Study on the Temporal and Spatial Evolution of the Total-Factor Water Efficiency in the Yangtze-River Economic Belt

Shengrui Zou* and Min Song*
School of Business, Hohai University, Nanjing, China

*Corresponding author e-mail: zoushengrui@hhu.edu.cn, songmin@hhu.edu.cn

Abstract. Based on the SBM-Malmquist model of unexpected output, the paper estimates and decomposes the total-factor water efficiency (TFWE) of 11 provinces and cities in Yangtze-river Economic Belt from 2000 to 2017. The study finds that: (i) TWFE in the Yangtze-river Economic Belt has been significantly improved during the sample time, which has an average value of 0.70, the highest value of 0.91 in 2017 and the lowest value of 0.56 in 2006; (ii) provinces or cities from the eastern region of Yangtze-river Economic Belt including Shanghai, Zhejiang and Jiangsu, tend to have higher efficiency than the central and western regions at the same time; (iii) the index of technical change (Tech) obtained by further decomposition of the efficiency is the main contributing factor of efficiency improvement.

1. Introduction
The 19th National Congress of the Communist Party of China pointed out that we should promote the development of Yangtze-river Economic Belt with the guidance of paying attention to the protection and development together. With the rapid development of economy and society, water resource plays a dominant role in production gradually, life and ecology [1, 2]. As one of the most important regions to promote high-quality economic development in China, the Yangtze-river Economic Belt is now facing serious problems of pollution-induced water shortage and imbalanced distribution of water resources in time and space. Regional development includes many factors, such as population, space, economy and society, which often emphasizes economic and social benefits, while water resource represents an ecological or environmental factor, mainly underlining ecological and technological effects, only when the value of water resources and all factors are unified can we achieve the development of sustainability and coordination.

Total-factor water efficiency (TFWE) was first proposed by Hu and Wang [3], which emphasizes the relationship between various comprehensive inputs and economic output, including capital, labor and water resources, and there is a trend to set pollutants as unexpected output. TFWE reflects the result of water consumption, economic development, technological innovation and other common factors, which has attracted the attention of many scholars recently [4, 5]. Take the whole country as the research scope, Caizhi Sun et al. [6] redefines the concept and connotation of green efficiency of water resources and divides into three dimensions, including economic, social and environmental connotation, and finds most of the regions with high values of water resource environmental efficiency are located in the eastern coastal areas. Take the Yangtze-river Economic Belt as the target, Xi Lu et al. [7] comes to the conclusion that the total factor productivity of water resources in the Yangtze-river...
Economic Belt has changed significantly, and their gap is narrowing and eventually it's all reaching the same steady-state level. Therefore, it is of great practical significance to study the total-factor water efficiency in the Yangtze-river Economic Belt in line with the requirements of the harmonious development of economy and ecology under the new normal economic situation.

2. Data and Measurement

2.1. Measurement Infrastructure

Many studies use the data envelopment analysis (DEA) to evaluate the TFWE, while the SBM model based on DEA model takes the unexpected output into account and solves the non-radial and non-angle problems, which is widely applied. Therefore, we use SBM model to calculate the efficiency:

\[
\rho^* = \min \left( \frac{1 - \frac{1}{m} \sum_{i=1}^{m} S_i^-}{1 + \frac{1}{S_1^- + S_2^-} \left( \sum_{r=1}^{S} y_{ro}^g + \sum_{r=1}^{S} y_{ro}^b \right)} \right)
\]

\[
\begin{align*}
S.T & \begin{cases} 
x_o^* = X^* \lambda + s^- \\
y_o^g = Y^g \lambda - s^g \\
y_o^b = Y^b \lambda + s^b \\
\lambda & \geq 0, s^- \geq 0, s^g \geq 0, s^b \geq 0
\end{cases}
\end{align*}
\]

In Formula (1), each decision-making unit (DMU) contains \( m \) inputs, \( S_1 \) expected outputs and \( S_2 \) unexpected outputs. \( S^- \), \( S^g \), and \( S^b \) correspond to their respective relaxation quantities, \( \lambda \) is the weight vector, and the objective function value is \( 0 \leq \rho \leq 1 \) and decreases strictly. Only when \( \rho^* = 1 \), the DMU is valid.

Then we use Malmquist productivity index to decompose the change of efficiency into technical change (Tech) and technical efficiency change (Effch). Comprehensive productivity index:

\[
M_i(x', y', x'^{t+1}, y'^{t+1}) = (M_i \times M_{i+1})^{1/2} = \left[ D_i(x', y') \times D_i(x'^{t+1}, y'^{t+1}) / D_i(x', y') \right]^{1/2}
\]

On the basis of Formula (2), technical efficiency change (Effch) is divided into pure technical efficiency change (Pech) and scale efficiency change (Sech).

\[
TFP = M_i(x', y', x'^{t+1}, y'^{t+1}) = \text{pech} \times \text{tech} \times \text{sec h} = \frac{D_i(x'^{t+1}, y'^{t+1})}{D_i(x', y')} \times \left[ D_i(x'^{t+1}, y'^{t+1}) / D_i(x', y') \right]^{1/2}
\]

In Formula (3), efficiency improves when total factor productivity (TFP) is greater than 1. Among them, Tech reflects the degree of technological production boundary moving, Effch represents the effect of catch-up, Pech is the technological efficiency change index under the assumption of variable returns to scale, and Sech represents the impact of scale economy on efficiency.

2.2. Description of Variables

The variables included in our estimations are as follows. We select 2000-2017 as the sample time and Yangtze-river Economic Belt as the research object. The input indicators are capital, labor and water.
resources, the expected output indicator is regional GDP, and the unexpected output indicator is wastewater discharge. Capital investment uses the perpetual inventory method to determine fixed assets, of that the base period is converted into 2000 years. Labor input is the arithmetic average of the number of employees in the current and previous period. Water resources input is the total water consumption of each province or city over the years. GDP is adjusted by using the GDP reduction index. Fixed assets, employment, GDP and sewage discharge are all from China Statistical Yearbook and Provincial Statistical Yearbook, and total water consumption is from China Water Resources Bulletin.

3. Empirical Results

3.1. Overall Analysis of the Efficiency

The following two points can be summarized in Table 1. On one hand, the efficiency shows an upward trend with significant changes after 2008. TWFE in the Yangtze-river Economic Belt has been significantly improved, which has an average value of 0.70, the highest value of 0.91 in 2017 and the lowest value of 0.56 in 2006. Before 2008, the efficiency fluctuated in a small range around 0.58, and the change was not obvious, which was related to the economic level and industrial structure at that time. Most provinces took the second industry or even the first industry as the leading industry, and the industry lacked reasonable allocation and systematic arrangement for water resource consumption, so the actual technical level of management was far from the demand. After 2008, with the substantial improvement of China's economic strength and the large-scale introduction and use of water-saving technology, the efficiency has been greatly improved, with the average value reaching 0.82, and showing a stable upward trend. Taking the year of 2008 as a turning point, the government reallocates water resources, which overcomes the distortion of resource allocation to some extent, and effectively improves the imbalance and inefficiency of regional distribution of water resources. In recent years, the strictest water resources management system has been introduced. All regions adhere to the "Three Red Lines" of water resource management, and coincidentally choose the requirements and objectives of water conservation first, which makes a qualitative leap in efficiency.

On the other hand, the efficiency shows significant differences in time and space. Shanghai, Zhejiang and Jiangsu are higher in each period, while Anhui, Guizhou and Jiangxi are lower. Water resource efficiency is closely related to economic geography. Considering the imbalance of economic development gap in different regions, we can obtain the conclusion of the regions of "East> West> Middle" in the Yangtze-river Economic Belt, and the eastern region is far higher than the central and western regions, while the efficiency difference in the central and western regions is not obvious. It can be inferred that the gap of water resource utilization efficiency in different regions is inseparable from the local geographical location, economic, scientific and technological level and policy support. The eastern region has a large per capita GDP, leading the country in comprehensive strength, while some provinces in the central and western regions are relatively rich in water resources reserves, the regional climate conditions and geographical environment are not suitable, coupled with backward technology of water resources development. We find that during the sample period, the efficiency of water resources utilization in Shanghai has reached 1, that is to say, the input and output have reached the optimal match, which shows that Shanghai has a high level of technology and water resources allocation capacity. The efficiency of Anhui, Guizhou and Jiangxi is only about 0.57 and there is a serious input-output mismatch.
Table 1. Estimation Results of the TFWE in Yangtze-river Economic Belt.

| Year | SH  | JS  | ZJ  | AH  | JX  | HB  | HN  | CQ  | SC  | GZ  | YN  | AVG |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 2000 | 1.00| 0.84| 1.00| 0.33| 0.35| 0.46| 0.40| 0.91| 0.48| 0.47| 0.38| 0.60|
| 2001 | 1.00| 0.79| 0.97| 0.31| 0.34| 0.44| 0.39| 0.85| 0.46| 0.44| 0.37| 0.58|
| 2002 | 1.00| 0.80| 0.95| 0.31| 0.35| 0.44| 0.39| 0.82| 0.47| 0.45| 0.37| 0.58|
| 2003 | 1.00| 0.79| 0.94| 0.34| 0.35| 0.43| 0.39| 0.80| 0.54| 0.44| 0.39| 0.58|
| 2004 | 1.00| 0.65| 1.00| 0.36| 0.31| 0.47| 0.41| 0.80| 0.59| 0.48| 0.43| 0.59|
| 2005 | 1.00| 0.63| 1.00| 0.34| 0.31| 0.43| 0.39| 0.79| 0.56| 0.39| 0.39| 0.56|
| 2006 | 1.00| 0.59| 1.00| 0.34| 0.35| 0.43| 0.43| 0.71| 0.56| 0.38| 0.39| 0.56|
| 2007 | 1.00| 0.55| 1.00| 0.32| 0.39| 0.46| 0.49| 0.67| 0.55| 0.44| 0.39| 0.57|
| 2008 | 1.00| 0.61| 0.97| 0.38| 0.45| 0.55| 0.57| 0.64| 0.53| 0.54| 0.46| 0.61|
| 2009 | 1.00| 0.69| 0.84| 0.45| 0.55| 0.69| 0.72| 0.60| 0.61| 0.65| 0.57| 0.67|
| 2010 | 1.00| 0.75| 0.86| 0.51| 0.62| 0.76| 0.80| 0.58| 0.66| 0.69| 0.61| 0.71|
| 2011 | 1.00| 0.80| 0.85| 0.64| 0.66| 0.84| 0.89| 0.60| 0.73| 0.72| 0.67| 0.76|
| 2012 | 1.00| 0.86| 0.84| 0.80| 0.71| 0.93| 0.95| 0.68| 0.78| 0.76| 0.74| 0.82|
| 2013 | 1.00| 0.86| 0.82| 0.91| 0.75| 0.92| 1.00| 0.75| 0.85| 0.72| 0.89| 0.86|
| 2014 | 1.00| 0.87| 0.82| 0.98| 0.76| 0.93| 1.00| 0.82| 0.83| 0.68| 0.90| 0.87|
| 2015 | 1.00| 1.00| 0.87| 1.00| 0.86| 0.84| 0.96| 0.93| 0.85| 0.63| 0.88| 0.89|
| 2016 | 1.00| 1.00| 0.89| 1.00| 0.97| 0.77| 0.92| 1.00| 0.84| 0.62| 0.82| 0.90|
| 2017 | 1.00| 1.00| 0.93| 1.00| 1.00| 0.77| 0.95| 1.00| 0.84| 0.72| 0.83| 0.91|
| Mean | 1.00| 0.78| 0.92| 0.57| 0.56| 0.64| 0.67| 0.77| 0.65| 0.57| 0.58| 0.70|

Rank 1 3 2 9 11 6 5 4 7 10 8

**NOTE:** Data above are calculated by MYDEA3.0. Some cities have replaced the abnormal data in individual years. The provinces or cities in Yangtze-river Economic Belt use their Initials as abbreviations, such as SH represents Shanghai.

3.2. Decomposition Results Analysis

After further decomposition by Malmquist productivity index, we find that the average value of TFP in the sample period is 1.020 with the year of 2008 as the turning point, which totally shows an obvious upward trend. The average annual change rate of Tech is 5.0% and maintains stable growth, which is the main contributing factor of efficiency improvement. The average annual change rate of Effch is -2.9%, while the average value of Pech is 0.978 and the average value of Sech is 0.992. In other words, Pech is the main reason to hinder the growth of Effch, while Sech is relatively weak due to the influence of water resource endowment and other factors. From the perspective of provinces, Fig. 1 shows that there are 7 provinces with TFP greater than 1, among which Shanghai is the first and Jiangxi is the last. The four provinces with lower efficiency are mainly in the central and western regions. This is mainly because these provinces, including Jiangxi, Anhui and Yunnan, are constrained by economic environment and geographical location, whose degree of industrial transfer is relatively low and are limited by the management and operation of soft power such as technology introduction and talent training.

Figure 1. Decomposition Result of the TFWE in Yangtze-river Economic Belt
4. Conclusions and Policy Recommendations

Taking the total-factor water efficiency as the research focus, this paper chooses the input and output data of 11 provinces or cities in the Yangtze-river Economic Belt, the sample period in the analysis is from 2000 to 2017. The results of the paper show that the average of TFWE was 0.70 and it had an upward trend during the sample period. Most provinces or cities with high efficiency came from the eastern region, which were obviously higher than the central and western regions. After Further decomposition, we find that technical change makes the greatest contribution of efficiency improvement. In view of the current water efficiency progress in the Yangtze-river Economic Belt, we give following recommendations in policy making.

Firstly, the government should actively promote the orderly transfer of industries in the Yangtze-river Economic Belt on the basis of the carrying capacity of water resources and environment in different regions, so as to form a reasonable and efficient spatial distribution pattern of industry and water resources utilization. Secondly, central authorities strengthen the macro supervision of water resources utilization and try to take the measures to improve transparency and identify responsibilities in every aspect, including appointing local government heads as river chiefs across the nation to clean up and protect its water resources. Meanwhile they should carry out river and lake water pollution control and water ecological restoration and emphasize the dual role of regional government's economic leverage and administrative means. Thirdly, regions of high water efficiency are supposed to drive their neighboring areas by cross-region spillover, at the same time, local government accelerates the improvement of technical efficiency of water resources utilization, especially encourages relevant enterprises to make technological innovation and improve management efficiency.

Acknowledgments

This work was financially supported by Postgraduate Research & Practice Innovation Program of Jiangsu Province (Grant No. SJKY19_0400) and the Fundamental Research Funds for the Central Universities (Grant No. 2019B69714).

References

[1] Qiwen Cao, Chao Bao, Chaolin Gu, et al, SD model and Simulation of China's Urbanization Based on water resource constraints, Geographic Research. 38(1) (2019) 167-180.
[2] YAN T, WANG J, HUANG J, Urbanization, agricultural water use, and regional and national crop production in China, Ecological Modelling. 318(5), (2015) 226-235.
[3] Hu J L, Wang S C, Yeh F Y, Total-factor water efficiency of regions in China, Resources Policy. 31(4) (2006) 217–230.
[4] Gaosheng Yang, Qiuhao Xie, Spatiotemporal differentiation of green water resource efficiency in the Yangtze River Economic Belt Based on SE-SBM and ML index method, Resources and Environment in the Yangtze-river Basin. 28(2) (2019) 349-358.
[5] Jingbo Wang, Qingwen Yuan, Miaomiao Yao, Provincial water resource efficiency measurement based on improved unexpected SBM model, Statistics and Decision Making. 34(21) (2018) 103-105.
[6] Caizhi Sun, Kun Jiang, Liangshi Zhao, Green efficiency measurement and spatial pattern of water resources in China, Journal of Natural Resources. 32(12) (2017) 1999-2011.
[7] Xi Lu, Changxin Xu, Study on the dynamic efficiency and absolute β convergence of water resources utilization in the Yangtze River Economic Belt Based on Three-stage DEA Malmquist index method, Resources and Environment of the Yangtze-river Basin. 26(9) (2017) 1351-1358.