Spatial Correlation of Water Innovation Efficiency in the Yangtze River Economic Belt

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Abstract. Based on the input and output data of the 11 provinces and cities in the 2006-2016 Yangtze River Economic Belt, the article selects R&D personnel's full-time equivalent nuclear R&D research expenditure as the input index, selects the number of patent grants as an indicator of acceptable output, water consumption and wastewater discharge. As a non-conforming output indicator, the EBM model considering undesired output is used to measure the water innovation efficiency of each province and city, and calculate the global Moran'I index value, and draw the Moran index map for 2006, 2009, 2012 and 2016. It is found that water use efficiency is generally on the rise, and there is significant spatial autocorrelation between regions. Shanghai, Jiangsu and Zhejiang have been at the frontier level of efficiency and have the positive correlation. Chongqing and Guizhou have negative correlations with neighboring provinces and cities. In order to more effectively improve the water innovation efficiency of the Yangtze River Economic Belt, in addition to paying attention to the development of the province and the city itself, it is also necessary to pay attention to the radiation belt actions of neighboring provinces and cities, and formulate differentiated water management measures.

1. Introduction
The rapid development of China's economy means that the demand for water resources is constantly increasing. China's water demand and supply have huge contradictions. The average annual growth rate of water consumption is 0.26% [1]. However, China's water resources are scarce and the per capita water resources are only 1/3 of the world average. With the development of the economy, problems such as water waste and water pollution have become increasingly prominent, and have become the main factors restricting economic development. The "green economy development" has also become the hot topic of government conferences. Furthermore, China has a vast territory, and the distribution of water resources in various regions is uneven. The economic development and water use are also different. Therefore, it is of theoretical and practical significance to study the water use efficiency, time evolution trend and spatial distribution characteristics to improve water problems. As one of the three major economic belts in China, the Yangtze River Economic Belt is the key area for the construction of ecological civilization. Its economy and population account for more than 40%. In recent years, the rapid development of cities has led to an increase in the contradiction between water use and pollution, and the study of the Yangtze River economy. The study of the temporal and spatial
differentiation of water use efficiency in the Yangtze River Economic Belt can promote the construction of water ecological civilization.

At present, scholars at home and abroad also study water resources. For the first time, Hu and other scholars used the data envelopment method to define the concept of "all-factor water use efficiency", and studied the water use efficiency of provinces and cities nationwide from 1997 to 2002, and found that there was a U-shaped relationship between water efficiency and per capita income [2]. Scholars continue to conduct in-depth research on water use efficiency, and some scholars have conducted spatial correlation analysis on the results of water resources efficiency measurement [3], and some scholars have adopted perfect efficiency. The calculation method considers the EBM model of undesired output to measure the water resource efficiency of each province and city, and uses the Tobit model to study its driving factors and influence paths [4]; some scholars also measure the water efficiency of the Yangtze River Economic Belt. It is found that technological progress and industrial structure are the main factors that reduce the intensity of water use [1][5]. Foreign scholars also carried out related research, Jannika Mattes et al. through the study of the status quo in Germany, proposed the quantitative relationship between energy structure and industrial structure to the development of regional resource efficiency [6]; Chemark et al., Njiraini et al. and Azad et al. use the data envelopment model to measure the water use efficiency of countries such as Tunisia, Kenya and Australia, and conduct an in-depth study of their evolution trends [7-9]. In this paper, the input-output indexes of 11 provinces and cities in the Yangtze River Economic Zone from 2006 to 2016 are used to measure the efficiency of the EBM model considering non-desirable output, and Moran'I index is used to study the spatial autocorrelation of the provinces and cities.

2. Model construction

2.1. The EBM model

Data envelopment analysis (DEA) is a commonly used efficiency measurement method in academic circles. This method is based on the technical efficiency evaluation method that is relatively compared between evaluated units. It was first proposed by Charnes, an American logician in 1978. Later some scholars continue to improve this model. In 2010, Tone K and Tsutsui [10] proposed EBM model, which takes into account the effect of relaxation variables on efficiency values. The system will always produce "bad" output, that is, undesired output. The study selects the EBM model with undesired output, that is, water consumption index and water pollution index, to improve the accuracy of the efficiency of the decision-making unit. In this paper, EBM model with non-desirable output is adopted, and the planning formula is as follows (formula 1)

\[
\begin{align*}
\min & \quad \frac{1}{\varphi + \varepsilon^+} \\
\text{s. t.} & \quad \lambda \leq x_k, \quad \forall \lambda - \varphi_k - s^* = 0, \quad \lambda \geq 0, \quad s^* \geq 0
\end{align*}
\]

2.2. Moran'I index

The spatial descriptive statistical method is mainly used to analyze the spatial distribution characteristics of observation units. The commonly used index is the spatial autocorrelation coefficient, which can intuitively show the degree of spatial dependence, which refers to the degree of mutual influence between the region and neighboring regions. The global Moran's I index reflects the spatial distribution characteristics of neighboring provincial units, which are divided into three characteristics: clustering, discrete and random. This paper mainly USES this index to study whether there is
geographical agglomeration of provinces and cities with similar carbon emission intensity between provinces and regions in the Yangtze river economic belt. Value range of Moran's I [-1, 1]: greater than 0 means positive spatial correlation of observed values; less than 0 means negative spatial correlation; greater absolute value means stronger spatial correlation; When Moran's I value is 0, it means that there is no spatial correlation, that is, random distribution.

The formula is as follows (formula 2):

$$\text{Moran'} I = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} W_{i,j} (Y_i - \bar{Y})(Y_j - \bar{Y})}{\sum_{i=1}^{n} \sum_{j=1}^{n} W_{i,j}}$$

(2)

3. Measurement of WUE

3.1. Indicator selection and data source
This paper measures the regional innovation efficiency of water resources in the Yangtze River Economic Belt. Therefore, the number of patent grants is selected as the target output index, which is measured by the average number of patent grants of domestic 10,000 people. Considering the undesired output, the water consumption and wastewater discharge are selected. The measurement indicators, each province and city economic development is different, so the ratio of water consumption to GDP, the ratio of wastewater discharge to GDP is used; the input index considers the innovation system input, selects the R&D personnel full-time equivalent and R&D research expenditure index. The data comes from the 2007-2017 China Statistical Yearbook, the China Technical Statistical Yearbook and the China Demographic Yearbook.

3.2. Empirical results
Based on the input-output index system of the 11 provinces and cities in the 2006-2016 Yangtze River Economic Belt, the EBM model was used to measure the water innovation efficiency. The results are shown in Table 1. It can be seen from Table 1 that the innovation efficiency of water use in the 2006-2016 Yangtze River Economic Belt is generally on the rise. Although some years have fluctuated, the efficiency value in 2016 has risen to 0.7756. From a regional perspective, there are differences between provinces and cities. Most of Shanghai, Zhejiang and Zhejiang have been above 1 and are at a high level. They are frontier cities with innovative efficiency, high level of economic development, large investment in innovation, advanced technology for pollution control and emission reduction, and leading other provinces and cities in wastewater treatment technology. At the same time, the government management system is relatively complete, and people's environmental awareness is strong. In the central provinces and cities of the Yangtze River Economic Belt, Hunan and Jiangxi experienced a slight decline in efficiency in 2007, and other years and provinces and cities were in a steady upward trend, especially in Anhui Province, which rose from 0.3864 in 2006 to 0.6361 in 2016. Chongqing's water innovation efficiency is relatively high, close to the medium-high level. The report of China Regional Science and Technology Innovation Evaluation Report 2016-2017 shows that Chongqing's comprehensive scientific and technological innovation level ranks eighth in the country, and the bureau's western region is the first, but 2016 innovation efficiency has .The decline is relatively low; the water use efficiency of Sichuan, Guizhou and Yunnan provinces is relatively low.

It can also be seen that the green total factor efficiency and geographical distribution of the Yangtze River Economic Belt seem to have a certain correlation.
Table 1. 2006-2017 Yangtze River Economic Belt, Provinces and Cities, Water Innovation Efficiency Table

| Province    | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|-------------|------|------|------|------|------|------|------|------|------|------|------|
| Anhui       | 0.386| 1.386| 0.437| 0.476| 0.516| 0.601| 0.606| 0.611| 0.619| 0.616| 0.636|
| Chongqing   | 0.753| 0.711| 0.635| 0.578| 0.621| 0.656| 0.859| 0.705| 1.074| 1.007| 0.729|
| Guizhou     | 0.572| 0.593| 0.350| 0.555| 1.005| 1.008| 0.675| 0.353| 0.411| 0.456| 1.066|
| Hubei       | 0.533| 0.555| 0.557| 0.532| 0.525| 0.500| 0.511| 0.542| 0.552| 0.583| 0.673|
| Hunan       | 0.539| 0.510| 0.480| 0.444| 0.442| 0.448| 0.458| 0.456| 0.787| 0.738| 0.670|
| Jiangsu     | 0.794| 0.845| 0.886| 1.005| 1.008| 1.014| 1.011| 1.013| 1.015| 1.016| 1.020|
| Jiangxi     | 0.374| 0.393| 0.357| 0.301| 0.273| 0.287| 0.296| 0.328| 0.409| 0.485| 0.663|
| Sichuan     | 0.555| 0.510| 0.580| 0.596| 0.618| 0.556| 0.606| 0.585| 0.581| 0.582| 0.549|
| Shanghai    | 1.043| 1.040| 1.031| 1.022| 0.994| 1.026| 1.014| 1.009| 1.020| 1.004| 1.006|
| Yunnan      | 0.611| 0.626| 0.594| 0.597| 0.549| 0.222| 0.235| 0.252| 0.295| 0.326| 0.301|
| Zhejiang    | 1.071| 1.071| 1.074| 1.097| 1.000| 1.000| 1.234| 1.000| 1.329| 1.192| 1.218|
| Mean        | 0.657| 0.749| 0.635| 0.655| 0.686| 0.665| 0.682| 0.623| 0.736| 0.728| 0.776|

4. Spatial correlation

4.1. Global Moran Index
Based on the 2006-2016 Yangtze River Economic Belt 11 provinces and cities, the total efficiency of water use innovation, using the stata software to calculate the Moran index, the results are shown in Table 2. It can be seen from the results that the P values are all less than 0.01, pass the 1% significance test, and the Moran index is positive, indicating that the water use innovation efficiency of the provinces and cities in the Yangtze River Economic Belt presents a significant spatial correlation, that is, provinces and cities with the same attributes.

More inclined to gather together, neighboring provinces and cities will affect each other; during the period of 2006-2016, the Moran index showed a violent wave dynamic potential, but generally showed a trend of rising first, then falling, rising again and then falling. Overall, in 2006 - 2009 and 2011-2013, both are on the rise, indicating that the spatial autocorrelation is strengthened and the agglomeration characteristics are significant; in 2009-2011, 2013-2016, there is a downward trend. In 2009, the Moran index was 0.571, which decreased to 0.374, after 2013, it also showed a sharp downward trend, from 0.623 in 2013 to 0.331, indicating that the spatial agglomeration of the provinces is weakened, and the spatial agglomeration property is correctly understood, so that the role of space effects can be utilized. When formulating policies or implementing measures. Taking full account of the impact on neighboring provinces and neighboring provinces will help to improve water efficiency more effectively.

Table 2. Global Moran’I Index of Water Innovation Efficiency in the Yangtze River Economic Belt, 2006-2017

| Year | Moran’I | z   | Prob | Year | Moran’I | z   | Prob |
|------|---------|-----|------|------|---------|-----|------|
| 2006 | 0.432   | 3.404| 0.001| 2012 | 0.460   | 3.506| 0.000|
| 2007 | 0.387   | 3.198| 0.001| 2013 | 0.623   | 4.445| 0.000|
| 2008 | 0.525   | 3.941| 0.000| 2014 | 0.396   | 3.078| 0.002|
| 2009 | 0.571   | 4.214| 0.000| 2015 | 0.458   | 3.423| 0.001|
| 2010 | 0.402   | 3.056| 0.002| 2016 | 0.331   | 2.732| 0.006|
| 2011 | 0.374   | 2.881| 0.004|
4.2. Moran scatter plot

Select some years (2006, 2009, 2012, 2016) to draw Moran scatter plots, one or three quadrants respectively indicate HH, LL type aggregation, that is, the provinces and cities have positive correlation; the second and fourth quadrants represent HL, LH type, indicating that Negative spatial correlation; 1-11 in the quadrant represent Anhui, Chongqing, Guizhou, Hubei, Hunan, Jiangsu, Jiangxi, Sichuan, Shanghai, Yunnan, and Zhejiang, as shown in Figure 1-4. As can be seen from the figure, most provinces and cities are in one or three quadrants, that is, there are more provinces and cities with spatial agglomeration. This is consistent with the above conclusions. The Yangtze River Economic Belt as a whole presents spatial agglomeration. Jiangsu, Shanghai, and Zhejiang have always been in the first quadrant, that is, HH agglomeration, and three provinces and cities are conducive to promoting the efficiency of neighboring regions, and the three provinces and cities are also adjacent, forming a “strong and strong alliance” situation 2009. In 2012 and 2016, Anhui Province is in the second quadrant, which has a negative correlation with neighboring provinces and cities. The water-saving innovation efficiency of the eastern provinces and cities of Anhui is relatively high, while the efficiency of the western provinces and cities is generally low, so the province should strengthen

The links between the eastern provinces and cities promote the flow of factors and improve the efficiency of the province; Chongqing and Guizhou provinces fluctuate in the LL and LH quadrants, indicating negative spillovers to neighboring provinces and cities; LL provinces and cities by 2006 and 2009. Seven of them became six in 2012 and 2016. Although the number is the first of the four quadrants, most provinces and cities have promoted the reduction of water innovation efficiency in adjacent areas, but the decrease in quantity indicates that the agglomeration effect is weakening.

![Figure 1](image.png)

**Figure 1.** Moran scatter plot of the Yangtze River Economic Belt in 2006
5. Conclusion and recommendations

Based on the input-output index system of the 11 provinces and cities in the 2006-2016 Yangtze River Economic Belt, the EBM model considering undesired output is used to measure the water innovation.
efficiency of each province and city, and the global Moran index value is calculated, and the Moran index map of some years is drawn. The research results are as follows: (1) The innovation efficiency of all-factor water use in the Yangtze River Economic Belt in 2006-2016 shows an upward trend, but it also presents regional imbalance. Relatively speaking, the eastern region has a high level of economic development and high water use efficiency; (2) Water use efficiency shows significant spatial agglomeration. Provinces and cities with the same attributes tend to gather together. The neighboring provinces and cities will influence each other. The Moran index presents a dynamic wave dynamic potential, but it generally rises first, then falls, and rises. (3) From the Moran scatter plot, Jiangsu, Shanghai, and Zhejiang have always been HH agglomerated, and the three provinces and cities are conducive to promoting the efficiency of neighboring regions, forming a “strong and strong alliance” situation, and the number of provinces and cities in the quadrants shows that the agglomeration effect is getting weaker.

Based on the above analysis, in order to more effectively improve the water innovation efficiency of the Yangtze River Economic Belt, in addition to paying attention to the development of the province itself, it is also necessary to pay attention to the radiation belts of neighboring provinces and cities. In addition, when formulating policies and implementing measures, it is necessary to adapt to local conditions. Develop differentiated water management policies and management systems, learn from neighboring provinces, and promote the flow of factors.

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