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An Empirical Analysis of China's Productivity Growth after Entering the 21st Century

Liwen Feng

Jinan University, Guangzhou, 510632, China

Abstract

In this paper we use the conventional Data Envelopment Analysis Malmquist approach to estimate the Malmquist index, efficiency change and technical change in China for the period of 2000-2017. The two methods of calculating the capital stock are compared, and the data of the capital stock calculated by the two methods are used to estimate. Furthermore, the results are analyzed by regions. The results show that China's total factor productivity increased by an average of 1.2% per year from 2000 to 2017, and the technical change increased by an average of 1.9% per year. The technical change is the most important driving force for the increase in total factor productivity. The total factor productivity growth in eastern regions is the highest at 2.7%, followed by 0.6% in the northeastern regions, 0.5% in the centre regions, and 0.3% in the western regions. The growth in total factor productivity in western regions is the least.

Keywords

Data Envelopment Analysis, Malmquist index, Total factor productivity.

1. INTRODUCTION

At the end of the last century, China carried out reform and opening up. Since the reform and opening up, the Chinese economy has maintained a momentum of long-term rapid growth [1]. Total factor productivity (TFP) measures the relationship between input and output. The increase in TFP shows that more output can be achieved with equal input. TFP is suitable for analyzing the trend of economic growth. TFP has been proven by economists to explain the collapse of the Soviet planned economy, the difference in per capita income levels between different countries. Therefore, TFP is more suitable for evaluating the government's performance in promoting economic development than gross domestic product (GDP) [2]. In order to understand how the productivity growth of China's provinces has changed since entering the 21st century, and how the measured results differ from those in other literature, this article attempts to select appropriate methods to measure China's provincial productivity from 2000 to 2017.

The rest of this paper proceeds as follows: Section 2 is a literature review related to TFP. Section 3 is the methods of productivity estimation. Section 4 is the empirical data sources and processing methods. Section 5 is the analysis of the empirical results; Section 6 is the summary.

2. LITERATURE REVIEW

The literature on China's TFP has used several different methods, calculated different results for different periods, and explained the different results accordingly. Guo Qingwang et al. (2005) compared several estimation methods of TFP in the study. The results of the calculation show that China's TFP fluctuated sharply before 1993, declined year by year before 2000, and increased year by year after 2000. The article found that from 1979 to 2004, China's economic

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growth mainly relied on the input of factors and did not make full use of production capacity and production technology [3]. Zhang Xiangsun et al. (2008) sorted out and analyzed the Malmquist index method and put forward the shortcomings of the method and the research disputes about the method, and then used the Malmquist index method to study the changes and decomposition of China's TFP from 1979 to 2005. The study concluded that the decline in TFP growth after 1997 was mainly due to the decline in technical efficiency, which widened the technological gap between regions, and China did not experience the convergence effect of TFP [4]. Fu Yong et al. (2008) uses the Malmquist index method to measure and decompose the changes in China's TFP. The study found that there was no decline from 1978 to 2006 and it increased at a rate of 3% every year. In the 1980s and 1990s, technological progress mainly promoted the growth of China's TFP [5]. Zhao Zhiyun et al. (2011) uses the Solow Method to measure China's TFP, and then quantitatively analyze the reasons for the changes in China's TFP. The study found that the reason for the changes in China's TFP since the reform and opening up is mainly due to the introduction of technology. After 1994, China's institutional changes have promoted economic growth by promoting the growth of TFP. It is believed that traditional economic growth methods cannot enable China to continue to develop. The key to maintaining stable growth in China is to change the economic growth method [6]. Zhang Jianhua et al. (2012) started with the re-estimation of capital depreciation rates by province, and the study found that China's TFP increased by an average of 2.48% from 1979 to 2010. It also pointed out that the use of different depreciation rates for each province in different periods will make the results different from those using the same depreciation rate [7].

For the same period, different scholars have different opinions and reasons. Zhang Jun (2002) points out that China's TFP growth has shown a declining trend after 1992, because China's capital has gradually deepened during this period, and the extensive growth model cannot drive China's sustained growth. Therefore, the study believes that China's economic growth lacks sufficient stamina [8]. Guo Qingwang et al. (2005) found that the average contribution rate of China's TFP to economic growth from 1979 to 2004 was 9.46%. The reason for the low contribution rate was the low contribution rate of technological progress to economic growth and low technical efficiency [3]. Yan Pengfei et al. (2004) found that the decline in TFP after 1997 was due to the slowdown in technological progress [9]. Zhang Xiangsun et al. (2008) points out that China's TFP has also declined after 1997 due to the decline in technical efficiency [4]. Li Bin et al. (2009) believes that China's annual economic growth rate in 2003-2007 exceeded 10%, which is inconsistent with other studies that believe that China's economic growth lacks stamina. It points out that the reason for the inconsistency is that other studies have used inappropriate investment flow indicators to increase the capital stock. The rate is overestimated, so China's TFP is underestimated [10].

3. METHOD

3.1. Literature Review Related to Productivity Estimation Methods

Traditional growth accounting methods treat TFP as technological progress, ignoring changes in technical efficiency and the impact of productivity changes [11]. Therefore, the defects of traditional growth accounting methods have further led to the study of TFP decomposition. The new research believes that productivity growth can be divided into changes in technological progress, changes in technical efficiency, and changes in scale efficiency. Panel data is used, which promotes the development of decomposition research on productivity [12] [13].

Zhang xiangsun et al. (2008) points out that the conclusions of TFP obtained by existing research are different due to different research methods. The main research methods are as

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follows: growth kernel algorithm, production function method, stochastic frontier analysis (SFA) and Data Envelopment Analysis (DEA) [4].

The TFP measurement method mainly has the following applications: using panel data, adopting a deterministic non-parametric frontier production model, estimating provincial productivity, and decomposing it into two parts: technical efficiency and technological progress [1]. Use current and previous input-output data to measure the most efficient production frontier and technical efficiency, and then analyze the reasons for China's economic growth through a triple decomposition of productivity [14]. In the presence of different controls on CO2 emissions, the Malmquist-Luenberger Productivity Index is used to measure the TFP of APEC countries and regions from 1980 to 2004 to analyze the relationship between environmental issues and productivity [15].

Jinghai Zheng et al. (2005) pointed out that traditional growth accounting methods did not take into account that changes in technical efficiency would have an impact on changes in productivity, so the panel data frontier production function model was used in the study. The study pointed out that the research using the stochastic production frontier model has problems when using enterprise data and province data, which will cause the results to be inconsistent with experience. The Malmquist index method is a relatively standardized and has proven to be an effective method for splitting productivity. To sum up, this article uses a deterministic non-parametric frontier production function model, namely the Malmquist index method [1].

Yanrui Wu (2008) uses SFA to evaluate the performance of China's economic growth, focusing on the role of technological progress in China's economic growth, in order to deepen the understanding of China's economic growth, and provide policy inspiration for China's future economic development. Research has found that China's growth comes from more factor inputs, and the contribution of technological progress is less. China's economic growth from 1993 to 2004 exceeded 20% [16].

Zhang Shaohua et al. (2014) used an input slack-based TFP index-ISP to measure and decompose China's TFP from 1985 to 2009, which can measure the impact of each input factor on TFP [17].

3.2. Malmquist Index

Refer to the research of Färe et al. (1994) and Jinghai Zheng et al. (2005) to illustrate the Malmquist index method [1] [12]. Regarding each province as a separate production decision-making unit, construct the best production frontier for China's production in each period, and then compare the production of each province with the best production frontier to further draw efficiency changes and technological changes. Assume that each period is t = 1, 2, ..., T. Define the production possible set as Pt. The set is expressed as follows:

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

The production technology Pt can make the transformation of inputs xt into outputs yt. Suppose there are k = 1, 2, ..., K provinces in each period t = 1, 2, ..., T using n = 1, 2, ..., N kinds of factor inputs to get m = 1, 2, ..., M types of output. According to Jinghai Zheng et al. (2005), assuming that the observed values of each input and output are positive and the observed values of each period are constant [1], then in period t, the best production frontier as a reference can be defined as:

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$$P^t = \{(x^t, y^t): y_m^t \le \sum_{k=1}^{K} z^{k,t} y_m^{k,t} \quad m = 1,2,\ldots,M; \\ x_n^t \ge \sum_{k=1}^{K} z^{k,t} x_n^{k,t} \quad n = 1,2,\ldots,N; \\ z^{k,t} \ge 0 \quad k = 1,2,\ldots,K\} \tag{2}$$

Further define the output-based distance function at time t:

$$D_0^t(x^t, y^t) = \inf\{\theta : (x^t, y^t/\theta) \in P^t\} = (\sup\{(x^t, y^t * \theta) \in P^t\})^{-1} \tag{3}$$

According to Färe et al. (1994) and Jinghai Zheng et al. (2005) define the Malmquist index, before defining the Malmquist index, a distance function containing two different periods needs to be given, as shown below:

$$D_0^t(x^{t+1}, y^{t+1}) = \inf\{\theta : (x^{t+1}, y^{t+1}/\theta \in P^t\} = (\sup\{(x^{t+1}, y^{t+1} * \theta) \in P^t\})^{-1} \tag{4}$$

The formulation in (4) expresses the ratio between the maximum output that can be achieved by input-output (x^{t+1}, y^{t+1}) and the output of the best technological frontier with the technology in period t as a reference. Another distance function is defined as follows:

$$D_0^{t+1}(x^t, y^t) = \inf\{\theta : (x^t, y^t/\theta \in P^{t+1}\} = (\sup\{(x^t, y^t * \theta) \in P^{t+1}\})^{-1} \tag{5}$$

The formulation in (5) expresses the ratio between the maximum output that can be achieved by the input-output (x^t, y^t) volume and the output of the best technological frontier with the technology in the t+1 period as a reference. Referring to the definition of Malmquist index by Jinghai Zheng et al. (2005) in order to avoid randomness when selecting the reference system of production technology, the Malmquist index is defined as follows:

$$M_0(x^{t+1}, y^{t+1}, x^t, y^t) = [(\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)})(\frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^t, y^t)})]^{\frac{1}{2}} \tag{6}$$

And assume that the scale efficiency of the production technology remains unchanged (constant returns to scale, CRS), $z^{k,t} \ge 0$. Further decompose (6) into efficiency change (7) and technical change (8):

$$E(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \tag{7}$$

$$T(x^{t+1}, y^{t+1}, x^t, y^t) = (\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})} * \frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)})^{\frac{1}{2}} \tag{8}$$

The formulation in (7) expresses the change in technical efficiency between periods t and t+1, which is called the efficiency change index. A efficiency change index greater than 1 means that technical efficiency is improved, and a efficiency change index less than 1 means that technical efficiency is reduced. If the efficiency change index is equal to 1, it means that there is no change

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in the technical efficiency. The formulation in (8) expresses the movement of the production technology frontier in the direction of output increase, which is called the technical change index. If the technical change index is greater than 1, it means that the technology has progressed. If the index is less than 1, it means that the technology has regressed. If the index of technical change is equal to 1, it means that the technology has not progressed or regressed. if both indexes are less than 1, it means that productivity has fallen. Therefore, to estimate the productivity of k' province between t and t+1, four different linear programming problems need to be solved, $D_0^t(x^t, y^t)$, $D_0^{t+1}(x^{t+1}, y^{t+1})$, $D_0^t(x^{t+1}, y^{t+1})$, $D_0^{t+1}(x^t, y^t)$:

$$\begin{aligned} &(D_0^t(x^{k',t}, y^{k',t}))^{-1} = \max \theta^{k'}, \\ &\theta^{k'} * y^{k',t} \le \sum_{k=1}^{K} z^{k,t} * y_m^{k,t} \qquad m = 1,2,\ldots, M \\ &x_n^{k',t} \ge \sum_{k=1}^{K} z^{k,t} * x_n^{k,t} \qquad n = 1,2,\ldots, N \\ &z^{k,t} \ge 0 \qquad k = 1,2,\ldots, K \end{aligned} \tag{9}$$

The formulation in (9) gives how to calculate the output distance function, which can further give other linear programming problem calculation formulas, as shown below:

$$\begin{aligned} &(D_0^{t+1}(x^{k',t}, y^{k',t}))^{-1} = \max \theta^{k'}, \\ &\theta^{k'} * y^{k',t} \le \sum_{k=1}^{K} z^{k,t+1} * y_m^{k,t+1} \qquad m = 1,2,\ldots, M \\ &x_n^{k',t} \ge \sum_{k=1}^{K} z^{k,t+1} * x_n^{k,t+1} \qquad n = 1,2,\ldots, N \\ &z^{k,t+1} \ge 0 \qquad k = 1,2,\ldots, K \end{aligned} \tag{10}$$

Jinghai Zheng et al. (2005) pointed out that the above linear programming problems may be applied to practical applications as a result of technological degradation, and the result of technological degradation is difficult to explain the reasons behind it. In the previous study, in order to highlight the research focus, including the best frontier provinces in t period in the production frontier in t+1 period, it is possible to avoid technological regression in the measurement results.

4. DATA

The data in this article are mainly derived from the statistical yearbooks of each province from 2000 to 2017. Then, using the Malmquist index method, according to the neoclassical growth theory, the main elements of economic growth are capital stock and labor, so the following basic variables are mainly involved: GDP, capital stock and labor.

According to the research of Jinghai Zheng et al. (2005), this article uses the GDP of each province as the output, and the nominal GDP of each province can be easily obtained from the statistical yearbook of each province. In order to further obtain the actual GDP of each province, this article uses 2000 as the base period, and converts the nominal GDP of each province through the GDP index given in the statistical yearbook of each province, and finally obtains the actual GDP of each province based on the year 2000. Liu Binglian et al. (2009) used the regional GDP plus the fiscal revenue of each city as a measure of output indicators, in order to prevent special deviations in GDP [18].

According to the research of Jinghai Zheng et al. (2005) and Zhang Xiangsun et al. (2008), the number of employees in each province is used as a measure of labor input. Jinghai Zheng et al.

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(2005) believe that a more appropriate measurement of labor input should be labor time rather than the number of laborers. However, it is still difficult to obtain data in this regard in China. Therefore, the improvement of labor input measurement is a problem that needs to be studied in the future. Liu Binglian et al. (2009) also pointed out that it is basically impossible to measure the amount of labor per hour in a city. Zhao Zhiyun et al. (2011) researched that the mid-year number of capital stock and labor factors put into use can better reflect the real input of the factors. In the future, when processing data, you can also consider the rationality of the use of data at the time point of the data.

The estimation of capital stock is more difficult than GDP and labor input. The estimation of capital stock involved in current research generally adopts the perpetual inventory method of Goldsmith in 1951. The basic formula for estimation is:

$$K_t = (1-r)*K_{t-1} + I_t \tag{11}$$

Kt is the capital stock in period t, Kt-1 is the capital stock in period t-1, r is the depreciation rate, and It is capital investment. Zhang Jun et al. (2004) studies the annual investment flow, the price index of investment products, the depreciation rate, and the selection of capital stock in the base year, using the total fixed capital formation as the investment indicator for the year. The result of the study is that the depreciation rate of the total fixed capital formation of each province is 9.6%, and the initial capital stock is selected by dividing the fixed capital formation of each province in 1952 by 10% [19]. Shan Haojie (2008) pointed out that the estimation formula of the perpetual inventory method requires attention in the following aspects. One is to determine the base period capital stock. The second is to determine the annual investment amount. The third is to determine the price index of investment products and convert them to constant prices. The fourth is to determine the economic depreciation rate. And believes that the amount of fixed capital formation can determine the investment data of the year. According to the "Historical Data of China's GDP Accounting (1952-1995)" and "The Historical Data of China's GDP Accounting (1952-2004)", the fixed capital formation price index of the country and each province from 1952 to 2004, calculate the price deflator to 1952 as the base period [20]. The study found that the estimation of capital stock is very sensitive to the depreciation rate. The depreciation rate reflects how much value the fixed assets have transferred in the current period. Only in the mode of geometric decline in relative efficiency can the depreciation rate be the same as the replacement rate. The formula of the balance depreciation method with diminishing geometric efficiency is:

$$d_T = (1-\sigma)^T \tag{12}$$

Where dT represents the relative efficiency of capital goods, σ represents the depreciation rate or replacement rate, and T represents the period.

Since the depreciation rate has a greater impact on the estimation of capital stock, this paper adopts the methods in Zhang Jun et al. (2004) and Shan Haojie (2008) when estimating fixed capital stock. Further examine how different methods and different depreciation rates will affect the final TFP estimation. Because this article studies China's productivity changes since entering the 21st century, this article selects 2000 as the base year. Find data through the data sources mentioned above, and then process the collected data accordingly. Therefore, Table 1 lists the relevant data on the average regional GDP, the number of employees, and the stock of fixed capital in each province in China from 2000 to 2017.

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Table 1. Average data of China's regional GDP, number of employees, and capital stock in various provinces from 2000 to 2017

Region	Actual GDP(Based on 2000, Billion)	Employees(Ten thousand)	capital stock(Billion)—— Zhang Jun et al. (2004)	capital stock(Billion)—— Shan Haojie (2008)
Xinjiang	3577.964	920.779	14431.530	12022.485
Ningxia	767.742	322.414	4984.729	4317.257
Qinghai	823.716	308.991	4356.548	3787.557
Gansu	2698.876	1488.567	8580.009	7221.680
Shaanxi	5496.218	1996.333	20948.158	17792.721
Tibet	371.084	176.002	1444.863	1134.588
Yunnan	5172.079	2664.372	18939.964	16099.083
Guizhou	2974.347	2046.553	11313.853	9720.168
Sichuan	12335.574	4755.313	31410.520	26253.740
Chongqing	5294.736	1581.325	15922.913	13387.904
Hainan	1455.785	438.262	4517.566	3840.703
Guangxi	6121.441	2752.758	22003.279	19101.064
Guangdong	29459.247	5398.147	67387.074	55752.059
Hunan	10919.677	3858.325	27345.933	23204.010
Hubei	12652.734	3579.106	31522.514	26596.084
Henan	15098.192	6018.845	50096.766	43061.878
Shandong	26940.545	6145.956	73257.346	60655.456
Jiangxi	6108.757	2395.778	16028.169	13444.674
Fujian	11856.183	2197.119	30496.976	25648.847
Anhui	8946.735	3940.038	22159.760	18477.724
Zhejiang	17751.931	3375.697	44120.436	35789.872
Jiangsu	27368.012	4652.402	68816.691	56479.800
Shanghai	12324.077	1054.156	31681.526	25324.456
Heilongjiang	8717.553	1860.539	20621.288	17470.327
Jilin	5538.811	1311.971	22101.226	19243.019
Liaoning	13357.763	2245.089	35199.699	29692.859
Inner Mongolia	6169.848	1203.322	24533.507	21925.985
Shanxi	4802.340	1647.642	17645.640	14899.269
Hebei	13901.453	3799.583	39475.472	32664.537
Tianjin	6390.476	684.478	20074.036	17347.168
Beijing	6787.963	964.650	23585.927	18827.239

The capital stock is calculated according to the method of Zhang Jun et al. (2004). The base period capital stock is divided by 10% of the total fixed capital formation in 1978 as the initial capital stock of the province, and the depreciation rate is 9.6%. Calculate the capital stock according to Shan Haojie (2008), using the balance depreciation method with diminishing geometric efficiency, and the depreciation rate is 10.96%.

From the data compiled in Table 1, it can be found that using different calculation methods and different depreciation rates to calculate the capital stock, the calculated results are different, which will affect the subsequent estimation and decomposition results of total factor productivity. Therefore, this paper uses two sets of capital stock data calculated by two different methods to estimate and decompose the TFP.

5. ANALYSIS OF RESULTS

According to the sorted data, two sets of fixed capital stock data calculated by two different methods were used to estimate and decompose the TFP, and the results were sorted into the following six tables. Table 2 and Table 3 are the 2000-2017 Malmquist index and its composition (national average) calculated using two different sets of fixed capital stock data. Table 4 and 5 are calculated using two different sets of fixed capital stock data to calculate the Malmquist index and its composition in China from 2000 to 2017. Table 6 and Table 7 are respectively the average technical efficiency and scale efficiency of China's provinces from 2000 to 2017 calculated using two different sets of fixed capital stock data. The last row of Table 2 to Table 7 are average values.

5.1. Comparison of the Empirical Results of the Two Sets of Capital Stock data

The following lists the Malmquist index and its composition (national average) from 2000 to 2017 calculated using two different sets of capital stock data.

Table 2. 2000-2017 Malmquist index and its composition (national average)-capital stock calculated according to Zhang Jun et al. (2004)

Year	Malmquist index(CRS)	Technical change(CRS)	Efficiency change(CRS)	Efficiency change(VRS)	Scale change
2000-2001	1.081	1.076	1.004	0.995	1.009
2001-2002	1.074	1.078	0.997	0.992	1.005
2002-2003	1.066	1.069	0.997	0.991	1.006
2003-2004	1.059	1.054	1.005	1.001	1.004
2004-2005	1.040	1.050	0.990	0.993	0.997
2005-2006	1.034	1.043	0.992	0.992	1.000
2006-2007	1.031	1.031	1.000	0.998	1.002
2007-2008	1.007	1.014	0.993	0.993	1.000
2008-2009	0.986	0.987	0.999	1.002	0.997
2009-2010	0.992	1.006	0.986	0.988	0.999
2010-2011	0.987	0.993	0.994	0.990	1.004
2011-2012	0.974	0.980	0.994	0.992	1.001
2012-2013	0.967	0.970	0.996	0.999	0.997
2013-2014	0.966	0.990	0.975	0.980	0.995
2014-2015	0.973	1.003	0.970	0.986	0.984
2015-2016	0.976	0.987	0.989	0.999	0.990
2016-2017	0.991	0.998	0.993	1.003	0.989
Average	1.012	1.019	0.993	0.994	0.999

Note: The capital stock is calculated according to the method of Zhang Jun et al. (2004). The base period capital stock is divided by 10% of the total fixed capital formation in 1978 as the initial capital stock of the province. The depreciation rate is 9.6%.

It can be seen from Table 2 that China's TFP increased by an average of 1.2% per year from 2000 to 2017, and the rate of technical change increased by an average of 1.9% per year. Since 2008, TFP has shown negative values until 2017. In general, the average value of the technical change index from 2000 to 2017 was 1.019, the average "technical progress" rate was 1.9%, and the efficiency change was -0.74%. This shows that "technical progress" has contributed to the

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increase in productivity. The main contribution, while the change in the provincial average technical efficiency is relatively small, and the contribution to productivity growth is negative.

Comparing Table 2 with Table 3, we can find that the capital stock calculated using two different methods is applied to TFP estimation and decomposition, and the results are different. In Table 2, China's TFP has increased before 2008 and has declined since 2008. In Table 3, China's TFP has declined since 2000. Second, Table 2 reflects that the increase in TFP is mainly attributed to technical change, while the technical change listed in Table 3 is negative growth. Zhao Zhiyun et al. (2011) pointed out that after China entry into the WTO, TFP has shown a growth state. Until the global financial crisis in 2008, TFP in 2009 was negative growth, that is, -0.402%. The results estimated in Table 2 are more consistent with the research results of Zhao Zhiyun et al. (2011). Zhang Xiangsun et al. (2008) pointed out that the empirical results of technical efficiency degradation during the period of reform and opening up are difficult to convince people. Therefore, compared with the results in Table 2 and Table 3, Table 2 is more convincing.

Table 3. 2000-2017 Malmquist index and its composition (national average)-capital stock calculated according to Shan Haojie (2008)

Year	Malmquist index(CRS)	Technical change(CRS)	Efficiency change(CRS)	Efficiency change(VRS)	Scale change
2000-2001	0.986	0.946	1.043	1.018	1.024
2001-2002	0.980	0.930	1.054	1.015	1.038
2002-2003	0.971	0.948	1.023	1.005	1.018
2003-2004	0.974	0.942	1.034	1.027	1.007
2004-2005	0.966	0.953	1.013	1.013	1.000
2005-2006	0.972	0.990	0.982	0.987	0.995
2006-2007	0.982	0.993	0.990	0.995	0.995
2007-2008	0.969	0.985	0.983	0.988	0.995
2008-2009	0.956	0.958	0.998	0.995	1.002
2009-2010	0.967	0.983	0.984	0.988	0.997
2010-2011	0.969	0.976	0.993	0.991	1.002
2011-2012	0.961	0.966	0.994	0.993	1.001
2012-2013	0.956	0.959	0.997	1.002	0.995
2013-2014	0.958	1.005	0.953	0.970	0.983
2014-2015	0.969	0.996	0.973	0.989	0.984
2015-2016	0.974	0.980	0.994	1.002	0.991
2016-2017	0.991	0.994	0.997	1.006	0.991
Average	0.971	0.971	1.000	0.999	1.001

Note: The capital stock is calculated according to Shan Haojie (2008), and the depreciation rate is 10.96%.

The following lists the Malmquist Index and its composition from 2000 to 2017 calculated using two different sets of capital stock data.

As can be seen from Table 4, the growth of TFP in China's provinces from 2000 to 2017 averaged 1.1%, and the rate of technical change increased by an average of 1.9 per year. The TFP of most provinces was increasing from 2000 to 2017, and the TFP of a small number of provinces was negative, such as Ningxia, Qinghai, Yunnan, Guangxi, Henan, Jilin, and Shanxi. Generally speaking, the growth of TFP in China's provinces is mainly driven by "technical progress", and the average contribution of the technical efficiency of each province to TFP is negative. From the data in Table 5, it can be seen that the TFP of most provinces has an average negative growth from 2000 to 2017, and only a few provinces have TFP growth, including: Zhejiang, Jiangsu, Shanghai, and Tianjin. Through the estimation and decomposition of TFP in Tables 4 and 5, it can be seen that two different methods of measuring the stock of fixed capital have a great influence on the results of TFP estimation and decomposition.

Table 4. 2000-2017 Malmquist index and its composition- capital stock calculated according to Zhang Jun et al. (2004)

Region	Malmquist index(CRS)	Technical change(CRS)	Efficiency change(CRS)	Efficiency change(VRS)	Scale change
Xinjiang	1.008	1.028	0.980	0.978	1.002
Ningxia	0.993	1.024	0.970	0.994	0.976
Qinghai	0.997	1.017	0.980	1.022	0.959
Gansu	1.004	1.009	0.994	0.994	1.001
Shaanxi	1.009	1.011	0.999	0.998	1.001
Tibet	1.017	1.009	1.008	1.000	1.008
Yunnan	0.987	1.009	0.977	0.976	1.001
Guizhou	1.001	1.009	0.992	0.990	1.002
Sichuan	1.017	1.009	1.008	1.007	1.000
Chongqing	1.018	1.010	1.007	1.007	1.001
Hainan	1.002	1.010	0.993	0.990	1.002
Guangxi	0.985	1.009	0.976	0.974	1.001
Guangdong	1.020	1.021	0.999	1.000	0.999
Hunan	1.003	1.009	0.994	0.994	1.000
Hubei	1.013	1.009	1.003	1.003	1.000
Henan	0.986	1.009	0.977	0.978	0.999
Shandong	1.024	1.017	1.007	1.004	1.003
Jiangxi	1.005	1.009	0.996	0.995	1.001
Fujian	1.017	1.027	0.991	0.992	0.999
Anhui	1.008	1.009	0.998	0.998	1.001
Zhejiang	1.036	1.026	1.009	1.009	1.000
Jiangsu	1.039	1.029	1.009	1.007	1.002
Shanghai	1.048	1.048	1.000	1.000	1.000
Heilongjiang	1.005	1.011	0.993	0.993	1.000
Jilin	0.999	1.027	0.972	0.971	1.002
Liaoning	1.015	1.028	0.988	0.989	0.999
Inner Mongolia	1.014	1.044	0.971	0.969	1.002
Shanxi	0.998	1.011	0.987	0.986	1.001
Hebei	1.010	1.011	1.000	0.997	1.003
Tianjin	1.045	1.045	1.000	1.002	0.998
Beijing	1.031	1.034	0.997	0.997	1.000
Average	1.011	1.019	0.993	0.994	0.999

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Table 5. 2000-2017 Malmquist index and its composition- capital stock calculated according to Shan Haojie (2008)

Region	Malmquist index(CRS)	Technical change(CRS)	Efficiency change(CRS)	Efficiency change(VRS)	Scale change
Xinjiang	0.977	0.998	0.978	0.978	1.001
Ningxia	0.957	0.985	0.972	1.001	0.971
Qinghai	0.972	0.983	0.988	1.037	0.953
Gansu	0.965	0.945	1.021	1.020	1.001
Shaanxi	0.965	0.957	1.008	1.007	1.002
Tibet	0.933	0.944	0.988	1.000	0.988
Yunnan	0.941	0.948	0.993	0.985	1.008
Guizhou	0.964	0.944	1.021	1.016	1.005
Sichuan	0.977	0.949	1.029	1.013	1.016
Chongqing	0.974	0.956	1.019	1.017	1.002
Hainan	0.971	0.971	1.000	1.001	0.999
Guangxi	0.935	0.940	0.995	0.981	1.014
Guangdong	0.988	0.988	0.999	1.000	0.999
Hunan	0.962	0.949	1.014	1.003	1.011
Hubei	0.977	0.957	1.021	1.013	1.008
Henan	0.936	0.944	0.992	0.975	1.017
Shandong	0.982	0.973	1.009	1.000	1.009
Jiangxi	0.952	0.943	1.010	1.001	1.009
Fujian	0.981	0.992	0.989	0.991	0.998
Anhui	0.959	0.942	1.018	1.003	1.015
Zhejiang	1.007	0.996	1.010	1.009	1.001
Jiangsu	1.004	0.996	1.008	1.003	1.005
Shanghai	1.032	1.032	1.000	1.000	1.000
Heilongjiang	0.978	0.975	1.003	1.003	1.000
Jilin	0.950	0.976	0.972	0.972	1.000
Liaoning	0.975	0.988	0.987	0.988	0.999
Inner Mongolia	0.947	0.982	0.964	0.965	0.999
Shanxi	0.951	0.959	0.992	0.993	0.999
Hebei	0.971	0.964	1.008	1.001	1.007
Tianjin	1.016	1.018	0.998	1.001	0.997
Beijing	0.998	1.003	0.995	0.995	1.000
Average	0.971	0.971	1.000	0.999	1.001

The following lists the average technical efficiency and scale efficiency of China's provinces from 2000 to 2017 calculated using two different sets of capital stock data.

According to the results in Table 6, the average technical efficiency of China's provinces from 2000 to 2017 was 78.3%, the average "pure" technical efficiency was 83.8%, and the average scale efficiency was 93.4%. Among them, the technical efficiency, "pure" technical efficiency, and scale efficiency of Shanghai and Liaoning are all 1, indicating that these two provinces are at the forefront of production. the technical efficiency of 14 provinces is below the average. It can be seen from Table 7 that the average technical efficiency of China's provinces from 2000 to 2017 is 68.4%, the average of "pure" technical efficiency is 77.0%, and the average of scale efficiency is 89.0%. Among them, the technical efficiency, "pure" technical efficiency, and scale efficiency of Shanghai, Liaoning and Inner Mongolia are all 1, indicating that these three provinces are above the production frontier. The technical efficiency of 18 provinces is below the average.

Table 6. The average technical efficiency and scale efficiency of China's provinces from 2000 to 2017— capital stock is calculated according to Zhang Jun et al. (2004)

Region	Technical efficiency(CRS)	Technical efficiency(VRS)	Scale efficiency
Xinjiang	0.686	0.717	0.957
Ningxia	0.458	0.568	0.805
Qinghai	0.465	0.582	0.800
Gansu	0.729	0.782	0.932
Shaanxi	0.578	0.588	0.983
Tibet	0.489	1.000	0.489
Yunnan	0.750	0.767	0.978
Guizhou	0.603	0.636	0.949
Sichuan	0.793	0.808	0.982
Chongqing	0.701	0.723	0.971
Hainan	0.726	0.857	0.847
Guangxi	0.847	0.869	0.974
Guangdong	0.947	1.000	0.947
Hunan	0.946	0.951	0.995
Hubei	0.816	0.837	0.975
Henan	0.867	0.912	0.951
Shandong	0.749	0.884	0.848
Jiangxi	0.917	0.946	0.969
Fujian	0.954	0.958	0.996
Anhui	0.899	0.909	0.989
Zhejiang	0.830	0.860	0.965
Jiangsu	0.801	0.888	0.902
Shanghai	1.000	1.000	1.000
Heilongjiang	0.977	0.988	0.989
Jilin	0.804	0.828	0.971
Liaoning	1.000	1.000	1.000
Inner Mongolia	0.884	0.934	0.946
Shanxi	0.693	0.712	0.973
Hebei	0.764	0.821	0.931
Tianjin	0.879	0.923	0.952
Beijing	0.733	0.742	0.988
Average	0.783	0.838	0.934

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Table 7. The average technical efficiency and scale efficiency of China's provinces from 2000 to 2017— capital stock calculated according to Shan Haojie (2008)

Region	Technical efficiency(CRS)	Technical efficiency(VRS)	Scale efficiency
Xinjiang	0.678	0.701	0.968
Ningxia	0.422	0.501	0.843
Qinghai	0.384	0.448	0.858
Gansu	0.452	0.485	0.932
Shaanxi	0.476	0.490	0.972
Tibet	0.669	1.000	0.669
Yunnan	0.549	0.634	0.866
Guizhou	0.352	0.395	0.891
Sichuan	0.539	0.719	0.749
Chongqing	0.563	0.592	0.951
Hainan	0.616	0.693	0.889
Guangxi	0.591	0.747	0.792
Guangdong	0.920	1.000	0.920
Hunan	0.655	0.799	0.820
Hubei	0.585	0.692	0.845
Henan	0.649	0.940	0.690
Shandong	0.705	0.935	0.754
Jiangxi	0.702	0.836	0.839
Fujian	0.949	0.952	0.997
Anhui	0.625	0.808	0.773
Zhejiang	0.808	0.855	0.946
Jiangsu	0.799	0.948	0.843
Shanghai	1.000	1.000	1.000
Heilongjiang	0.814	0.818	0.996
Jilin	0.778	0.784	0.992
Liaoning	1.000	1.000	1.000
Inner Mongolia	1.000	1.000	1.000
Shanxi	0.624	0.625	0.998
Hebei	0.654	0.766	0.853
Tianjin	0.901	0.937	0.962
Beijing	0.755	0.762	0.990
Average	0.684	0.770	0.890

From the comparison of the data in Table 6 and Table 7, it can be found that the difference in fixed capital stock will make the provinces on the best production frontier different, and will also affect the average technical efficiency.

Through the comparative analysis of the above empirical results, we can understand that the calculation method of the fixed capital stock and the depreciation rate will have a significant impact on the subsequent estimation and decomposition of TFP, which will further make the subsequent research conclusions will be quite different. Therefore, the data processing process of the capital stock should be fully considered when estimating and decomposing TFP, and then

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the analysis based on the TFP estimation and decomposition can be more adequate and reasonable.

5.2. Estimation and Analysis of TFP in Four Regions

According to the comparison of two different calculation methods of capital stock, the calculation method of capital stock by Zhang Jun et al. (2004) is more suitable for explaining the changes in China's TFP from 2000 to 2017.

In the study of Liu Binglian et al. (2009), the regions of China were divided according to the coordinated regional development strategy implemented by China during the "Eleventh Five-Year Plan" period. This paper divides China's provinces into eastern regions, centre regions, western regions, and northeast regions. The eastern regions includes 10 provinces and cities including Beijing, Tianjin, Hebei, Jiangsu, Shanghai, Fujian, Zhejiang, Guangdong, Shandong and Hainan. The centre regions includes 8 provinces, municipalities and autonomous regions including Shanxi, Jiangxi, Anhui, Hubei, Hunan, Henan, Inner Mongolia, and Shaanxi. The western regions includes: Sichuan, Chongqing, Yunnan, Guizhou, Gansu, Tibet, Ningxia, Qinghai, Xinjiang, Guangxi and other 10 provinces, municipalities and autonomous regions. The northeast regions includes 3 provinces and cities including Liaoning, Heilongjiang and Jilin. Divide provinces, municipalities, and autonomous regions to further study and analyze the changes in TFP among various regions in China.

Table 8. Changes in TFP in eastern, centre, western and northeastern China from 2000 to 2017

Region	Malmquist index(CRS)	Technical change(CRS)	Efficiency change(CRS)	Efficiency change(VRS)	Scale change
Eastern(10)	1.027	1.027	1.001	1.000	1.001
Centre(8)	1.005	1.014	0.991	0.990	1.001
Eastern(10)	1.003	1.013	0.989	0.994	0.995
Northeast(3)	1.006	1.022	0.984	0.984	1.000

Table 8 lists the relevant data on changes in TFP in eastern regions, centre regions, western regions, and northeastern regions from 2000 to 2017, from which we can further analyze and compare the changes in TFP in various regions of China.

The eastern regions includes 10 provinces and cities. The average value of the Malmquist index from 2000 to 2017 is 1.027. Combining the data in Table 4, it can be seen that the average value of China's Malmquist index from 2000 to 2017 is 1.011. The increase in regional TFP is higher than the average level in China. Second, the increase in TFP in the eastern regions mainly comes from the increase in the rate of technical change. The average value of the rate of technical change index from 2000 to 2017 was 1.027. The change in technical efficiency is almost unchanged. Among the 10 provinces and cities in the eastern regions, the Malmquist index of each province is greater than 1, the TFP of each province is improving. The technological progress rate index of each province is greater than 1, indicating that the technology of each province is improving. The technical efficiency changes in 4 of the 10 provinces have declined, including Hainan, Guangdong, Fujian, and Beijing, but they have little effect on the average value of technical efficiency changes in the eastern regions.

The centre regions includes 8 provinces and cities. The average value of the Malmquist index from 2000 to 2017 is 1.005. According to the data in Table 4, the average value of China's Malmquist index from 2000 to 2017 is 1.011. The increase in TFP is lower than China's average. Second, the increase in TFP in the centre regions is mainly due to the increase in the rate of technical change. Similar to the situation in the eastern regions, the average value of the index

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of technological progress from 2000 to 2017 was 1.014, the rate of technical change increased by 1.4%. The technical efficiency dropped by 0.94% on average. Among the eight provinces, municipalities and autonomous regions in the central regions, two provinces have experienced a decline in TFP, namely Henan and Shanxi. The technical efficiency of most provinces has declined, resulting in a change in technical efficiency of 0.991 in the central regions from 2000 to 2017, which is a decrease of 0.94%. The technological progress index of the eight provinces, municipalities, and autonomous regions is greater than 1, indicating that the technological progress of each province, municipality, and autonomous region is improving.

The western regions includes 10 provinces and cities. The average value of the Malmquist index from 2000 to 2017 is 1.003. The increase in TFP in the western regions is lower than the average level of China. Second, the increase in TFP in the western regions is mainly due to the increase in the rate of technical change, similar to the situation in the eastern and centre regions, the average value of the index of technological progress from 2000 to 2017 was 1.013. The technical efficiency dropped by 1.08% on average. From the data collation, it can be seen that among the 10 provinces, municipalities and autonomous regions in the western region, the TFP of 4 provinces has declined, namely Ningxia, Qinghai, Yunnan and Guangxi. The index of technological progress rate of 10 provinces, municipalities, and autonomous regions is greater than 1, indicating that the technological progress of each province, municipality, and autonomous region is improving. The technical efficiency of most provinces, municipalities, and autonomous regions has declined, resulting in a change in technical efficiency of 0.989 in the western regions during 2000-2017, which is a decrease of 1.08%.

The northeast regions includes 3 provinces. The average value of the Malmquist index from 2000 to 2017 was 1.006, which did not improve China's TFP. Secondly, the increase in TFP in the Northeast is mainly due to the increase in the rate of technical change. Similar to the situation in the eastern, centre and western regions, the average value of the technological progress index in the northeastern regions from 2000 to 2017 is 1.022 . However, technical efficiency dropped by an average of 1.57%. Among the three provinces in the northeastern regions, only one province has a Malmquist index less than 1, that is, Jilin, which is 0.999. The index of technical change rate of each province is greater than 1, indicating that every province maintains technological progress. The change in technical efficiency of each province is a decline, indicating a decline in technical efficiency.

The TFP in eastern regions has the highest growth-2.7%, followed by northeast regions-0.6%, centre regions-0.5%, and western regions-0.3%. The growth of TFP in western regions is the least. Liu Binglian et al. (2009) studied the TFP of Chinese cities from 1990 to 2006, and found that the improvement of TFP in Northeast regions is the most backward, which is related to the depletion of energy and economic structure transformation of the old industrial bases in northeast regions. Compared with the Liu Binglian et al. (2009), the results of this paper show that the scale efficiency of most regions has been improved from 2000 to 2017. According to Liu Binglian et al. (2009), the technical efficiency of each region, including pure technical efficiency and scale efficiency, was in a state of decline from 1990 to 2006. The results of 2000-2017 calculated in this article show that the scale efficiency of eastern regions, centre regions, and northeastern regions have all been improved, and only the scale efficiency of western regions is in a state of decline. Compared with the research of Liu Binglian et al. (2009), there is still some improvement.

6. CONCLUSIONS

This paper uses the panel data of Chinese provinces from 2000 to 2017, uses two different methods to calculate the capital stock, and then uses the Malmquist index to measure the changes in TFP of 31 provinces in China. Further decompose changes in TFP into changes in

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technological progress and changes in technical efficiency, and decompose changes in technical efficiency into changes in pure technical efficiency and changes in scale efficiency. The results calculated by the two methods are discussed in different periods and by provinces, municipalities, and autonomous regions, and the differences between the two methods are compared and the results calculated by which method are more realistic. After that, the comparison and analysis between regions are carried out.

Through comparison, it is found that the changes in TFP calculated using the capital stock data measured by Zhang Jun et al. (2004) are more in line with China's actual development. The calculation found that China's TFP increased by an average of 1.2% per year from 2000 to 2017, and the rate of technical change increased by an average of 1.9% per year. Since 2008, TFP has been negative until 2017; the change in technical efficiency is -0.74%, which shows that "technical progress" has made a major contribution to the growth of productivity, while the change in average technical efficiency between provinces relatively small, its contribution to productivity growth is negative. The growth of TFP in China's provinces from 2000 to 2017 averaged 1.1%, and the rate of technical change increased by 1.9% annually. The TFP of most provinces was increasing from 2000 to 2017, and the TFP of a few provinces was negative. The TFP in eastern regions has the highest growth-2.7%, followed by the northeast regions-0.6%, the centre regions-0.5%, and the western regions-0.3%. The growth of TFP in the western regions is the least.

The decline in technical efficiency is the main problem that affects the growth of TFP. Therefore, how to promote the improvement of China's technical efficiency is a problem that needs to be solved at present.

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