in period $t+1$, namely, $D_o^{t+1}(x^{t+1}, y^{t+1})$ can be defined as (2) with t replaced by $t+1$.

We define a two-mixed periods output distance function as the following :

$$D_o^t(x^{t+1}, y^{t+1})=\min\{\lambda : (x^{t+1}, y^{t+1}/\lambda)\in P^t\} \quad (3)$$

This distance function can measure the maximal proportional changes in outputs for the given inputs x^{t+1}, under the technology of period t. Similarly, we define the other two-mixed periods output distance function as :

$$D_o^{t+1}(x^t, y^t)=\min\{\lambda : (x^t, y^t/\lambda)\in P^{t+1}\} \quad (4)$$

This distance function measures the maximal proportional changes in outputs for the given inputs x^t, under the technology or period $t+1$.

Following Caves et al. (1982), the Malmquist productivity index is defined as :

$$M_o^t=\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \quad (5)$$

This productivity index measures the productivity changes resulted from changes in technical efficiency at periods t and $t+1$ under the technology of period t. The efficiency change from period t to period $t+1$ also can be measured under the technology of period $t+1$. This Malmquist productivity index is defined as the following :

$$M_o^{t+1}=\frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^t, y^t)} \quad (6)$$

In order to avoid the problem of the arbitrary benchmark, we specify the output-oriented Malmquist productivity index as the geometric mean of two types Malmquist productivity indices :

$$M_o^{t,t+1}=\left[\left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)}\right)\left(\frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^t,y^t)}\right)\right]^{1/2} \quad (7)$$

Equation (7) also can be written as :

$$M_o^{t,t+1}=\frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \times\left[\left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})}\right)\left(\frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)}\right)\right]^{1/2} \quad (8)$$

$$EC=\frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \quad (9)$$

$$TC=\left[\left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1})}\right)\left(\frac{D_o^t(x^t, y^t)}{D_o^{t+1}(x^t, y^t)}\right)\right]^{1/2} \quad (10)$$

Where EC is the efficiency change index that measures the level of the "catching-up" to the best-practice frontier for each observation between periods t and $t+1$. TC is the technical change index that measures the shifting in the frontier of technology between two periods t and $t+1$.

The decomposition of the Malmquist productivity index allows us to identify the contribution from the improvement in efficiency or the innovation in technology to the productivity growth. If $M_o^{t,t+1}>1$, it implies that the productivity increased. Conversely, $M_o^{t,t+1}<1$ indicates the decline in productivity. $M_o^{t,t+1}=1$ implies no change in the productivity due to no changes in inputs and outputs.

Similarly, the increase in technology or efficiency is also associated with score larger than one, and any decline is associated with score smaller than one.

In order to calculate the Malmquist productivity index of province k between period t and $t+1$, we use the *DEA* approach to calculate the following four distance functions under the constant returns to scale: $D_o^t(x^t, y^t)$, $D_o^{t+1}(x^t, y^t)$, $D_o^t(x^{t+1}, y^{t+1})$ and $D_o^{t+1}(x^{t+1}, y^{t+1})$. These distance functions are the reciprocals of the Farrell's output-oriented efficiency. $D_o^t(x^t, y^t)$ and $D_o^{t+1}(x^t, y^t)$ can be defined as follows :

$$\begin{aligned}&[D_o^t(x_k^t, y_k^t)]^{-1}=\max\phi_1^k\\ &z_k^t Y_k^t \geq \phi_1^k y_k^t\\ &z_k^t X_k^t \leq x_k^t\\ &z_k^t \geq 0\end{aligned} \tag{11}$$

$$\begin{aligned}&[D_o^{t+1}(x_k^{t+1}, y_k^{t+1})]^{-1}=\max\phi_2^k\\ &z_k^{t+1} Y_k^{t+1} \geq \phi_2^k y_k^{t+1}\\ &z_k^{t+1} X_k^{t+1} \leq x_k^{t+1}\\ &z_k^{t+1} \geq 0\end{aligned} \tag{12}$$

The two-mixed periods distance functions, $D_o^t(x^{t+1}, y^{t+1})$ and $D_o^{t+1}(x^{t+1}, y^{t+1})$ can be defined as :

$$\begin{aligned}&[D_o^t(x_k^{t+1}, y_k^{t+1})]^{-1}=\max\phi_3^k\\ &z_k^t Y_k^t \geq \phi_3^k y_k^{t+1}\\ &z_k^t X_k^t \leq x_k^{t+1}\\ &z_k^t \geq 0\end{aligned} \tag{13}$$

$$\begin{aligned}&[D_o^{t+1}(x_k^t, y_k^t)]^{-1}=\max\phi_4^k\\ &z_k^{t+1} Y_k^{t+1} \geq \phi_4^k y_k^t\\ &z_k^{t+1} X_k^{t+1} \leq x_k^t\\ &z_k^{t+1} \geq 0\end{aligned} \tag{14}$$

III. Data and Empirical Results

1. The Data Source

The data employed in this study are provincial-level inputs, outputs of twenty-five provinces (including three municipalities) in China for 1993–2002. These data are taken from the China Statistical Yearbook from 1994–2003. Inputs include labor and capital stock. We use the number of employees multiplied by the average wage of employees as our proxy for labor. The output is gross domestic product (GDP). GDP and capital stock was transformed into real values with GDP deflator (1978 = 100). We will use "onfronts" computer program to estimate the distance functions for twenty-five provinces during the 1993–2002 periods.

According to the development level of economy, twenty-five provinces in China are classified into three regions: the eastern region, the central region and the western region. The eastern region is the most developed region, followed by the central region and the western region. The eastern region includes nine provinces that are Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, and Guangdong. The central region includes seven provinces that are Shanxi, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan. The western region includes nine provinces that are Guangxi, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang. We will mainly focus on the three regions to compare the differences in TFP, technology and efficiency among them.

Table 1 presents average annual growth rate of GDP, capital stock and labor in the Chinese manufacturing industry in twenty-five provinces over the time 1993-2002 period. The national annual growth rate of GDP in the Chinese manufacturing industry is 11.78%, the eastern region 12.73%, the central region 12.34%, the western region 10.27%. The growth rates of GDP of the eastern and central regions showed larger than the western region. These data show that Chinese manufacturing industry had a high economic growth supported by the increase of capital stock and labor. Most of provinces depended on capital stock more than labor to achieve their economic growth (Only Shanxi was an exception). In addition, for most of provinces, the growth rate of capital stock is faster than that of GDP. We can know that the Chinese economic growth extremely depended on capital stock during the 1993-2002 periods.

Table 1 Average Annual Growth Rate of GDP, Labor and Capital (1993-2002)

	GDP	Labor	Capital
National	11.78	7.84	12.78
Eastern	12.73	9.32	14.71
Beijing	9.72	9.36	14.18
Tianjin	11.92	4.34	11.38
Hebei	12.47	9.38	14.87
Shanghai	11.00	6.51	16.70
Jiangsu	12.66	5.92	13.58
Zhejiang	14.44	14.06	18.43
Fujian	15.44	13.87	16.55
Shandong	12.67	9.84	12.60
Guangdong	14.23	10.60	14.08
Central	12.34	7.37	11.50
Shanxi	10.46	12.91	8.16
Heilongjiang	9.18	2.95	9.36
Anhui	13.37	7.62	11.73
Jiangxi	14.98	6.86	12.22
Henan	12.24	10.88	12.67
Hubei	13.77	3.62	13.70
Hunan	12.41	6.77	12.69
Western	10.27	6.83	12.14
Guangxi	11.02	7.36	13.63
Sichuan	12.14	6.27	12.78
Guizhou	10.24	8.77	12.51
Yunnan	10.54	6.66	14.26
Shaanxi	10.39	5.76	11.09
Gansu	9.55	5.00	11.49
Qinghai	8.99	5.62	9.80
Ningxia	9.87	10.43	11.44
Xinjiang	9.66	5.62	12.25

Source : China Statistical Yearbook, 1994-2003

2. The Empirical Results

Because the measures of technical efficiency relate to the basic component of the Malmquist productivity index, we also report the technical efficiencies of twenty-five provinces under the constant returns to scale from 1993-2002 in Table 2. If the score of efficiency for a province is equal to one, it indicates that the province is on the frontier or technically efficient. Conversely, if the score is smaller than one, it implies that the

Table 2 Technical Efficiency under the Constant Returns to Scale (1993-2002)

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	average
National	0.722	0.742	0.765	0.762	0.756	0.706	0.746	0.713	0.714	0.746	0.737
Eastern	0.821	0.843	0.856	0.849	0.835	0.786	0.809	0.792	0.806	0.842	0.824
Beijing	0.645	0.613	0.610	0.575	0.541	0.495	0.568	0.518	0.508	0.478	0.555
Tianjin	0.625	0.637	0.658	0.676	0.667	0.613	0.671	0.654	0.690	0.758	0.665
Hebei	0.725	0.704	0.719	0.725	0.704	0.654	0.641	0.641	0.649	0.680	0.684
Shanghai	1.000	1.000	1.000	0.943	0.962	0.885	0.885	0.826	0.840	0.909	0.925
Jiangsu	0.800	0.909	0.917	0.917	0.893	0.862	0.877	0.901	0.935	0.980	0.899
Zhejiang	0.971	0.980	1.000	1.000	0.990	0.952	0.943	0.943	0.935	0.935	0.965
Fujian	0.840	0.926	0.926	0.917	0.877	0.833	0.820	0.826	0.840	0.885	0.869
Shandong	1.000	1.000	1.000	1.000	1.000	0.893	0.980	0.901	0.917	0.952	0.964
Guangdong	0.787	0.813	0.877	0.885	0.885	0.885	0.893	0.917	0.943	1.000	0.889
Central	0.741	0.772	0.812	0.834	0.843	0.809	0.860	0.835	0.847	0.884	0.824
Shanxi	0.588	0.592	0.625	0.637	0.680	0.599	0.725	0.625	0.629	0.694	0.639
Heilongjiang	0.893	0.917	0.926	0.877	0.877	0.935	0.980	0.935	0.943	1.000	0.928
Anhui	0.840	0.935	0.926	0.990	1.000	0.917	1.000	0.952	0.971	1.000	0.953
Jiangxi	0.758	0.800	0.943	0.990	1.000	1.000	1.000	1.000	1.000	1.000	0.949
Henan	0.781	0.806	0.826	0.820	0.775	0.709	0.714	0.725	0.741	0.769	0.767
Hubei	0.671	0.690	0.730	0.775	0.813	0.775	0.877	0.885	0.917	0.980	0.811
Hunan	0.658	0.667	0.709	0.746	0.758	0.730	0.725	0.725	0.725	0.741	0.718
Western	0.608	0.618	0.637	0.621	0.609	0.545	0.595	0.538	0.519	0.543	0.583
Guangxi	0.699	0.735	0.746	0.730	0.725	0.633	0.709	0.610	0.575	0.621	0.678
Sichuan	0.413	0.431	0.469	0.483	0.478	0.441	0.472	0.418	0.426	0.431	0.446
Guizhou	0.592	0.575	0.588	0.602	0.588	0.549	0.532	0.524	0.505	0.500	0.556
Yunnan	0.581	0.676	0.725	0.649	0.592	0.495	0.562	0.500	0.500	0.538	0.582
Shaanxi	0.645	0.699	0.758	0.752	0.752	0.704	0.714	0.637	0.610	0.658	0.693
Gansu	0.562	0.538	0.546	0.562	0.559	0.500	0.532	0.498	0.498	0.543	0.534
Qinghai	0.565	0.546	0.556	0.532	0.524	0.485	0.568	0.552	0.508	0.490	0.533
Ningxia	0.645	0.606	0.610	0.559	0.538	0.467	0.503	0.407	0.383	0.413	0.513
Xinjiang	0.769	0.758	0.735	0.719	0.725	0.629	0.763	0.694	0.671	0.694	0.716

Note: The value of technical efficiency close to one means more efficiently.

province is below the frontier or technically inefficient. From Table 2, we know that there are four provinces in the eastern region appeared on the best practice frontier during the 1993-2002 period : Shandong appeared five times, Shanghai three times, Zhejiang two times and Guangdong one time. In the central region, there are three provinces to lie on the frontier: Jiangxi six times, Anhui three times and Heilongjiang one time. In the western region, no province lied on the frontier during the 1993-2002 period.

In addition, both of the scores of technical efficiency of the eastern region and central region are 0.824. It indicates that the levels of technical efficiency for the eastern and central regions were almost same during this period, both of them were 82.4 percent, in other words, both of regions had 17.6 percent technically inefficiency. The score of technical efficiency for the western region is 0.583, much lower than other two regions. It implies that there was rather large gap in technical efficiency between the poorest western region and the other two regions. From this result, we can know that the production patter of the western region was extremely inefficient or wasteful over the period 1993-2002.

As above-mentioned, we decomposed the Malmquist productivity index into the TC index and EC index. In order to obtain the Malmquist productivity index and other indices for each province, we used the DEA approach to calculate the output distance functions by solving nonparametric linear programming problems. Table 3 presents the average annual changes of Malmquist productivity index and its components for twenty-five provinces during the 1993-2002 periods. The score of Malmquist productivity index larger than one indicates the improvement in TFP. Conversely, the score of Malmquist productivity index less than one implies the decline in TFP.

The results show that the average productivity growth in the Chinese manufacturing production was 2.4 percent for the whole country during the 1993-2002 period. The efficiency change and the technical change that contribute to the TFP growth were 0.3 percent and 2.4 percent, respectively. It implies that although efficiency increased a little, the TFP growth in the Chinese manufacturing industry was mostly attributable to the technological progress over the period 1993-2002. The TFP growth rate of the most developed eastern region was 1.1 percent, lower than the average productivity growth rate 2.4 percent. This is an unexpected result in this study. The eastern region's productivity growth was achieved by the efficiency change of 0.2 percent and the technical change of 1.0 percent. This result shows that the TFP growth for the eastern region also was attributable to the technological progress more than the improved efficiency. The TFP growth rate of the central region was 4.1 percent with the efficiency change of 2.1 percent and the technical change of 2.2 percent. Thus, we can say that the contributions of the improvement in efficiency and the innovation in technology to the TFP of the central region were almost same over the period 1993-2002. At last, we want to observe the western region's result. Its productivity growth rate was 2.4 percent, with the efficiency change of −1.0 percent and the technical change of 4.0 percent. This result tells us that the TFP growth of the western region was attributable to the technological progress rather than the improved efficiency from 1993 to 2002.

In details, among the twenty-five provinces, Hebei and Zhejiang in the eastern region, Guizhou and Ningxia in the western region had negative average growth rates in the TFP during the 1993-2002 period.

Table 3 Average Annual Changes of Malmquist Indices under the Constant Returns to Scale (1993-2002)

	Malmquist Index	Efficiency Change	Technical Change
National	1.024	1.003	1.024
Eastern	1.011	1.002	1.010
Beijing	1.014	0.969	1.052
Tianjin	1.033	1.022	1.012
Hebei	0.997	0.993	1.002
Shanghai	1.016	0.990	1.030
Jiangsu	1.009	1.023	0.990
Zhejiang	0.974	0.994	0.979
Fujian	1.008	1.007	1.003
Shandong	1.022	0.997	1.032
Guangdong	1.022	1.026	0.993
Central	1.041	1.021	1.022
Shanxi	1.038	1.023	1.018
Heilongjiang	1.072	1.014	1.059
Anhui	1.034	1.020	1.017
Jiangxi	1.041	1.033	1.008
Henan	1.004	0.999	1.009
Hubei	1.082	1.042	1.039
Hunan	1.017	1.012	1.004
Western	1.024	0.990	1.040
Guangxi	1.033	0.991	1.052
Sichuan	1.020	1.007	1.017
Guizhou	0.987	0.980	1.008
Yunnan	1.040	0.997	1.054
Shaanxi	1.048	1.004	1.048
Gansu	1.007	0.998	1.010
Qinghai	1.041	0.988	1.059
Ningxia	0.999	0.956	1.054
Xinjiang	1.041	0.992	1.059

Zhejiang had the greatest decline in the TFP because of its poorest performances in both technology and efficiency. Hebei, Guizhou and Ningxia had decline in TFP because of their decrease of technical efficiency. Therefore, totally four provinces had declined in technology when thirteen provinces (more than 50 percent) had declined in technical efficiency during this period. It illustrates again that the Chinese manufacturing productivity growth was fundamentally attributable to technological progress rather than the improved efficiency.

Since the Malmquist productivity index and its components are multiplicative, we can calculate the cumulated Malmquist productivity indices and its components such as the cumulated technical change and the cumulated efficiency change. Table 4 shows the cumulated Malmquist productivity indices and its components under the constant returns to scale from 1993 to 2002. The cumulated indices measure the total changes in the TFP, technology and efficiency during the 1993-2002 periods. Among all of the provinces, only Zhejiang had reduction in TFP due to its decline in both technological progress and efficiency during this period. For the entire country, the total changes in the TFP, technology and efficiency showed the improvement. The productivity growth was 18.4 percent, technical progress 17.5

Table 4 Cumulated Malmquist Indices under the Constant Return to Scale (1993-2002)

	Malmquist Index	Efficiency Change	Technical Change
National	1.184	1.018	1.175
Eastern	1.095	0.999	1.101
Tianjin	1.185	1.061	1.119
Hebei	1.025	0.942	1.076
Shanghai	1.071	0.921	1.166
Jiangsu	1.078	1.117	0.981
Zhejiang	0.913	0.982	0.923
Fujian	1.110	1.042	1.082
Shandong	1.171	0.970	1.224
Guangdong	1.146	1.110	1.012
Central	1.272	1.109	1.165
Shanxi	1.243	1.101	1.147
Heilongjiang	1.378	1.048	1.334
Anhui	1.257	1.130	1.135
Jiangxi	1.341	1.239	1.102
Henan	1.083	0.979	1.113
Hubei	1.441	1.184	1.244
Hunan	1.163	1.084	1.080
Western	1.203	0.967	1.257
Guangxi	1.269	0.981	1.322
Sichuan	1.208	1.083	1.129
Guizhou	1.022	0.931	1.102
Yunnan	1.313	1.018	1.330
Shaanxi	1.380	1.074	1.312
Gansu	1.072	0.957	1.116
Qinghai	1.265	0.954	1.334
Ningxia	1.062	0.773	1.330
Xinjiang	1.239	0.933	1.334

percent, the improvement of efficiency 1.8 percent. From this result, we also can know that total change in the TFP in Chinese manufacturing production was mainly attributable to the innovation in technology. The contribution to TFP growth from the improved efficiency was relatively rather lower during this period.

To observe how TFP changes of three regions in each period, we will turn to investigate the results illustrated in Figure 1, 2, 3. Figure 1 shows cumulated results including TFP, efficiency change and technical change for the eastern region. The TFP of the eastern region consistently increased due to higher growth of technical progress from 1993 to 1998. After reaching the top point in 1998, the TFP basically had no improvement, conversely, showed very lower decreasing trend. It implied that the TFP growth almost did not contribute to the economic growth of the eastern region in manufacturing production after 1998.

Figure 2 presents the cumulated results for the central region over from 1993 to 2002. The central region achieved higher TFP growth from 1993 to 1998, and kept the same level until 1999, and then had a lower increase in 2000. After 2000, it showed a much lower decreasing trend. For the central region, both of the innovation in technology and improvement in efficiency contributed to the productivity growth during this period. Between these two factors, the influence on TFP from technological progress had still been larger than that from efficiency change all the time.

Figure 3 shows the cumulated results for the western region during the 1993-2002 period. The western region also achieved TFP growth from 1993 to 1998 like other two regions and kept this productivity level from 1998 to 2000. After 2000, it appeared a decreasing trend. For the western region, both of technology and efficiency change contributed to the TFP growth from 1993 to 1996. After 1996, almost technical progress brought the positive impact on the productivity growth. It implies that the western region has great potentials to increase the TFP by the improved efficiency in the future.

We compared the productivity change among three regions as shown in Figure 4. The central region showed the relatively highest productivity growth during the 1993-2002 period, and followed by the western region while the lowest one was the eastern region. It implies that the eastern region achieved the high economic growth by depending on the introduction of capital or labor rather than through productivity lifting during this period.

In order to determine which provinces shifted the frontier (Fare et al., 1994, pp. 79), that is, which provinces were the "innovators" in Chinese manufacturing sector, we can see the component distance functions in the technical change index. If the following conditions were satisfied for a given province k simultaneously,

$$TC^k > 1$$

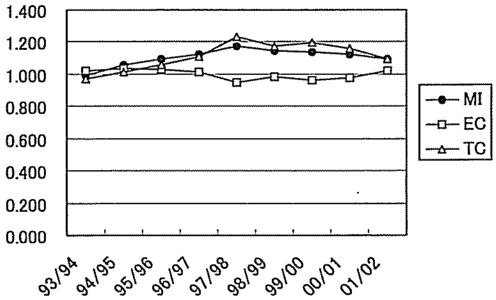

Figure 1 Cumulated Results for the Eastern Region (1993-2002)

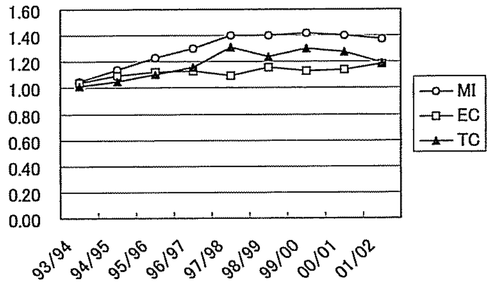

Figure 2 Cumulated Results for the Central Region (1993-2002)

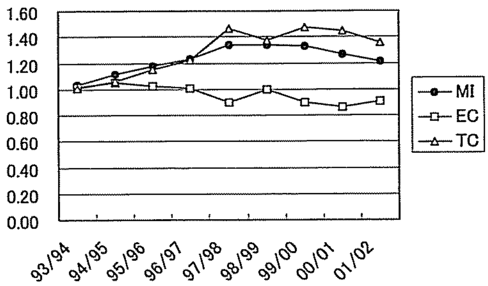

Figure 3 Cumulated Results for the Western Region (1993-2002)

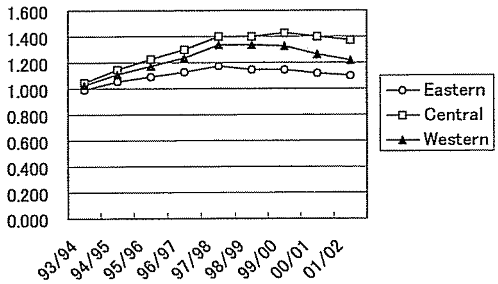

Figure 4 Cumulated Malmquist Indices for Three Regions (1993-2002)

$$D_o^t(x^{k,t+1}, y^{k,t+1})>1$$
$$D_o^{t+1}(x^{k,t+1}, y^{k,t+1})=1$$

Then that province has contributed to a shift in the frontier between periods t and $t+1$. As Table 5 shows, Shandong shifted the frontier in four of two-year periods, and Jiangxi did in three of two-year periods. Shanghai and Anhui also shifted the frontier once, respectively.

Table 5 Provinces Shifting the Frontier (1993-2002)

Year	Province
93-94	Shandong
94-95	Shanghai, Shandong
95-96	Shandong
96-97	Shandong, Anhui, Jiangxi
97-98	Jiangxi
98-99	—
99-00	Jiangxi
00-01	—
01-02	—

Ⅳ. Summary and Conclusions

This study applied a DEA approach to measure total factor productivity, technological progress, and efficiency change in Chinese manufacturing sector from 1993 to 2002. According to the development level of economy, twenty-five provinces employed in this paper were divided into three regions, the most developed eastern region, followed by the central and western regions. The Malmquist productivity index was used to measure productivity growth in this paper. We followed Fare et al. (1994) to decompose the Malmquist productivity index into technical change index and efficiency change index. This decomposition allowed us to identify the contributions of the innovation in technology and the improvement in efficiency to productivity growth in Chinese manufacturing production.

Among the total twenty-five provinces, twenty-one provinces experienced industrial productivity growth during the 1993-2002 period. Most of their TFP growths were because of the improvement of technological progress in manufacturing production. Efficiency changes had little contribution to productivity growth. In addition, although the productivity growth brought larger impact on the economic growth in Chinese manufacturing sector from 1993 to 1998, it almost could not contribute to economic growth after 1998 due to the little improvement of TFP in this period. It implies that the high economic growth in Chinese industry in the recent years mainly depended on the introduction of capital and labor rather than the improvement of TFP. China should introduce high technologies from the developed countries, meanwhile, also should increase the investment for research and development (R&D) in order to realize more advanced economic growth by productivity lifting for its more sustainable growth.

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