Assessing the Green Total Factor Productivity of Water Use in Mainland China

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Summary
The significance of high-quality development and green total factor productivity has attracted widespread attention and research, while few studies on green total factor productivity that considers the use of water resources have been conducted in the context of water shortages and water stress. In this study, the green total factor productivity of water use from 2005 to 2015 in mainland China is evaluated based on the global Malmquist-Luenberger productivity index. Results show that: (1) China's green total factor productivity of water use has been improving since 2005 with an annual global Malmquist-Luenberger productivity index of 1.0104. (2) At the regional level, the eastern zone in mainland China owns the highest green total factor productivity of water use, while that in the intermediate zone ranks last. (3) The green total factor productivity of water use in the southern region (1.0113) significantly higher than that in the northern region (1.0095), and also higher than the national average level in the same period. BPC index has been the most important incluencing factor of green total factor productivity of water use at both national level and regional level since 2011.

Keywords: *Green total factor productivity; water use; Data Envelopment Analysis, Global Malmquist-Luenberger index*

1. Introduction

China is facing severe water use problems. As one of the countries with the poorest water resources per capita in the world, China's water resources per capita are only 2,300 cubic meters, equivalent to 25% of the world's average level. Judging from water resources per capita, there are currently 16 provinces (autonomous regions and municipalities) in China whose per capita water resources are below the severe water shortage standard, with water resources per capita being less than 1,000 cubic meters. In addition to the shortage of water resources, China is also facing water-related problems such as over-exploitation of groundwater and serious water pollution. In 2014, only 10.8% of China's 202 prefecture-level and above cities had good groundwater quality. Efforts have been paid to ease China's water pressure. Pollutants discharged in wastewater exceeding national standards shall be charged according to the quantity and concentration of the discharged pollutants and according to regulations. At the same time, China has also adopted preferential tax policies to guide enterprises and individuals in their water use behavior. Real estate, land, vehicles and ships used by environmental protection units that support environmental protection undertakings and the national financial department for their own use are exempted from property tax and vehicle and vessel use tax; various sprinklers, garbage vehicles and ships used by environmental protection departments are exempt from vehicle and vessel use tax.

Studies have also been launched on the utilization, especially the use efficiency of water resources. Using Data Envelopment Analysis (DEA) model, Deng et al. (2016) estimates water use efficiency (WUE) of 31 provinces in China from 2004 to 2013, finding that WUE is generally higher in economically developed provinces. Using a three-stage DEA-Malmquist index method, Lu and Xu (2019) investigated the total factor productivity instead of WUE in China from 2008 to 2015. The same object was also been studied by Wang et al. (2018), yet only 30 provinces in mainland China were selected. On a finer scale, Pan et al. (2020) studied the water use efficiency of 17 prefecture-level cities in Shandong Province, China from 2006 to 2015.

Focusing on analysis of returns to scale, Gadanakis et al. (2015) evaluate agricultural water use of 66 horticulture farms based on different river basin catchments across England. They conclude that 47% of the farms operate under increasing returns to scale, indicating that farms will need to develop economies of scale to achieve input cost savings. Also using DEA method, Yan (2019) conducts an empirical analysis on investment efficiency of China's rural water conservancy during the period of 2011 to 2015 in 31 mainland provinces, coming to the conclusion that he average investment efficiency of China s rural water conservancy in each year during the study period is 0.732 and the investment efficiency fluctuates for the same period, which is mainly caused by scale efficiency. Wang et al. (2015) explore the changing trajectories of agricultural water use and WUE in the Heihe River Basin in China. Irrigation WUE in crop production was also evaluated in

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Louisiana, USA by DEA method (Gautam et al., 2020). Huong et al. (2020) assessed WUE of pig farming systems in Vietnam with 247 pig farms as decision making units (DMUs).

In the industry field, Liu et al. (2020) investigates industrial WUE in mainland China during 2012-2015. The results indicate that the industrial WUE in China is improving with the efficiency value increasing. Wang et al. (2015) investigate WUE and related pollutants' abatement costs of regional industrial systems in China, verifying the great potentials to reduce water consumption and pollutants' discharges and their evident geographic disparities in China. In addition to single industry research, scholars have also conducted comparative research on WUE in multiple industries. For example, Liu et al. (2020) compared WUE and their influential factors in three industrials in China.

Efficiency and productivity of wastewater treatment plants is also a research hotspot in recent years worldwide, which tended to take wastewater treatment plants and water utilities as the objects of research. Abbott et al. (2012) evaluated the different levels of productivity and efficiency of urban water and wastewater sectors in Australia. Fuentes et al. (2017) analyses the productivity of 199 wastewater treatment plants in Spain. Considering both input contractions and output expansions, Molinos-Senante et al. (2014) assess 22 water companies' productivity performance in England and Wales. Cetrulo et al. (2020) carry out water utilities performance of 77 Brazilian water utilities emphasizing the realization of the human right to water, water losses, quality of service, quality of available data, and the need for maximization of services provided.

It can be concluded from the analysis above that the existing literature has conducted studies more on WUE from the dimensions of region and industry. In all related studies, DEA is the most commonly used method. However, but there are few studies on the total factor productivity (TFP) of water use. Therefore, this paper also applies DEA method to assess the provincial green total factor productivity of water use (GTFPW) in mainland China from 2005 to 2015. Limited by the availability of the data, 30 provinces except Tibet are taken as samples in this paper. This paper contributes to the existing literature in: (1) assessing the green total factor productivity of water use in mainland China and (2) using the GML index for assessment thus avoid the infeasibility problem.

The remaining paper is organized as follows: Section 2 presents the method as well as the variables and datasets used in this paper for assessing GTFPW. Section 3 green total factor productivity of water-use. Section 4 concludes.

2. Methodology, Variables and Datasets

2.1 Global Malmquist-Luenberger index

By studying the existing literature, it is found that the DEA method, first proposed by Charnes et al. in 1978 (Charnes et al., 1978), is one of the most commonly used methods in measuring efficiency and productivity. The first DEA model, Charnes-Cooper-Rhodes (CCR) model, established by the linear programming method, laid the foundation for the DEA method and its application. The constant return to scale (CRS) assumption on which the CCR model based does not conform to the nature of actual production activities, Therefore, Banker et al. (1984) further extended the CCR model and proposed the Banker-Charnes-Cooper (BCC) model established under the variable return to scale assumption. However, none of these traditional DEA models can solve the unavoidable environmental pollution problems in the production process. For example, in water-use field, economic outputs are always accompanied by the discharge of wastewater generated during the use of water resources and the pollutants in wastewater. To solve this problem, Chung et al. (1997) proposed the directional distance function (DDF) to take undesirable outputs in the efficiency and productivity assessment when using DEA method.

Denote that there are n DMUs over T time periods ($t=1,\ldots,T$), for DMU_j ($j=1,\ldots,n$) it can obtain p desirable outputs $\boldsymbol{y}=\left(y_1,\ldots,y_p\right)$ and q undesirable outputs $\boldsymbol{u}=\left(u_1,\ldots,u_q\right)$ by using m inputs $\boldsymbol{x}=\left(x_1,\ldots,x_m\right)$. Therefore, at time t, the inputs and outputs of all the DMUs can be defined as X,Y,U Then, the production possibility set (PPS) at time t can be defined by:

The GMLPI under CRS assumption can be decomposed into different components of productivity growth:

$$PPS^t=\left(X^t,Y^t,B^t\right)\Big|X^t\ can\ produce\left(Y^t,B^t\right),t=1,\ldots,T.$$

$$GMLPI_t^{t+1} = \frac{1+\vec{D}_o^t\left(x^t, y^t, u^t; g_y^t, g_u^t\right)}{1+\vec{D}_o^{t+1}\left(x^{t+1}, y^{t+1}, u^{t+1}; g_y^{t+1}, g_u^{t+1}\right)} \times \frac{1+\vec{D}_o^G\left(x^t, y^t, u^t; g_y^t, g_u^t\right)}{1+\vec{D}_o^G\left(x^{t+1}, y^{t+1}, u^{t+1}; g_y^{t+1}, g_u^{t+1}\right)}$$
$$\times \frac{1+\vec{D}_o^{t+1}\left(x^{t+1}, y^{t+1}, u^{t+1}; g_y^{t+1}, g_u^{t+1}\right)}{1+\vec{D}_o^t\left(x^t, y^t, u^t; g_y^t, g_u^t\right)} = \frac{TE^{t+1}}{TE^t} \times \frac{BPG_{t+1}^{t,t+1}}{BPG_t^{t,t+1}} = EC^{t,t+1} \times BPC^{t,t+1}$$

where TE^t (technical efficiency, TE) represent the technical efficiency at time t, $EC^{t,t+1}$ (efficiency change, EC) represent the efficiency change from time t to $t+1$, $BPG_t^{t,t+1}$ (best practice gap, BPG) represents the best practice gap between the contemporaneous technology frontier and the global technology frontier, and $BPC^{t,t+1}$ (best practice gap change, BPC) measures the technical change from time t to $t+1$.

$EC^{t,t+1} > 1$ means the increase of the technical efficiency of DMU_j during the period t to $t+1$, $EC^{t,t+1} < 1$ means the decrease of the technical efficiency of DMU_j during the period t to $t+1$, $EC^{t,t+1} = 1$ means the invariability of the technical efficiency of DMU_j during the period t to $t+1$. $BPC^{t,t+1} > 1$ means the increase of the best practice of DMU_j during the period t to $t+1$, $BPC^{t,t+1} < 1$ means the decrease of the best practice of DMU_j during the period t to $t+1$, $BPC^{t,t+1} = 1$ means the invariability of the best practice of DMU_j during the period t to $t+1$.

2.2 Variables and datasets

Input-output indicator system for GTFPW assessment is constructed according to relevant research in this research field (Table 1). Input indicators are necessary inputs in the production process, including total investment in fixed assets, employed persons, total energy consumption, and total water consumption. Output indicators are divided into two categories, one is desirable output, and the other is undesirable output. Among them, desirable output is the desired output during the production process. The more the desirable output, the better. In this paper, gross domestic product (GDP) is selected as the representative of desirable output. Undesirable outputs are expected to be as less as possible in the production process. In this paper, total wastewater discharge, chemical oxygen demand (COD) emission in wastewater, and ammonia nitrogen (AN) emission in wastewater are selected as representatives of undesirable output when measuring GTFPW. The economic indicators used in the calculations in this paper are all converted into comparable prices based on the GDP price index (2005=100).

Table 1. Input and output variables for assessing GTFPW

Dimension	Variable	Unit
input	total investment in fixed assets	billion yuan
	employed persons	10,000 persons
	total energy consumption	10,000 tons of standard coal equivalent (SDE)
	total water consumption	billion tons
desirable output	GDP	billion yuan
undesirable output	total wastewater discharge	billion tons
	COD emission in wastewater	10,000 tons
	AN emission in wastewater	10,000 tons

3. Empirical Results and Analysis

3.1 Green total factor productivity of water use on the country level

From 2005 to 2015, the average value of GMLPI of China's GTFPW was 1.0104, indicating a trend of continuous improvement of the overall efficiency water use in the production process. Specifically, China's GTFPW has shown a sustained growth trend from 2005 to 2009, while significant fluctuations occurred during the period from 2009 to 2015. There were 4 periods (i.e., 2005-2006, 2006-2007, 2011-2012, 2013-2014) when the GMLPI values of GTFPW were less than 1, indicating the regression of GTFPW in these periods has regressed compared with the previous years. In other periods, the GMLPI values of GTFPW were greater than 1, indicating an enhancement of GTFPW in these periods has regressed compared with the previous years. The maximum GMLPI value of GTFPW appeared in the period of 2010-2011, achieving the greatest improvement over the previous year with the GMLPI value of 1.0625. On the contrary, the minimum value GMLPI value of GTFPW appeared in 2011-2012, indicating the GTFPW in 2012 was significantly degraded from the previous year.

The GMLPI value of China's GTFPW from 2005 to 2015 was affected to a greater extent by the BPC index not only in terms of value but also the trends of change, while the EC index had a smaller impact on China's GTFPW. Similar to the GMLPI, the BPC index continued to grow steadily from 2005 to 2009, and fluctuated continuously from 2009 to 2015. In 2005-2009, the BPC index was also less than 1 in 2005-2006 and 2006-2007, and it was greater than 1 in 2007-2008 and 2008-2009, indicating that China's GTFPW best practice levels were lower than that in the previous years in 2006 and 2007, whereas the best practice level of China's GTFPW was higher than that in the previous years in 2008 and 2009. It is worth noting that although the BPC index is very similar to GMLPI, the amplitude of fluctuation of BPC index is higher than that of GMLPI over the years. In 2005-2015, the change direction of EC is completely opposite to that of GMLPI and BPC index. EC index continued to decline from 2005 to 2009. Although there have been fluctuations in 2009-2015, the direction of change is opposite to that of GMLPI and BPC index (Figure 3).

3.2 Green total factor productivity of water use on the regional level

This section analyses the regional GTFPW in China through two regional classification methods: one is to divide the Chinese mainland into three regions according to the eastern, the intermediate, and the western zones, and the other is to divide the Chinese mainland into two regions according to the north and south regions.

Among the three zones, the eastern region has the highest annual GMLP from 2005 to 2015 with 1.0136, which is also higher than the national average level in the same period. However, the leading advantage of the GMLPI in the eastern zone relative to the intermediate and western zones was only obvious in 2005-2010. Since 2011, especially since 2013, the GTFPW in the eastern region has began to lost its leading position relative to the central and western regions. In terms of the influencing factors of GMLPI, the GMLPI in the eastern region in 2011 and before was more affected by the EC index. After that, BPC has become a more important factor affecting GMLPI in the eastern region. From this phenomenon, it can be inferred that the water-use type in the eastern zone before 2011 can meet the requirements of efficiency improvement, under which only the improvement of pure technical efficiency can achieve the increase of total factor water efficiency. However, the original production method has been unable to meet the improvement of water-use efficiency in the eastern region since 2012. The improvement of efficiency needs to rely on changes in water use methods.

The GMLPI of GTFPW in the intermediate zone ranks last among the three major zones with an average annual GMLPI value of 1.0070. During 2005-2015, the intermediate zone experienced a decline in GTFPW level nearly half of the time with the corresponding GMLPI value was less than 1. However, the intermediate zone has made significant progress in the second half of 2005-2015. In the two periods of 2010-2011 and 2012-2013, the GMLPI of GTFPW in the intermediate zone was higher than that of the eastern and the western zones, ranking first in mainlan China. In terms of the influencing factors of the GTFPW, the GMLPI value in the intermediate zone is always more affected by the BPC index. Both the value and the changing direction and trend of GMLPI are very similar to the BPC index, showing that the intermediate zone has a low level of GTFPW is due to the backwardness of water use.

The GMLPI of GTFPW in the western zone is lower than that of the eastern zone but higher than that of the intermediate zone, but it is also lower than the national average. The western zone performed unstable in the early period from 2005 to 2015, sometimes higher than the eastern zone, and sometimes became the zone with the lowest GTFPW level among the three zones. However, the GTFPW level in the western zone has reached a relatively high level since 2012, with the GMLPI ranking first among the three zones in the eastern, the intermediate, and the western zones, which has also a clear leading advantage relative to the national average over the same period. In terms of the influencing factors of GTFPW, the value of GMLPI in the western zone depends on both the EC index and the BPC index, but the correlation with the BPC index in the direction of change is higher than that of the EC index.

4 Conclusions and discussions

This paper assessed the GTFPW and its changing process in mainland China by DEA approach. Four input variables (capital, labour, energy consumption, and water consumption), one desirable output variable (GDP), and three undesirable output variables (total wastewater discharge, COD emission in wastewater, and AN emission in wastewater) for the evaluation of GMLPI and its decompositions from 2005 to 2015. The main findings are as follows:

(1) China's overall GTFPW level continued to improve with an average annual GMLPI value of 1.0104, indicating a continuous improvement of WUE during 2005 to 2015. China's GTFPW has shown a sustained growth trend from 2005 to 2009, while significant fluctuations occurred during the period from 2009 to 2015. In terms of influencing factors of GTFPW, China's GTFPW from 2005 to 2015 was affected to a greater extent by the BPC index not only in terms of value but also the trends of change, while the EC index had a smaller impact on China's GTFPW.

(2) In terms of regional GTFPW, the eastern region has the highest annual GMLP from 2005 to 2015 with 1.0136 in the eastern, the intermediate, and the western zones. The level of GTFPW in the eastern zone is also higher than the national average level in the same period. The level of GTFPW in the intermediate zone ranks last among the three major zones with an average annual GMLPI value of 1.0070. During 2005-2015, the intermediate zone experienced a decline in GTFPW level nearly half of the time with the corresponding GMLPI value was less than 1. GTFPW in the western zone is lower than that of the eastern zone but higher than that of the intermediate zone, but it is also lower than the national average.

(3) The average GMLPI of GTFPW in the southern region (1.0113) significantly higher than that in the northern region (1.0095), and also higher than the national average in the same period (1.0104). Although the average GMLPI values of the southern region are higher than that of the northern region, the GTFPW levels of the southern region lag behind that of the northern region in most years. GMLPI of GTFPW in the southern region is affected more by BPC index in most of the years, while GMLPI of GTFPW in the north region is affected more by EC index in 2005-2010 and by BPC index in 2011-2015.

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