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GREEN TOTAL FACTOR PRODUCTIVITY MEASUREMENT AND GREEN TECHNOLOGY CAPABILITY SPILLOVER IN WESTERN REGION OF CHINA

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Abstract

In the current situation of increasingly urgent environmental problems, how to improve the capacity of green technology through spillover means based on the existing green knowledge and technology stock in the western region of China, so that the economy of the western region can move towards a low-carbon, coordinated and sustainable direction in a short period of time is worthy of our deep discussion. This study measured the carbon dioxide emissions and calculated the green total factor productivity (TFP), green technology progress and technology efficiency in Western region of China. The results are as follows: first, the highest CO_2 emissions in western region of China is Inner Mongolia, the CO_2 emissions of Shanxi, Xinjiang, Sichuan and Guizhou province are in a downward trend, the CO_2 emissions of Ningxia, Guangxi, Chongqing, Yunnan, Gansu and Qinghai province are relatively stable. Second, the results of TFP without considering the non-expected input and output are higher than the results of green TFP, while the efficiency change calculated by Malmquist productivity index is significantly different from that calculated by SBM, and the efficiency calculated by Malmquist productivity index is basically 0.2-0.3 higher than that calculated by SBM. Third, the level of green technology efficiency scored differently in west region of China, ranking high to low was Qinghai, Ningxia, Xinjiang, Inner Mongolia, Shaanxi, Guizhou, Chongqing, Guangxi, Sichuan, Gansu and Yunnan province.

Keywords: green technology capability, green TFP, Malmquist productivity index, SBM model, western region of China

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1. Introduction

Global environmental problems have become more and more noticeable, such as climate change, energy security and resource scarcity with the expansion of economic activities for a long time. Global CO_2 emission and other gases emissions are increasing, and the CO_2 emissions of different countries are also quite different. Global climate and environmental change have posed severe challenges to human economic and social development. Low carbon or even zero carbon has become the inevitable trend of the future development of the world economy. Therefore, climate change mitigation has become one of the most important policy goals in the world, and more and more policy areas and regions have reached consensus (Alameddine et al., 2018; Andersen, 2010; Košir et al., 2018; Oltra and Jean, 2007).

In recent years, the relationship between innovation and environment has attracted more and more attention. Innovation is a new method to solve environmental problems. Green innovation is regarded as an important means to solve national ecological problems without reducing economic activities that cause ecological problems (Beise and Rennings, 2003; Liang et al., 2019; Oltra and Saint, 2009; Rennings, 2000). Therefore, the concept of green innovation is closely related to the green growth policy (Kemp, 2011), which indicates the increasing synergy between environment and innovation policy.

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Governments are increasingly trying to actively support the development and adoption of green technologies. Green technology innovation is seen as a core driver of economic development and even an important means of "green recovery" in the current severe global economic downturn (Gorantla et al., 2018; Kammerer, 2009; Kapoor and Lee, 2013; Lanoie et al., 2011; O'Hare and Aloone, 2014; Oksanen and Hautamki, 2014; Yakobu et al., 2019).

Green technology can run through the whole production process of the enterprise. No matter what kind of green innovation technology, it can play a role in protecting or improving the ecological environment. The western region of China is in the rising stage of development which will inevitably consume resources and discharge various pollutants at present. Therefore, the emergence of green innovative technology is of great significance to the development of the western China and the protection of the ecological environment.

At present, the green technology of the western region of China grows slowly and the foundation is weak, so the gap with the eastern, central and other regions is still very big. So the western region of China needs to shorten the gap quickly and improve the ability of green technology as soon as possible through the overflow means based on the existing stock of green knowledge and technology so that the economy of the western region can move towards a low-carbon, coordinated and sustainable direction in a short period of time.

Therefore, it is important to study the spillover of green technology capability. This study used the method of Malmquist productivity index and SBM model to calculate and compare the green total factor productivity (TFP), green technology progress and technology efficiency in Western China by introducing the data of gross domestic product (GDP), capital stock, labor force, CO_2 emissions and energy consumption.

The article starts with introducing the material and methods including the research scope, selection of the research indexes and data source, research model. In section 3, we concentrate on the results and discussion including the measurement and geographical distribution of carbon emissions in western China, and analysis of calculation results of green TFP and results of time series measurement by SBM. Finally, section 4 is devoted to summarize the research results and point out the limitation as well as future reserach of this paper.

2. Material and methods

2.1. Research scope

The calculation of green TFP in this paper was based on panel data covering 11 provinces in the western region of China, and the data of Tibet autonomous region was still processed in the mode of elimination. The sample observation interval was set as 2007-2016 according to the availability of the data.

2.2. Selection of the research indexes and data source

This study selected the annual number of employees (labor force), capital stock and terminal energy consumption as production input indicators, and selected GDP of each province as the expected output, while the industrial CO_2 emissions represented the non-expected output in this paper. Data on industrial CO_2 emissions of the provinces were estimated from industrial energy consumption. The data are from *"China energy statistics yearbook*, *China statistics yearbook* and *China science and technology statistics yearbook"*.

(1) *Labor force.* Owning to the lack of statistical indicators that can comprehensively include labor time and labor efficiency in the relevant statistical yearbook, this study used the number of industrial employees to estimate the input of labor force considering the availability and comparability of the data.

(2) *Capital stock.* The capital stock was estimated by using the PIM method commonly used by scholars. This study took the year 2000 as the base year and calculated the capital stock at constant prices (Ding, 2015).

$$K_{it} = (1-\delta)K_{it-1} + I_{it}\frac{I_{it}}{P_{it}}(t = 1,2,...,n) \tag{1}$$

Among them, K_{it}, P_{it}, I_{it} represents capital stock of province i in year t, fixed asset price index and fixed asset investment in that year respectively. K_{it-1} represents the capital stock in year t-1. δ represents the depreciation rate. According to the research results of Zhang and Shi (2003), this study set the capital depreciation rate as 9.6%.

(3) *Energy consumption.* The energy consumption was divided into nine categories: coal, diesel, gasoline, kerosene, natural gas, crude oil, fuel oil, electricity and coke. Their respective converted standard coal coefficient and carbon emission coefficient refer to the data published by China statistical yearbook and IPCC respectively (Ding, 2015).

(4) *GDP.* This study selected GDP as the proxy indicator of expected output, and used the price deflator to calculate the real GDP.

(5) *CO_2 emissions.* This study used the balance algorithm to calculate carbon emissions in western region of China, and the main calculation formula is given by Eq. (2) (Ding, 2015):

$$c_{it} = \sum_{j}^{9} E_{ijt}\delta_j \tag{2}$$

Among them, C_{it} is the total CO_2 emissions in the t year of province i; E_{ijt} is the total energy consumption of the j energy in the t year in province i; δ_j is the carbon emission coefficient of the j energy source.

(6) *Solid waste emissions.* The data of the solid waste emissions were derived from *China's environmental statistics yearbook* from 2007 to 2016 years (Tables 1 and 2).

Table 1. Reference coefficients of various energy discount standard coal (kg standard coal)

Energy varieties	***Standard coal coefficient***	***Energy varieties***	***Standard coal coefficient***	***Energy varieties***	***Standard coal coefficient***
Coal (kg)	0.7143	Kerosene (kg)	1.4714	Coke (kg)	0.9714
Diesel (kg)	1.4571	Crude (kg)	1.4286	Electricity (kWh)	0.1229
Gasoline (kg)	1.4714	Fuel oil (kg)	1.4286	Natural gas (m^3)	1.33

Source: China Statistical Yearbook, 2013

Table 2. Carbon emission coefficient of various energy sources (t carbon/tce)

Energy varieties	***Standard coal coefficient***	***Energy varieties***	***Standard coal coefficient***	***Energy varieties***	***Standard coal coefficient***
Coal	0.7476	Kerosene	0.3416	Coke	0.1128
Diesel	0.5913	Crude	0.5854	Electricity	2.2132
Gasoline	0.5532	Fuel oil	0.6176	Natural gas	0.4479

Source: Intergovernmental Panel on Climate Change (2007)

2.3. Research model

2.3.1. DEA-SBM model

The DEA-SBM model assumes that there are *n* decision making units, which include m input variables $X \in R^m$, *p* expected output variables $Y^g \in R^p$ and *q* non-expected output variables $Y^b \in R^q$ (Eqs. 3-5):

$$X = [x_1, x_2, \cdots x_n] \in R^{m \times n} (X > 0) \tag{3}$$

$$Y^g = [y_1^g, y_2^g, \cdots y_n^g] \in R^{p \times n} (Y^g > 0) \tag{4}$$

$$Y^b = [y_1^b, y_2^b, \cdots y_n^b] \in R^{q \times n} (Y^b > 0) \tag{5}$$

System production may be set as given by Eqs. (6-8) (Li et al., 2018):

$$P = \left\{ (x, y^g, y^b) \mid x \geq X\lambda, y^g \geq Y^g\lambda, y^b \geq Y^b\lambda, \lambda \geq 0 \right\} \tag{6}$$

$$\min \rho = \frac{1 - \frac{1}{m} \sum_{i=1}^{m} \frac{s_i^-}{x_{i0}}}{1 + \frac{1}{p+q} \left(\sum_{r=1}^{p} \frac{s_r^g}{s_{r0}^g} + \sum_{r=1}^{q} \frac{s_r^b}{s_{r0}^b} \right)} \tag{7}$$

$$s.t. \begin{cases} x_0 \\ y_0^g = Y^g\lambda + s^g \\ y_0^g = Y^g\lambda + s^g \\ s^- \geq 0, s^g \geq 0, s^b \geq 0, \lambda \geq 0 \end{cases} \tag{8}$$

In Eqs. (7, 8), *s* is the relaxation variable of input and output, *λ* is weight vector, the objective function *ρ* is ecological efficiency value and $\rho \in [0,1]$. For a specific evaluation unit, if and only if *ρ*=1, when $s^- = s^g = s^b = 0$, the decision unit is completely efficient; $\rho < 1$ indicates that the DUM has an efficiency loss, which can be improved by optimizing the input-output relationship.

2.3.2. Malmquist productivity index

Malmquist productivity index can be expressed by Eq. (9) (Lv and Chen, 2010):

$$M_0^t = D_0^t(x^{t+1}, y^{t+1}) \Big/ D_0^t(x^t, y^t) \tag{9}$$

Here, D_0^t is the output distance function at time *t*. The Malmquist productivity index measures the change of technical efficiency from time *t* to *t*+1 under the technical condition at time *t*. Similarly, the Malmquist productivity index can be defined for the change of technical efficiency at time *t*+1.

$$M_0^t = D_0^t(x^{t+1}, y^{t+1}) \Big/ D_0^{t+1}(x^t, y^t) \tag{10}$$

In Eq. (10):

$$D_0^t(x^t, y^t) = \inf\left\{\theta : (x^t, y^t/\theta) \in S^t\right\} = \left(\sup\left\{\theta : (x^t, \theta y^t) \in S^t\right\}\right)^{-1}$$

$$D_0^{t+1}(x^{t+1}, y^{t+1}) = \inf\left\{\theta : (x^{t+1}, y^{t+1}/\theta) \in S^{t+2}\right\} = \left(\sup\left\{\theta : (x^{t+1}, \theta y^{t+1}) \in S^{t+2}\right\}\right)^{-1}$$

S^t, S^{t+1} is the production technology at time *t*, *t+1*; x^t, $x^t + 1$ is the input time *t*, *t+1*; y^t, $y^t + 1$ is the output at time *t* and *t+1*. For $(x^t, y^t) \in s^t$, there exist $D_0^t(x^t, y^t) \leq 1 \cdot D_0^t(x^t, y^t) = 1$ is established if and only if (x^t, y^t) is at the forefront of production technology.

In order to avoid the errors that may be caused by the randomness of period selection, we used the geometric average of Malmquist productivity index calculated by the above two formulas to measure the productivity change from time *t* to *t*+1. If the index is greater than 1, it shows that total factor productivity increases from time *t* to *t*+1 which means that the level of comprehensive productivity increases. If the index is less than 1, it indicates that total factor productivity is decreasing. When a change ratio of the index is greater than 1, it shows that it is the root cause of the increase of productivity level (Eq. 11).

$$
\begin{aligned}
M_0\left(x^{t+1},y^{t+1},x^t,y^t\right) &= \left[\frac{D_0^t\left(x^{t+1},y^{t+1}\right)}{D_0^t\left(x^t,y^t\right)}\times\frac{D_0^{t+1}\left(x^{t+1},y^{t+1}\right)}{D_0^{t+1}\left(x^t,y^t\right)}\right]^{\frac{1}{2}} \\
&= \frac{D_0^{t+1}\left(x^{t+1},y^{t+1}\right)}{D_0^t\left(x^t,y^t\right)}\times\left[\frac{D_0^t\left(x^{t+1},y^{t+1}\right)}{D_0^{t+1}\left(x^{t+1},y^{t+1}\right)}\times\frac{D_0^t\left(x^t,y^t\right)}{D_0^{t+1}\left(x^t,y^t\right)}\right]^{\frac{1}{2}} \\
&= EFFCH\times TECH = PEFFCH\times SEFFCH\times TECH
\end{aligned}
\tag{11}
$$

Malmquist productivity index can be decomposed into efficiency change (EFFCH) and technological change (TECH) in general. Efficiency change (EFFCH) reflects the contribution degree of technical efficiency change to productivity, and the technological change (TECH) mainly reflects the contribution of the movement of production frontier to productivity change which indicates the degree of technological progress or innovation. If TECH>1, it means that the production technology has made some progress, and if TECH<1, it means that the production technology has made some retrogression. The efficiency change index can be decomposed into pure technical efficiency change index (PEFFCH) and scale efficiency change index (SEFFCH).

3. Results and discussion

3.1. Measurement and geographical distribution of carbon emissions in western China

In order to reflect the heterogeneity of different regions in western region of China, this study calculated the CO_2 emission and annual emission growth of each province in western region of China through the balance algorithm.

It can be seen from the Fig. 1 that the carbon emission of provinces in western region of China can be divided into three categories: first, Neimenggu, whose carbon emission far exceeds that of other provinces and becomes the largest CO_2 emissions. Second, the annual CO_2 emissions of Shaanxi, Xinjiang, Sichuan and Guizhou province are above 50 million tons, and the CO_2 emissions of Sichuan have been declining and its CO_2 emissions are below 50 million tons. CO_2 emissions in Shaanxi, Xinjiang and Guizhou have shown a significant upward trend in the past 10 years. Third, the CO_2 emissions of Ningxia, Guangxi, Chongqing, Yunnan, Gansu and Qinghai province are relatively stable without any significant increase or decrease, which may be closely related to the industrial structure of the region itself. The main industry of these provinces is agriculture.

According to the growth rate shown in Fig. 2, the CO_2 emissions rate fluctuates greatly and is in a downward trend, and a large number of negative growth rates appear in each year on the whole. In terms of the decrease range, the decrease range of Qinghai, Ningxia and Guizhou province are more than 30% indicating that enterprises in these three provinces also attach great importance to the concept of low-carbon and environmental protection in the production process and the whole province has made remarkable achievements in carbon emission reduction.

3.2. Analysis of calculation results of green TFP

3.2.1. A comparative study on the results of time series measured by Malmquist productivity index

According to the method of Malmquist productivity index, this study calculated the TFP based on the data of 11 provinces and autonomous regions in western region of China from 2007 to 2016 years. Among them, measurement of traditional TFP took labor force and capital stock as input and real GDP as output.

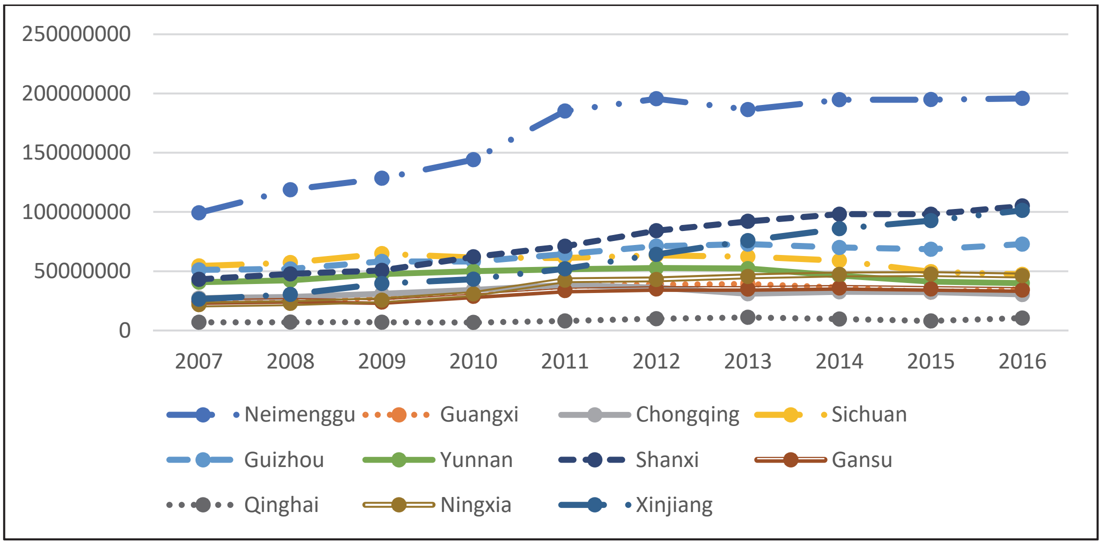

Fig. 1. CO_2 emissions in western region of China from 2007 to 2016 years

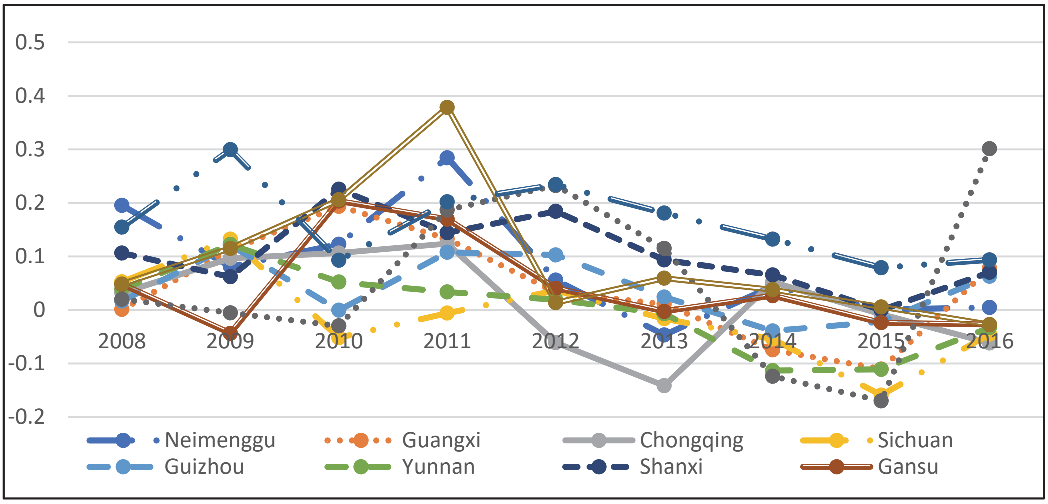

Fig. 2. The annual growth rate of CO_2 emissions in western region of China from 2007 to 2016 years

Green TFP took labor force and Capital stock, energy consumption as expected input, and real GDP and CO_2 emissions as output. This study used the multiplicative method to calculate the TFP value and took 2007 as the base year, and set the TFP value as 1. It can be seen from the Table 3 and Table 4 that the traditional green TFP did not show a stable and consistent trend in recent 10 years.

It can be seen from Fig. 3 and Fig. 4 that the variation of green technology capability is larger than that of comprehensive technology capability in the western region of china. The results of TFP without considering non-expected input and output are higher than those of green TFP. The green Malmquist index has a maximum of 1.263 and a minimum of 0.926 (excluding the base year), while the traditional Malmquist index has a maximum of 1.289 and a minimum of 0.931 from 2007 to 2016 years. The total factor productivity considering the non-expected output is lower than that without considering the non-expected output, so the result may be more real. From the perspective of variation trend, the two Malmquist indexes show different trends from 2008 to 2010 years. The overall Malmquist index shows a trend of fluctuation and increase, while the green Malmquist index shows a trend of decrease, which is due to the deviation between the change trend of green technology efficiency and the change of technological progress from 2008 to 2010 years.

In particular, the green technology efficiency index is the lowest in 2008, and the change value of technology progress is the highest. After that, the technical efficiency index rises very slowly, but the change of technology progress declines significantly, so it leads to the decrease trend of green Malmquist index from 2008 to 2010 years. In addition, the traditional Malmquist index of green Malmquist in 2013-2014 and 2015-2016 shows a declining trend, while the traditional Malmquist index of green Malmquist in these two periods shows a rising trend.

The opposite situation shows that the development of the western region of China in these two periods only focused on economic development and ignored the protection of the ecological environment, which was inefficient and unsustainable. And since 2012, the comprehensive technical progress and technical efficiency green respectively displayed falling volatility and linear downward trend especially considering the Malmquist index of non-expected output of CO_2.

3.2.2. Analysis on regional results measured by Malmquist productivity index

Table 5 and Table 6 are respectively the results of traditional of Malmquist estimation TFP and the results of green Malmquist estimation of TFP in western region of China from 2007 to 2016 years.

Table 3. Results of TFP in western region of China from 2007 to 2016 years

Period	***EFFCH***	***TECH***	***PEFFCH***	***SEFFCH***	***Malmquist***	***TFP***
2007	1	1	1	1	1	1
2008	0.923	1.009	0.944	0.977	0.931	0.931
2009	1.069	1.077	0.997	1.072	1.151	1.072
2010	1.007	1.068	0.99	1.018	1.075	1.153
2011	0.998	1.292	1.006	0.992	1.289	1.487
2012	1.068	1.129	1.079	0.989	1.206	1.793
2013	1.03	1.086	1.036	0.995	1.119	2.005
2014	1.032	1.123	1.063	0.971	1.159	2.324
2015	1.017	1.026	0.976	1.042	1.043	2.425
2016	1.025	1.058	1.017	1.008	1.084	2.63

Table 4. Green TFP results from 2007 to 2016 years in western region of China

Period	*EFFCH*	*TECH*	*PEFFCH*	*SEFFCH*	*Malmquist*	*TFP*
2007	1	1	1	1	1	1
2008	0.954	1.097	0.954	1	1.046	1.046
2009	0.989	0.985	1.051	0.941	0.974	1.019
2010	1.004	0.922	0.998	1.006	0.926	0.943
2011	1.085	1.349	1.039	1.044	1.263	1.192
2012	1.02	1.045	1.007	1.014	1.066	1.27
2013	1.037	1.023	1.007	1.029	1.06	1.346
2014	1.007	1.009	1.001	1.006	1.017	1.369
2015	0.993	1.014	0.998	0.996	1.007	1.379
2016	1.017	0.981	1.002	1.015	0.997	1.375

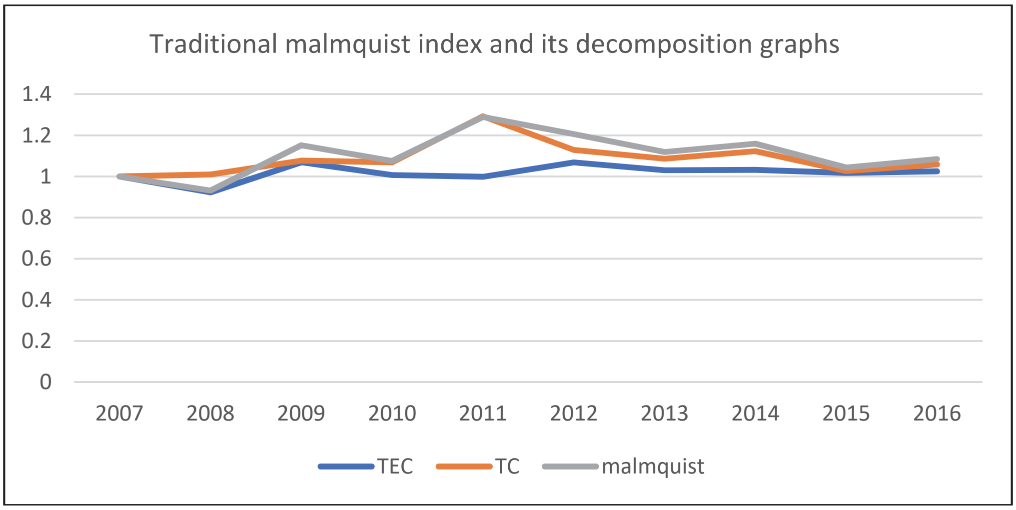

Fig. 3. The traditional Malmquist index and its decomposition index trend

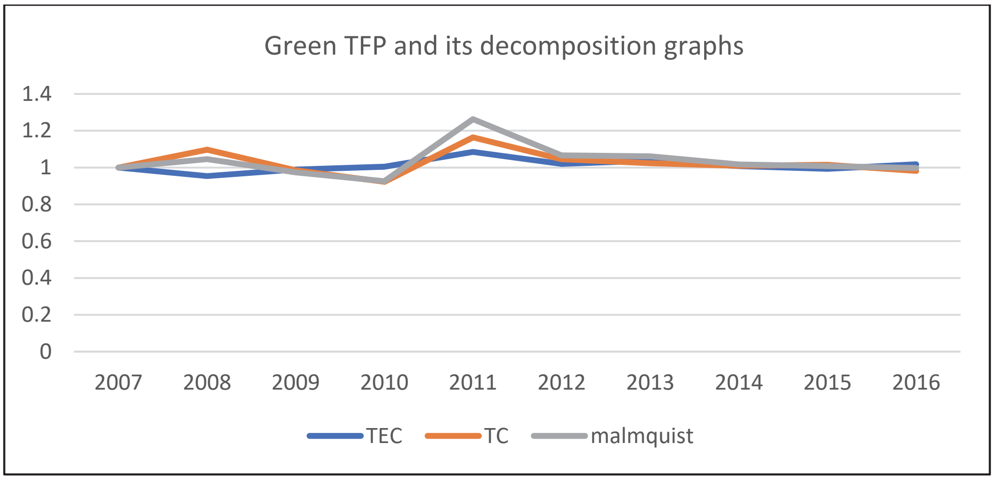

Fig. 4. Green Malmquist index and its decomposition index trend

The Fig. 5 and Fig. 6 respectively shows the trend of traditional Malmquist index, green Malmquist index, and technological progress and efficiency change of 11 western regions of China from 2007 to 2016 years. It can be seen from Fig. 5 and Fig. 6 that two Malmquist indexes are roughly the same in most areas, but the green Malmquist index of some cities is higher than the traditional Malmquist index, which indicates that these cities have a better performance in terms of energy utilization, CO_2 emissions and other environmental performance. The green Malmquist index of some provinces is slightly higher than the traditional Malmquist index, such as Guangxi, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu province. Among them, the green effect of Sichuan, Guizhou, Gansu and Shaanxi province is more obvious on the Malmquist index, which indicates that the development and environment of these four provinces are well balanced. On the other hand, provinces such as Neimenggu, Chongqing and Ningxia and Xinjiang have a lower green index than traditional index, because these provinces are concentrated in western heavy industry with more traditional industries and rough development model. Especially, Neimenggu and Xinjiang as typical resource-dependent regions have a higher proportion of heavy industry than other western provinces, and the improvement of green technology capacity is still relatively slow.

3.3. Ananysis on the results of time series measurement by SBM

In order to calculate the efficiency of green technology with non-expected output more accurately, this study introduced SEM model to focus on measuring the efficiency of green technology, and compared the differences between the two methods. Fig. 7 shows the comparison of change trend of green technology efficiency measured by SBM model in western region of China from 2008 to 2016 years with the results measured by traditional Malmquist productivity index. Fig. 8 shows the average change trend of green technology efficiency measured by SBM model in western regions. It can be seen form Fig. 7 that there is a significant gap between the efficiency change calculated by Malmquist productivity index and the efficiency index of green technology calculated by SBM.

Table 5. The results of traditional Malmquist estimation of TFP in western region of China from 2007 to 2016 years

Region	***EFFCH***	***TECH***	***PEFFCH***	***SEFFCH***	***TFP***
Neimenggu	1.036	1.08	1	1.109	1.119
Guangxi	1.011	1.049	1.011	1.057	1.061
Chongqing	1.067	1.017	1.149	1.069	1.085
Sichuan	1.034	1.017	1.032	1.044	1.052
Guizhou	1.043	1.027	0.992	1.06	1.071
Yunnan	0.99	1.1	0.994	1.092	1.089
Shanxi	1.03	1.017	1.061	1.04	1.048
Gansu	0.983	1.017	0.998	1.004	1
Qinghai	1	1.161	1	1.161	1.161
Ningxia	1.017	1.028	1	1.041	1.045
Xinjiang	0.988	1.15	0.902	1.139	1.136

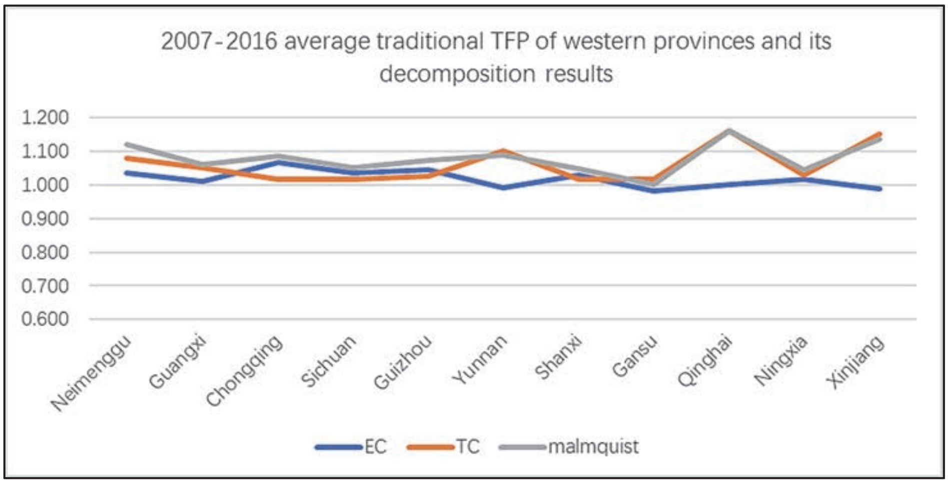

Fig. 5. The average results of traditional TFP in western region of China and its decomposition results from 2007 to 2016 years

Table 6. The results of green Malmquist measurement of TFP in western regions of China from 2007 to 2016 years

Region	***EFFCH***	***TECH***	***PEFFCH***	***SEFFCH***	***TFP***
Neimenggu	1	0.99	1	1	0.99
Guangxi	1	1.094	1	1	1.094
Chongqing	1	1.084	1	1	1.084
Sichuan	0.989	1.146	1.004	0.985	1.133
Guizhou	1.099	1.017	1.041	1.056	1.117
Yunnan	1.022	1.079	1.004	1.017	1.102
Shanxi	1.007	1.096	1.008	0.999	1.103
Gansu	1.003	1.062	1.013	0.999	1.065
Qinghai	1	0.961	1	1	0.961
Ningxia	1.017	0.895	1	1.017	0.91
Xinjiang	0.992	1.061	0.997	0.995	1.053

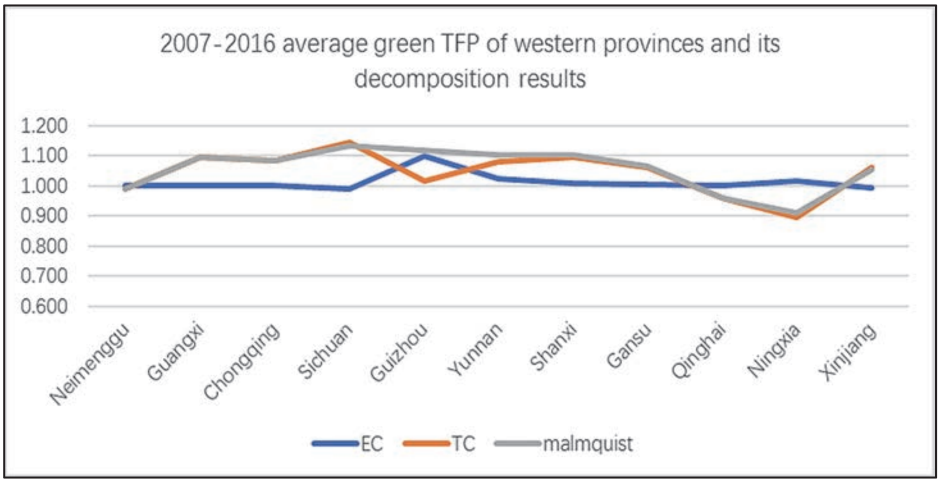

Fig. 6. The results of green TFP in western region of China and its decomposition results from 2007 to 2016 years

The efficiency calculated by Malmquist productivity index is basically 0.2-0.3 higher than the efficiency of green technology calculated by SBM model. Of course, the difference is related to the principle of the algorithm (the efficiency value calculated by SBM model is not greater than 1). However, it can be seen from the change trend that Malmquist productivity index is not accurate in measuring the technical efficiency, because the change range of this value is very small during the study period. Especially after 2012, almost all of them remained at the level of 1. The technical efficiency has remained almost unchanged for several years in western region of China which is not accord with the actual situation, and it indicates that the method cannot measure the real change of the green technology efficiency with considering non-expected factors.

The technical efficiency value calculated by SBM model introducing relaxation variable is in a state of fluctuation and increase during the study period, especially in 2011. The green TFP index calculated by Malmquist productivity index above surged in 2011, and the efficiency change calculated by Malmquist productivity index also increase significantly. The growth of technical efficiency calculated by Malmquist productivity index helped the progress of total factor productivity in western region of China in 2011. However, this result shows a completely opposite result to the technical efficiency calculated by SBM model, which declines significantly in 2011.

It can be seen from Fig. 8 that the efficiency of green technology can be divided into four categories: the first is Qinghai whose efficiency of green technology is 0.934 in western region of China from 2007 to 2016 years. The second is of Ningxia, Xinjiang and Neimeng, and their green technology efficiency is 0.829, 0.825 and 0.801 respectively. The green technology efficiency values calculated by SBM model of these three provinces are all above 0.8. The third is Shaanxi, Guizhou, Chongqing and Guangxi, and their green technology efficiency is above 0.6.

The fourth is Sichuan, Gansu and Yunnan provinces, and their green technology efficiency is between 0.5 and 0.6. It can be seen that the frontier area of western region of China is Qinghai, and the technical efficiency of most provinces is below 0.8, which is obviously behind the frontier area. Guangxi, Sichuan, Gansu and Yunnan do not perform as well in green technology efficiency.

4. Conclusions

The study shows that the measurement results of traditional TFP without considering the non-expected input and output are higher than the results of green TFP according to the measurement results of green total factor productivity.

Table 7. The change of green technology efficiency annually

Period	*EFFCH by MI*	*Green technology efficiency of SBM*
2008	0.954	0.681
2009	1.051	0.718
2010	0.998	0.742
2011	1.039	0.661
2012	1.007	0.753
2013	1.007	0.824
2014	1.001	0.803
2015	0.998	0.836
2016	1.002	0.842

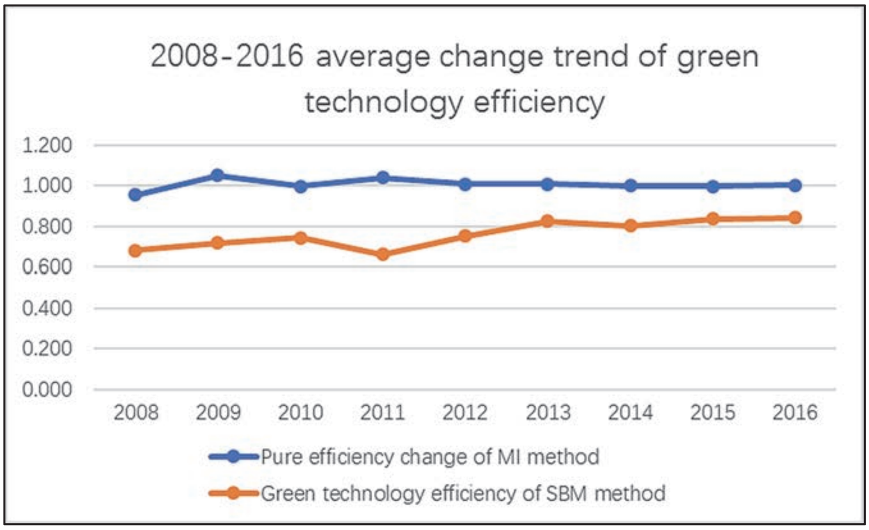

Fig. 7. The average change trend of green technology efficiency from 2008 to 2016 years

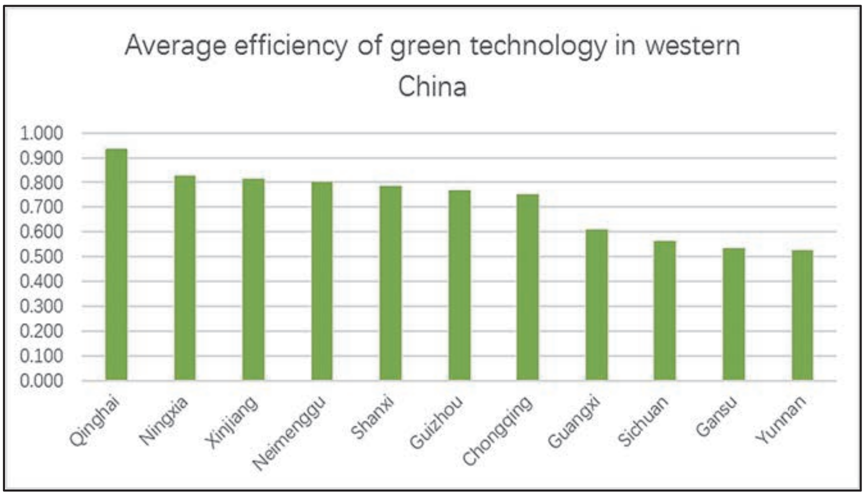

Fig. 8. The average change trend of green technology efficiency measured by SBM model in western region of China

The change of technical progress and technical efficiency slightly higher than the change of technological progress and technical efficiency by the traditional way especially considering CO_2 as non-expected output, it indicates that the western region belongs to inland areas in China, and the information is relatively closed, and the introduction and absorption of green technology ability is insufficient, so it needs the overall planning of the central government, and the local government should adjust the measures to local conditions and take different development strategies. In addition, the results of green TFP measured by Malmquist productivity index method are more consistent with the actual social production activities, but the method does not fully reflect the influence of green input and output factors. The green technology efficiency the efficiency calculated by Malmquist productivity index is basically 0.2-0.3 higher than that calculated by SBM, and it is concluded that the green technology efficiency shows the trend of fluctuations significantly, it also suggests that the development of green technology of the western region in recent years is enhanced. Therefore, scientific and practical measures should be established as soon as possible to solve the problems of low efficiency and waste of resources in production. At the same time, the progress of green technology needs to be further improved. It can improve the technical progress and the efficiency of green technology in western region of China so as to achieve the growth of TFP only through making the positive policy to guide the enterprises to develop and introduce environmental production technology, improve the production process and pay attention to cooperate with universities and scientific research institutes.

Of course, there are some limitations in the research of this paper. For example, we only study the green total factor productivity and spatial spillover effect of green technology capacity in Western China, and do not analyze the situation of all provinces in China. Next, we will consider China as the research object, and compare and analyze the regional differences of spatial spillover benefits of green technology capabilities.

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