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Original Research Paper

Study on the Change and Regional Differences About Total Factor Productivity Considering the Environmental Pollution in China

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ABSTRACT

By the directional distance function method, this paper calculated and compared the TFP (Total Factor Productivity) in 30 regions of China from 2000 to 2011 considering the environmental pollution. The study indicated that the TFP of each region has been ever-increasing whether consider environmental pollution factors, but the growth rate has been decreasing. The TFP has been in recession situation since the financial crisis in 2008. According to regional differences, the average annual growth rate of TFP in east was much higher than that of the central and west regions. Considering the environmental pollution, the average TFP in each region fell slightly. Comparing with the TFP without environment factor, the TFP in west region fell sharper, while it appeared double win of environment and economy development in the east region.

INTRODUCTION

The economy has been rapidly developing for 30 years since the reform and open policy in China, but the high economy growth is at the cost of severe environmental pollution, huge energy waste, and low productivity. The extensive high investment, high energy consumption, and high emission have become the striking features for Chinese economy growth. According to neoclassical growth theory, the economy growth depends on the increasing of factor input and improvement of TFP (Total Factor Productivity). With the increase of energy and carbon emission constraint, excessive depending on the traditional economic growth mode of input expansion is unsustainable, so low-carbon economy development is an inevitable choice for Chinese economy growth.

Transforming economic developing mode needs more contribution of TFP to economy growth. Furthermore, scientific measurement and objective assessment to the green TFP growth under energy and environment restriction have a theoretical value and practical significance for transforming economic developing mode and realizing a long-term economic sustainable growth in China.

TFP, firstly raised by Solow, is an important index of measuring the output with all inputs in the process of production. It was also called Solow Surplus Value. TFP, being one of the most popular research fields of economy growth, has been widely applied in the field of agriculture, manufacture, service industry, comparison of regional economy and so on. However, the traditional measurement methods ignored the decline of undesirable output or bad output. So it made the growth rate overestimated (Dension et al. 1979, Repetto et al. 1997), yet, the lopsided processing of output distorted the evaluation of economic performance and changed the level of social welfare (Hailu & Veeman 2000). In view of the deficiency of the traditional method, Chung et al. (1997) advanced environmental TFP measurement model based on directional distance function, which reasonably fitted the environment factors during processing and also made it possible to calculate the real economic effect of environmental regulation.

Henceforth, many Chinese scholars have started to research industrial TFP, agricultural TFP, and so forth under environmental constraints. In manufacturing, the main research conclusions as follows: Firstly, with the global DEA and Malmquist-Luenberger productivity index, the paper measured the low-carbon-oriented industrial TFP growth accounting for energy consumption and carbon emissions. The results indicated that industrial green TFP generally experienced an increasing, then decreasing, at last rising evolution. The industrial green TFP growth was mainly derived from technological progress and industrial technical efficiency draws back industrial green TFP growth (Zhou & Nie 2012). Secondly, by the Slacks-based Measured (SBM) approach, the paper (2012) measured green TFP of 27 manufacturing industries in China from 2002 to 2010, and examined the influence of environmental regulation intensity on green TFP when they were involved in the process of international vertical specialization. Meanwhile, testing the industry disparity of environmental regulation intensity on green TFP, the results showed that there was a U-type relationship between the intensity of environmental regulation and manufacturing green TFP, and the initial weaker intensity of environmental regulation weakened the green TFP. However, with the increase of intensity of environmental regulation, the rate of green TFP gradually increased. Meanwhile, there was a certain difference of the impact of environmental regulation on green TFP between cleaning pollution intensive departments. Therefore, moderately increasing the intensity of environmental regulation and adopting various flexible methods of environmental regulation could not protect the environment, but also promote technical innovation and enhance the green TFP of manufacturing enterprises in China (Yin 2012). Thirdly, with Sequential Malmquist-Luenberger Index, the paper measured regional industrial total factor productivity (TFP) growth under environmental pollution in China from 1998 to 2008, then explored the reasons of TFP growth with the Panel Smooth Transition Regression (PSTR) methods. The major conclusions included: the growth of TFP has been a very important driving force to industrial growth. Technical progress was the source of TFP growth, and relative efficiency improved weakly. The fluctuation of TFP index showed that China's environmental protection efforts and international financial crisis respectively impacted industrial TFP growth positively and negatively. The result of PSTR model indicated that industrial TFP growth under environmental regulation had a significant heterogeneity (He et al. 2011). The fourth, combining with the directional distance function and inter-temporal DEA, the paper gave the empirical analysis results of Chinese provincial industries as following: if not considering environmental pollution, it would over-estimate the change of TFP and confound the contributions of technology and technical efficiency (Yang & Long 2012). In agriculture, the main research conclusions are as follows: Firstly, with the Malmquist-Luenberger productivity index method based on the directional distance function (DDF), the paper evaluated the agricultural non-point source pollution (NSP) of each province in China, empirically analyzed the agricultural TFP growth and its sources under environmental pollution in China from 1978 to 2008, and embraced the agricultural growth resource conservation and environmental protection into a unified framework. The study showed that under the environmental restrictions, the agricultural TFP growth as well as environmental technical efficiency (ETE) slightly increased mainly because of the frontier technological progress. And the dynamic tendency of agricultural TFP growth can be classified into six phases from 1978 to 2008, giving overall consideration of resource conservation, environmental protection and agricultural growth, the differences among regional TFP growth and its patterns were great (Li et al. 2011). Secondly, by the unit investigation and evaluation method, the paper calculated the agricultural non-point source pollution and made the bad output of the processing involving into the model of agricultural TFP. It also employed the Malmquist-Luenberger productivity index method to analyse the growth of agricultural TFP of 29 provinces under environmental regulations in China from 1993 to 2010. The study showed that the agricultural TFP under environmental regulations gets improved to some extent, and it was mainly driven by the agricultural technological progress. However, the agricultural technology efficiency has decreased in each region of China (Han & Zhao 2013). Thirdly, by the Malmquist-Luenberger index, the paper estimated agricultural total factor productivity accounting for water resource and agricultural non-point source pollution under environmental and resource restriction in China from 1998 to 2009. The research showed that the agricultural TFP which considered the restriction, was much lower than that without considering environmental and resource constraints. Also, the agricultural economy of China was proved to be extensive growth pattern at the cost of serious ecological environment destruction and huge resource consumption (Pan & Ying 2013).

DATA INTERPRETATION AND RESEARCH METHODS

Data Interpretation

This paper adopts the data of 30 regions in China from 2001 to 2011. The input index includes capital deposit and labour force, and the output index includes GDP and SO_2. The calculation of capital deposit is by the perpetual inventory method. Equation for perpetual inventory method was $K_{it} = K_{it-1}(1-\delta) + I_{it} / P_{it}$, where δ implies depreciation factor, which values 10%. The initial capital deposit can be calculated by making the gross investment in fixed asset divided by 10% in 2000, and converting the price index of investment in fixed asset of each province into constant price (Young 2003). The labour force is the number of regional employees and GDP data are converted into constant price. For bad output, CO_2, SO_2, COD, wastewater charge and so on are currently common index. Due to the restriction of data acquisition, this paper regards the emission of SO_2 as bad output (Chen et al. 2014).

Research Methods

The mathematical expression of environmental

production technology: During the regional economy development, it is inevitable to produce some byproducts, such as waste water and gas called bad output or undesirable output when the good output is increased. In order to achieve a coordinated development of resource, environment, and economy, the resource and environment factors need to be involved in the production function to build a production possibility set, which is environmental technology, including some good output like GDP as well as bad output like environmental pollution. Supposing a city is a decision making unit, and each city employs N input $X = (x_1, x_2, \cdots, x_N) \in R_+^N$, makes M good output $Y = (y_1, y_2, \cdots, y_N) \in R_+^M$, and I bad output $U = (u_1, u_2, \cdots, u_N) \in R_+^I$, so the production possibility set of environmental technology is as following:

$$T = [(x, y, u) : (y, u \in P(x), x \in R_+^N)] \qquad ...(1)$$

The production possibility set $p(x)$ is a bounded closed set, and it has following features:

First, the jointly weak disposability of good output and bad output:

If $(y, u) \in p(x)$, and $0 \le \theta \le 1$, so $(\theta y, \theta u) \in p(x)$

It shows that in some level of input, the good output will decrease accordingly if the bad output decreases.

Second, the strong disposability of input and good output:

If $x' \le x$, so $p(x') \subseteq p(x)$; if $(y, u) \in p(x)$ and

$y' \le y$, so $(y', u) \in p(x)$. It implies that good output is discretionary while bad output remains unchanged.

Third, the null-jointness of good output and bad output:

If, and, so. It shows that it is unavoidable to produce bad output while the good output is produced. According to the scholars' research, it still requires two conditions to satisfy the null-jointness:

$$\sum_{i=1}^{K} u_{ki} \succ 0, \; i = 1, \cdots, I \qquad ...(2)$$

$$\sum_{i=1}^{I} u_{ki} \succ 0, \; k = 1, \cdots, K \qquad ...(3)$$

Equation (2) implies that at least one production unit produces one bad output; equation (3) implies that each production unit produces at least one bad output.

Directional distance function: In order to realize the increase of good output and the decrease of bad output during the process of regional economy growing, this paper employs directional distance function. The directional distance function represents that the possibility of bad output decreases proportionately while good output increases with desired direction g = (g_y, - g_b), input *x* and production possibility set *p(x)*. It is defined as:

$$\overrightarrow{D_0^t}(x^t, y^t, u^t; g_y, -g_u) = \sup[\beta : (y^t + \beta g_y, u^t - \beta g_u) \in p^t(x^t)] \qquad ...(4)$$

Equation (4), (y^1, u^1) comparing with production frontier, which is the directional distance function in *t* period $g = (g_y, - g_u)$ is the direction factor. In fact, the output distance function raised by Shephard is a special situation in distance function. The relation between the two can be expressed as:

$$\overrightarrow{D_0}(x^t, y^t, u^t; g^t) = (1 / D^t(x^t, y^t, u^t)) - 1 \qquad ...(5)$$

If good output and bad outputs are equally treated to increase or decrease by the same proportion, the direction vector is neutral $g = (y, -u)$. The directional distance function of production unit $k'(x_k^t, y_k^t, u_k^t)$ in *t* period can be solved by converting data envelopment analysis to linear programming.

$$\overrightarrow{D_0^t}(x_{k'}^t, y_{k'}^t, u_{k'}^t; y_{k'}^t, -u_{k'}^t) = \max \beta$$

$$\text{s.t. } \sum_{k=1}^{K} z_k^t y_{km}^t \ge (1 + \beta) y_{k'm}^t, \; m = 1, \cdots, M$$

$$\sum_{k=1}^{K} z_k^t u_{ki}^t = (1 - \beta) u_{k'i}^t, \; i = 1, \cdots, I$$

$$\sum_{k=1}^{K} z_k^t x_{kn}^t \le x_{k'n}^t, \; n = 1, \cdots, N; \; z_k^t \ge 0, \; k = 1, \cdots, K \qquad ...(6)$$

ML productivity index: According to directional distance function and Chung et al. (1997) research, the ML productivity index based on output can be calculated via four directional distance function:

$$ML_t^{t+1} = \left[\frac{1 + \overrightarrow{D_0^t}(x^t, y^t, u^t; y^t, -u^t)}{1 + \overrightarrow{D_0^t}(x^{t+1}, y^{t+1}, u^{t+1}; y^{t+1}, -u^{t+1})} \times \frac{1 + \overrightarrow{D_0^{t+1}}(x^t, y^t, u^t; y^t, -u^t)}{1 + \overrightarrow{D_0^{t+1}}(x^{t+1}, y^{t+1}, u^{t+1}; y^{t+1}, -u^{t+1})} \right]^{1/2} \qquad ...(7)$$

If ML index is greater than 1, it implies that the productivity from *t* period to *t*+1 period rises. On the contrary, it declines. Further, ML index can be decomposed into efficiency change index (MLEFFCH) and technology progress index (MLTECH):

$$ML_t^{t+1} = MLEFFCH_t^{t+1} \times MLTECH_t^{t+1} \qquad ...(8)$$

Table 1: The TFP index and components in each region from 2001 to 2011.

Region	Take account of environmental factor			Take no account of environmental factor		
	ML	MLEFFCH	MLTECH	M	EFFCH	TECH
Beijing	1.086	1.000	1.086	1.044	0.979	1.066
Tianjin	1.045	0.977	1.069	1.043	0.980	1.064
Hebei	1.026	0.978	1.049	1.024	0.977	1.048
Shanxi	0.961	1.000	0.961	1.012	0.981	1.032
Neimenggu	0.972	0.949	1.024	1.011	0.960	1.053
Liaoning	1.108	1.000	1.108	1.048	0.982	1.067
Jilin	1.010	0.975	1.036	1.009	0.962	1.048
Heilongjiang	1.005	0.994	1.012	1.023	0.990	1.034
Shanghai	1.088	1.000	1.088	1.082	1.000	1.082
Jiangsu	1.134	1.007	1.127	1.105	1.007	1.098
Zhejiang	1.060	0.991	1.069	1.085	0.993	1.093
Anhui	1.023	0.970	1.055	0.990	0.956	1.035
Fujian	1.021	0.987	1.034	1.030	0.986	1.045
Jiangxi	1.000	0.954	1.048	0.975	0.948	1.028
Shandong	1.057	1.000	1.057	1.080	0.991	1.089
Henan	1.020	0.965	1.058	1.000	0.963	1.038
Hubei	1.036	0.995	1.041	1.033	0.998	1.035
Hunan	0.999	0.988	1.011	1.020	0.987	1.034
Guangdong	1.092	1.000	1.092	1.087	1.000	1.087
Guangxi	0.912	0.957	0.953	0.999	0.973	1.027
Hainan	0.992	0.959	1.035	0.976	0.947	1.031
Chongqing	1.028	0.990	1.039	1.027	0.985	1.043
Sichuan	1.018	0.987	1.031	1.023	0.987	1.036
Guizhou	1.049	1.029	1.020	1.010	0.984	1.027
Yunnan	1.019	0.980	1.040	1.006	0.980	1.027
Shanxi	1.023	0.993	1.029	1.017	0.987	1.030
Gansu	1.008	0.992	1.016	1.019	0.993	1.027
Qinghai	0.988	0.971	1.017	1.046	1.007	1.040
Ningxia	1.003	0.996	1.007	1.026	0.981	1.046
Xinjiang	1.010	0.990	1.020	1.033	0.982	1.052
Eastern China	1.064	0.991	1.074	1.055	0.986	1.070
Central China	1.007	0.980	1.028	1.008	0.973	1.036
Western China	1.003	0.985	1.018	1.020	0.984	1.037
Average	1.026	0.986	1.041	1.029	0.982	1.049

$$MLEFFCH_t^{t+1} = \frac{1+\overrightarrow{D_0^t}(x^t, y^t, u^t; y^t, -u^t)}{1+\overrightarrow{D_0^{t+1}}(x^{t+1}, y^{t+1}, u^{t+1}; y^{t+1}, -u^{t+1})} \quad ...(9)$$

$$MLTECH_t^{t+1} = \sqrt{\frac{1+\overrightarrow{D_0^{t+1}}(x^t, y^t, u^t; y^t, -u^t)}{1+\overrightarrow{D_0^t}(x^{t+1}, y^{t+1}, u^{t+1}; y^{t+1}, -u^t)} \cdot \times \frac{1+\overrightarrow{D_0^{t+1}}(x^{t+1}, y^{t+1}, u^{t+1}; y^{t+1}, -u^{t+1})}{1+\overrightarrow{D_0^t}(x^{t+1}, y^{t+1}, u^{t+1}; y^{t+1}, -u^{t+1})}} \quad ...(10)$$

If the efficiency change index (MLEFFCH) is greater than 1, it implies that the decision making unit approaches to the production frontier, and the efficiency rises. Conversely, the decision making unit gets far away from the production frontier. In the same way, the technology index (MLTECH) is greater than that implies decision making unit production technology is in progress, otherwise, it is in recession.

RESULT ANALYSIS

According to the above methods, by the data of 30 regions in China from 2001 to 2011, the results are given in Table 1 and Fig. 1. Table 1 shows the total factor productivity index (Malmquist index), technical progress (tech) and the technical efficiency (effch) under the two circumstances of considering environmental factors and not. Fig. 1 shows the total factor productivity, technical progress and technical efficiency under environmental factors in different years.

1. Generally, the TFP in different regions of China keeps ever-growing. From 2001 to 2011, its annual average rate under environment restriction grows to 2.6%, in which, technical progress annually grows by 4.1%, while technical efficiency declined by 1.4% annually. It implies that technical progress is a major factor influencing the TFP growth in different regions of China.
2. From the time trend, the growth rate of TFP in all re-

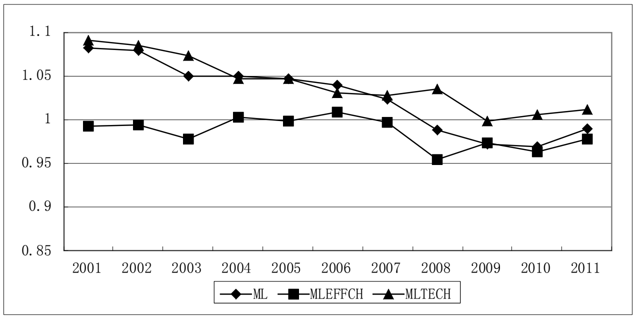

Fig. 1: The TFP index and components under environmental pollution from 2001 to 2011.

gions of China is gradually descending. From 2001 to 2007, the annual TFP growth rate in China under environmental constraints gradually declined from 8.2% to 2.4%. Also, since 2008, TFP has decreased obviously, by 1.2% in 2008, 2.8% in 2009, and 3.1% in 2011. From its decomposition, the technical progress is the major factor of decreasing TFP. Since the new century, China is constantly absorbing new technology from developed countries with the opening-up policy which has narrowed the gap with the developed countries, and at the same time, Chinese enterprises, who used to introduce new technology and be lack of independent innovation capacity, made the technical progress down, so the TFP gradually declines in China. Financial crisis after 2008 is another factor for the decreasing of TFP in China.

3. From the point of regional differences, the annual growth rate of TFP in each region of China is a bit different. From the ranking of TFP, the top five successively are Jiangsu(13.4%), Liaoning(10.8%), Guangdong(9.2%), Shanghai(8.8%) and Beijing(8.6%). The last five are Guangxi(-8.8%), Shanxi(-3.9%), Neimenggu(-2.8%), Qinghai(-1.2%) and Hainan(-0.8%).
4. From the three regions, it shows a gradual decrease from east to west. Considering environmental factor during 2001 to 2011, the difference of annual average TFP growth in three regions of China is extra great. The increase is by 6.4% in east, only 0.7% in the central China, and the lowest 0.3% in west.
5. The comparison of considering the environmental factor or not: From the result, China's TFP declines when the environmental factor is taken into consideration. It indicates that the TFP calculated with traditional method is overestimated. According to the comparison result of the three regions, the annual average growth rate of TFP with environmental factor is higher than that of without environmental factor. It also shows that a win-win of environment and economy development situation in east of China.

CONCLUSIONS

When considering the economic impact of environmental pollution, economic efficiency will be significantly reduced. While the traditional TFP measurement method does not consider the environment pollution, and it is wrongly recognized the productivity. This paper adopts the directional distance function method raised by Chung (1997) to calculate and compare the TFP considering the environmental pollution in 30 regions of China from 2000 to 2011. The study indicates that the TFP of each region had been everincreasing, but the growth rate has been decreasing; the TFP has been in recession situation since the financial crisis in 2008. According to regional differences, the average annual growth rate of TFP in east is much higher than that of the central and west regions; considering the environmental pollution, the average TFP in each region falls slightly; comparing with the TFP without environment factor, the TFP in west region falls sharper; while it appears double win of environment and economy development in the east region.

Now, China has entered the later stage of industrialization. According to international experience, heavy and chemical industry in this period develops so fast which will aggravate the energy consumption and environment pollution. Hence, there will be higher emission reduction pressure in the sustainable development in China for the next 10-20 years. It is a major issue for the government to think about further idea that how to achieve the coordinated development of environment and economy.

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