Measurement of Environmental Sustainability in China: Based on Global Malmquist-Luenberger Model

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Abstract. Environmental sustainability is related to the sustainable development of economy and society. The green total factor productivity (GTFP) is very suitable to measure environmental sustainability. Based on the panel data of 30 regions in China from 2010 to 2019, this paper uses super-SBM and Global Malmquist-Luenberger (GML) method to evaluate GTFP of China. Results show that the overall level of GTFP in China is not high, but with a trend of improvement. The improvement of GTFP is mainly driven by technological progress. And the spatial distribution of GTFP is in accordance with the "East Middle and West" gradient distribution. Government should optimize the industrial layout, strengthen environmental regulation, and promote technological innovation and management level to achieve environmental sustainability.

Keywords: environmental sustainability · green total factor productivity · global Malmquist-Luenberger

1 Introduction

Since the reform and opening up, China has made great achievements in economic development. However, the rapid growth of China's economy mainly depends on large-scale resource investment. The rough economic growth model not only consumes a lot of energy, but also brings serious ecological and environmental problems. Whether from the perspective of resource constraints or environmental constraints, the development of China's resources, environment and economy is not coordinated. This requires us to establish a green and circular economic system and improve total factor productivity (TFP), that is, in the process of economic development, we should minimize investment and reduce environmental pollution while improving economic benefits (Shi and Li, 2019 [1]), so as to ensure environmental sustainability. Compared with the traditional concept of TFP, green total factor productivity (GTFP) with environmental pollution as the reverse constraint is more suitable for the requirements of environmental sustainability (Liu and Xin, 2019 [2]; Ben et al. 2019 [3]). Therefore, it is of great significance for

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China's environmental sustainable development to measure GTFP and study its imbalance and evolution characteristics. This paper analyzes the China's GTFP, which is of great significance to sustainable development of environment.

The existing research on GTFP mainly focuses on two aspects. One is the selection of indicators. Tao et al. (2017) chose "three industrial wastes" as the unexpected output to study the situation of GTFP [4]. Xu et al. (2019) measured China's agricultural GTFP and selected carbon emissions as negative output [5]. Lin et al. (2013) took carbon emissions as negative output, measured the GTFP of 70 countries [6]. In terms of input index selection, most of the above studies choose labor input and capital input. The second is the selection of research samples. Chen (2010) calculated the GTFP of 38 industry [7]. Shi and Li (2019) used the meta-frontier Malmquist Luenberger index to measure the GTFP of manufacturing industry, and found that the GTFP of China's manufacturing industry showed an increasing trend, which was mainly due to technological progress [1]. Li and Wang (2021) measured the GTFP of China's logistics industry [8]. Li et al. (2020) analyze the GTFP of China's tourism industry, and found that there are obvious differences in the spatial distribution of China's tourism industry, and the performance of GTFP in the eastern region is better than that in the central and western regions [9]. Xie et al. (2021) measures the GTFP of 27 EU Member States, and studies the relationship between the transformation of energy consumption and GTFP. It is found that although the energy consumption transformation is green, it has no positive impact on GTFP [10].

To sum up, there are few systematic studies on GTFP in all provinces of China, and the input index is relatively thin. Therefore, this paper constructs a GML based on super-SBM model to measure China's provincial GTFP. The possible innovations are as follows: (1) Energy input is included in the index system, which can reflect the comprehensive utilization of resources and further reflect environmental sustainability. (2) GML index model is constructed based on super efficiency model, which can effectively solve the problem of relaxation in GTFP estimation process, and compare effective DMUs. (3) Explore the regional heterogeneity of GTFP, which is conducive to in-depth analysis of the differences of GTFP. The next structure of this paper is: the second chapter is the method and model construction, the third chapter is the empirical analysis, and the fourth chapter is the discussion and suggestions.

2 Method and Model Construction

2.1 Super-SBM

Tone (2002) proposed super-SBM model based on SBM model [11], which not only has the non-radial and non-angular characteristics of SBM model, but also avoids the deviation caused by angle and radial. At the same time, and can also solve the scheduling problem of multiple effective DMUs. The super-SBM model with unexpected output is as follows:

$$min\Theta = \frac{\frac{1}{m}\sum_{i=1}^{m}\frac{\overline{x}_i}{x_{i0}}}{\frac{1}{s_1+s_2}(\sum_{r=1}^{s_1}\frac{\overline{y^g}_r}{{y^g}_{r0}} + \sum_{j=1}^{s_2}\frac{\overline{y^b}_j}{{y^b}_{j0}})} \tag{1}$$

S.t

$$X \geq \sum_{k=1,\neq 0}^{n} x_k\lambda_k,\ Y^g \leq \sum_{k=1,\neq 0}^{n} {y^g}_k\lambda_k,\ Y^b \geq \sum_{k=1,\neq 0}^{n} {y^b}_k\lambda_k$$

$$X \geq x_0,\ \mathrm{Y} \leq y_0,\ \mathrm{B} \geq b_0$$

$$x_0 = X\lambda + s^-,\ y_0 = Y\lambda - s^y,\ b_0 = B\lambda - s^b$$

where X is input, Y^g is expected output, Y^b is unexpected output, s^- is input relaxation, s^y is expected output relaxation, and s^b is unexpected output relaxation. m, s_1 and s_2 represents the number of input indicators, expected output indicators and unexpected output indicators, respectively.

2.2 GML Model

The efficiency calculated by traditional DEA is current and cannot reflect the dynamic change. This paper selects the GML index model (Oh, 2010[12]), which is global reference, has the characteristics of cross period comparison, and there will not be no feasible solution. GML model is as follows:

$$GML^{t,t+1} = \frac{1 + D_G^T(x^t, y^t, b^t)}{1 + D_G^T(x^{t+1}, y^{t+1}, b^{t+1})} \tag{2}$$

where, $D_G^T(x^t, y^t, b^t)$ represents the global directional distance function. The value of GML index greater than 1 indicates GTFP growth. GML can be divided into technical efficiency change index (EC) and technical progress change index (TC), as Eq. (3).

$$GML^{t,t+1} = EC^{t,t+1} * TC^{t,t+1} \tag{3}$$

where, TC does not directly compare the front surfaces of two adjacent periods, but measure their distance from the common front respectively, and judge whether the technology has been improved by whether the distance between the front surface of adjacent periods and the common front has been reduced.

2.3 Variable Description and Data

Input indicators: labor input, capital input and energy input. Labor input is the total number of employment in each region. The capital investment is calculated by the perpetual inventory method, and the calculation formula is $K_{it} = (1 - \delta)K_{i,t-1} + I_{it}$, , where K is the capital stock and I is the fixed asset investment of the whole society, δ is set to 9.6% (Zhang et al., 2004 [13]). The total energy consumption of each region (10000 tons of standard coal) is taken as the proxy variable of energy input.

Expected output index: real GDP of each region.

Unexpected output index: referring to the research of Hou et al. (2020) [14], this paper selects sulfur dioxide emission as the unexpected output.

This paper selects 30 provinces in China as samples. According to the eastern, central and western regions, this paper divides the research area into three parts. In the East, there are Anhui, Hebei, Jiangsu, Liaoning, Shandong, Tianjin, Fujian, Guangdong, Shanghai, Zhejiang, Guangxi and Hainan. In the central region, there are Jilin, Inner Mongolia, Shanxi, Heilongjiang, Hubei, Hunan, Anhui, Henan and Jiangxi. And there are Gansu, Guizhou, Ningxia, Qinghai, Shaanxi, Sichuan, Xinjiang, Yunnan and Chongqing in West. The data of labor input comes from China Population and Employment Statistical Yearbook, the data of energy input comes from China Energy Statistical Yearbook, and the rest comes from China Statistical Yearbook.

3 Results and Discussion

3.1 Temporal and Spatial Characteristics of GTFP

As shown in Fig. 1, there is little change in China's GTFP from 2011 to 2019, and remains fluctuating around 1. On the whole, from 2011 to 2019, GTFP has improved, but it is still not high, with an average value of 0.989. Observing the trend of GTFP and its decomposition index, we can find that the trend of GTFP is consistent with that of TC. This means that the improvement of GTFP mainly benefits from the progress of technology. Specifically, from 2012 to 2013, GTFP decreased most sharply, while EC increased significantly. However, the sharp rise of EC cannot offset the negative effect brought by technology retrogression. From 2013 to 2017, China's GTFP generally maintained an upward trend, which was mainly due to the contribution of technological progress. During this period, the management level declined. On the whole, GTFP is limited by both technical progress and technical efficiency. In the future development, we should pay attention to technological innovation and management level.

Next is the spatial distribution of GTFP. As shown in Fig. 2, it can be seen that the spatial distribution of GTFP in China shows the characteristics of spatial agglomeration, and the north is mainly low efficiency and low efficiency. The south is mainly concentrated with medium and high efficiency. In the Middle East, the level of GTFP is not high. On the whole, the GTFP in China is low in the north and high in the south. It can be seen from the Table 1. Beijing's GTFP ranks first in the country. There are also Shanghai, Chongqing, Henan, Liaoning, etc. ahead of GTFP. Most of these provinces have

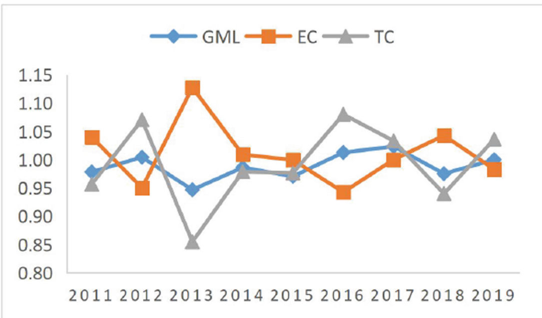

Fig. 1. Time-trend of GTFP and decomposition

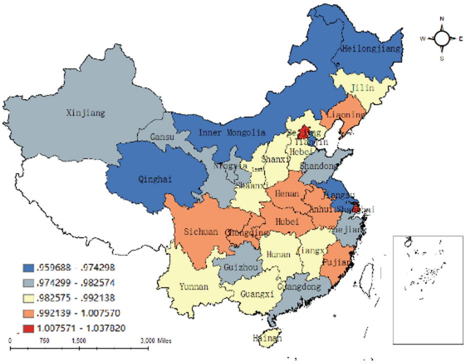

Fig. 2. Spatial characteristics of GTFP

Table 1. Top five and bottom five provinces of gtfp

Top 5											Mean
Beijng	1.014	0.924	0.994	1.112	1.043	1.179	0.74	1.065	1.269	1.038	1.038
Shanghai	1	0.735	1.079	0.945	0.939	1.011	1.404	0.735	1.36	1.023	1.023
Chongqing	1.025	0.944	1.048	0.965	1.039	0.993	1.2	0.811	1.044	1.008	1.008
Henan	1.031	0.96	1.008	0.963	0.986	1.03	0.88	1.12	1.029	1.001	1.001
Liaoning	0.84	1.547	0.634	1	0.968	0.975	1.018	1.081	0.925	0.999	0.999
Bottom 5											Mean
Qinghai	0.834	1.133	0.842	0.993	0.944	0.988	0.937	1.036	0.929	0.96	0.96
Jiangsu	1	1	0.679	1.004	0.973	1.067	0.947	1.047	0.959	0.964	0.964
Heilongjiang	0.88	1.25	0.816	1.029	0.913	1.074	0.911	1.041	0.852	0.974	0.974
Inner Mongolia	0.862	1.274	0.733	1.004	0.963	1.012	0.927	1.068	0.925	0.974	0.974
Guizhou	1.027	0.926	1.008	0.996	1	0.976	0.919	0.979	0.982	0.979	0.979

a high level of economic development. Economy can promote the development of science and technology, which is conducive to their treatment of environmental pollution. The last five provinces are Qinghai, Jiangsu, Heilongjiang, Inner Mongolia, Guizhou. Except Jiangsu, these provinces are economically underdeveloped areas. According to the environmental Kuznets curve hypothesis, with the improvement of economic development level, the degree of environmental pollution will show an upward trend. After an "inflection point", with the further improvement of the level of economic development, environmental pollution will show a downward trend year by year. At present, Qinghai, Heilongjiang, Inner Mongolia and other provinces are still in the stage of pursuing economic growth in a rough development mode, often at the expense of the environment, thus inhibiting the development of GTFP.

Table 2. GTFP in east, central and west regions

	2011	2012	2013	2014	2015	2016	2017	2018	2019	Mean
East region	0.987	0.963	0.955	0.999	0.975	1.027	1.035	0.959	1.026	0.992
Central region	0.951	1.104	0.895	0.991	0.968	1.028	0.971	1.022	0.962	0.988
West region	0.994	0.959	0.988	0.964	0.967	0.977	1.06	0.95	1.003	0.985

3.2 Regional Heterogeneity of GTFP

Due to the difference of economic level and industrial structure, this paper divides the region from the eastern, central and western geographical characteristics to explore the regional heterogeneity of GTFP. From Table 2, it can be seen can that the variation of GTFP presents the spatial characteristics of gradient distribution in the East, the West and the East. The GML index of Eastern, Western and central China is 0.992, 0.988 and 0.985 respectively. That is, the GTFP of the eastern, central and western regions are not effective. On the whole, the performance of GTFP in the eastern area is better than that of the middle and western area, and GTFP in the middle area is better than that in the western area. The eastern region has played a "leader" role in green development. In the early stage of economic development, in order to pursue economic growth, the rough development mode is often adopted to pursue economic growth at the expense of the environment. The economic development of the eastern region has always been the best, which explains that the GTFP in the eastern region was low from 2011 to 2012 and showed an upward trend from 2012 to 2017. As far as 2019 is concerned, GTFP in the eastern region is also performs best. The development of the central and western regions is mainly in pursuit of economic growth. Many regions focus on the primary and secondary industries in the industrial structure, and ignore energy conservation and emission reduction while vigorously developing the economy. Therefore, it is very necessary to realize the optimization and reorganization of industrial structure.

4 Conclusion

At present, both resources and environment have gradually become the constraints of economic development.

It is particularly important to pay attention to environmental sustainability and realize green development. Based on the panel data of China from 2010 to 2019, this paper studies the GTFP including energy input and environmental pollution and its driving factors. The conclusions are as follows: Firstly, during 2011–2019, China's GTFP decreased by 1.1% on average. And the decline is mainly due to the technology retrogression. Secondly, from the perspective of provinces, Beijing, Shanghai, Chongqing, Henan and so on have the best GTFP performance. Most of them are economically developed provinces, and their GTFP growth is mainly driven by technological progress and technical efficiency. Finally, in terms of regions, China's GTFP presents a gradient distribution in the eastern, central and western regions. The eastern region exists as a "leader" in the development of ecological economy, while the central and western regions play a "catcher".

To sum up, improving GTFP can from the following aspects: First, starting from two aspects of technology and management ability, producers should realize the progress of technology and the improvement of management level at the same time, so as to improve GTFP and realize environmental sustainable development. Second, the eastern region should give full play to its regional advantages, further introduce advanced technology and improve the level of production management. The central and western regions should actively carry out regional exchanges, actively learn from the eastern region, and let the eastern region play a leading role in radiation. Third, the industrial structure should be optimized, especially in the central and western regions. Government should guide the allocation of resources to enterprises and industries with high production efficiency and good environmental benefits, reducing environmental pollution emissions while improving economic efficiency. Last, to strengthen environmental regulation, especially in the central and western regions, the government should actively guide producers to change the rough economic growth mode, pay attention to the sustainable development of environment, to realize the balance between economic growth and environmental benefits.

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