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Study on The Evaluation of Eco-Economic Efficiency in The Yangtze River Economic Zone

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ABSTRACT: Eco-economic efficiency is of tremendous significance to the coordinated development of ecological environment and economy. This study uses the super-SBM model to assess the Yangtze River Economic Belt's ecological and economic performance from 2011 to 2020. The Malmquist index approach is then used to dynamically analyze the total factor productivity. The findings indicate that there is a non-equilibrium feature in space and that the eco-economic efficiency of the Yangtze River Economic Zone as a whole exhibits a fluctuating rising trend. A downstream > midstream > upstream pattern is shown. Based on the dynamic Malmquist index and its decomposition, the Yangtze River Economic Zone's total factor productivity has a robust upward tendency. The primary cause of the shift in total factor productivity is technological advancement.

KEYWORDS: Ecological Economy, Malmquist Index, Super-SBM Model.

I. INTRODUCTION

Since the reform and opening up, China's rapid economic development has consumed a large number of natural resources and seriously polluted the ecological environment. In order to support green development, it is imperative that the green transformation of the development method be accelerated. Chinese modernization, according to the Report of the 20th National Congress of the Communist Party of China, is the modernization of peaceful coexistence between humans and the natural world. It seeks to actualize the organic union of socialist modernization and socialist ecological civilization building. The The Yangtze River Economic Belt is China's "golden belt" and the nation's first ecological civilization-building demonstration belt. A thorough knowledge of the Yangtze River Economic Zone's eco-economic operations is facilitated by the assessment of the zone's eco-economic efficiency. To give the ecological and economic development in the Yangtze River region a scientific foundation.

II. LITERATURE REVIEW

The term "eco-economic efficiency" was originally used in 1990 by the well-known German ecological economists Sehaltegger and Sturm. In 1998, OECD further defined eco-economic efficiency as an input of resources and capital. While obtaining a certain economic output, produce less negative environmental impact. It is evident that the main goal of eco-economic efficiency is to maximize economic gains while minimizing ecological damage and resource usage.

Scholars domestically and internationally have studied ecological economy to investigate the connection between ecological environment and economic development. In terms of eco-economic efficiency evaluation, it can be divided into two categories. One is to take the region as the research object. At the national level, Yamasaki and Junya (2021) calculate the environmental load based on the LIME3 method. Assessment of eco-efficiency in 42 mainly OECD countries, It is found that the top three cities with ecological efficiency are Paris, London and Berlin. It enriches the standard method of local government environmental accounting. At the regional level, Sun et al. (2023) analyzed the spatial and temporal evolution of eco-efficiency in six major geographic regions of China and the characteristics of the differences between regions using the Gini coefficient and σ-convergence. At the city level, Zhang (2022) used the super-SBM model to measure the eco-efficiency of the middle reaches of the Yangtze River, Chengdu-Chongqing, Yangtze River Delta, Yangtze River, Beijing-Tianjin-Hebei, and Pearl River Delta urban agglomerations. The results showed the law of spatio-temporal evolution of eco-efficiency of the five major urban agglomerations. The other is to study specific industries. Qian et al. (2022) used the SBM-undesirable model, kernel density estimation, and spatial analysis to investigate the spatio-temporal evolution characteristics of tourist eco-efficiency in the Yangtze River Delta urban agglomeration. Qian and Liu(2024) measured agricultural green and low-carbon production efficiency through a three-stage SBM-DEA model, and analyzed the structural characteristics of the spatially related network of agricultural green and low-carbon production efficiency in the Yellow River Basin using social network analysis. In terms of research methods, Ma & Li et al. (2018) expanded the eco-efficiency assessment index system of the circular economy to include the characterisation index of ecological resource stock and total investment in environmental pollution prevention, as well as the non-expected output index. Han and Chen (2021) introduced Malmquist index into DEA evaluation framework from a dynamic perspective. He et al. (2022) analyzed the level of coupled and coordinated development of composite ecological and economic systems in the Three Gorges Ecological and Economic Corridor area of the Yangtze River by using the model of coordinated development of composite ecological and economic systems in the watershed area.

To sum up, academics at home and abroad have generated rich research breakthroughs on ecological economy.Few experts have investigated the Yangtze River Economic Zone's ecological effectiveness. This study used the super-SBM model to quantify eco-economic efficiency objectively, based on eleven provinces and cities in the Yangtze River Economic Zone. By combining it with the Malmquist index, the Yangtze River Economic Zone's total factor productivity is dynamically estimated, revealing the state of eco-economic development at the moment. in order to serve as a model for enhancing the Yangtze River Economic Zone's eco-economic efficiency.

III. METHODS AND DATA

A. Super-SBM Model and Malmquist Index

DEA generally regards less resources producing more output as an efficient mode of production. Based on DEA, SBM is suggested as a viable solution to the influence and deviation brought on by radial and angle selection. The super-SBM model can effectively solve the problem that the decision-making efficiency of multiple units is 1 and cannot be compared in practical application. Therefore, this paper constructs a super-efficiency SBM model of undesirable output, and the model evaluation DMU is shown in formula (1):

$$\rho = \min \frac{1+\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^x}{x_{i0}}}{1-\frac{1}{S_1+S_2}\left(\sum_{k=1}^{S_1}\frac{s_k^y}{y_{k0}}+\sum_{l=1}^{S_2}\frac{s_l^z}{z_{l0}}\right)} \qquad (1)$$

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$$\text{s.t.}\begin{cases} x_{i0} \geq \sum_{j=1,\neq 0}^{n} \lambda_j x_j - s_i^x, \forall i \\ y_{k0} \leq \sum_{j=1,\neq 0}^{n} \lambda_j y_j + s_k^y, \forall k \\ z_{l0} \geq \sum_{j=1,\neq 0}^{n} \lambda_j z_j - s_l^z, \forall l \\ 1 - \frac{1}{s_1 + s_2}\left(\sum_{k=1}^{s_1} \frac{s_k^y}{y_{k0}} + \sum_{l=1}^{s_2} \frac{s_l^z}{z_{l0}}\right) \\ s_i^x \geq 0, s_k^y \geq 0, s_l^z \geq 0, \lambda_i \geq 0, \forall i, j, k, l \end{cases}$$

Malmquist Index is a tool for dynamic analysis, which uses the ratio of distance function to calculate input-output efficiency. Then, the trend and reasons of productivity change are further explained. Under the assumption of constant returns to scale, the total factor productivity index (TFP) can be divided into two components: technical efficiency change (EC) and technological progress change (TC). The formula for the Malmquist index from period t to t+1 is shown below:

$$m_{i,t+1}\left(x_i^t, y_i^t, x_i^{t+1}, y_i^{t+1}\right) = \left[\frac{D_i^t\left(x_i^{t+1}, y_i^{t+1}\right)}{D_i^t\left(x_i^t, y_i^t\right)} \times \frac{D_i^{t+1}\left(x_i^{t+1}, y_i^{t+1}\right)}{D_i^{t+1}\left(x_i^t, y_i^t\right)}\right] = EC * TC \qquad (2)$$

MI>1 indicates an increase in total factor productivity and vice versa; EC>1 indicates an improvement in technical efficiency and vice versa; TC>1 indicates technical progress and vice versa. The technical efficiency change can be broken down into the pure technical efficiency index (pech) and the scale efficiency index (sech) in the presence of variable returns to scale.

B. System of Indicators

The assessment of eco-economic efficiency ought to consider the correlation between environmental conservation and economic development. Following the principles of scientificity and feasibility, the evaluation index system of eco-economic efficiency is constructed, as shown in Table 1.

Table 1. Eco-economic efficiency evaluation index system

Indicator type	Secondary indicators	Description of indicators
Input variable	Capital input	Total investment in fixed assets/100 million yuan
	Labor input	Number of employed persons/person
	Land input	Built-up area/km2
	Resource input	Energy consumption/10,000 tons of standard coal
Expected output	Economic output	Gross regional product/100 million yuan
	Social output	Per capita GDP/yuan
	Environmental output	Green coverage rate of built-up area/%
Unexpected output	Negative environmental output	Industrial wastewater discharge/10,000 tons
		Industrial sulfur dioxide emission/10,000 tons
		Total discharge of industrial solid waste/10,000 tons

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The China Statistical Yearbook, China Urban Statistical Yearbook, China Energy Statistical Yearbook, and China Energy Statistical Yearbook from 2011 to 2020 are the primary sources of the research data. Public statistics, statistical bulletins, and yearbooks covering eleven provinces and cities within the Yangtze River Economic Zone are available for public use.

IV. RESULTS

A. Analysis of Results of Eco-economic Efficiency Measurements

The eco-economic efficiency efficiency values of 11 provinces and cities in the Yangtze River Economic Belt from 2011 to 2020 were calculated using the super-SBM model based on the input-output index system, as indicated in Table 2. The eco-economic efficiency value is divided into four levels: low, lower, higher and high, with lower than 0.5 as the low efficiency zone, 0.5 to 0.75 as the lower efficiency zone, 0.75 to 1 as the higher efficiency zone, and higher than 1 as the high efficiency zone.

Overall, there is a varying upward trend in the eco-economic efficiency of the Yangtze River Economic Zone; the average increased from 0.867 to 0.907. At the regional level, the Yangtze River Economic Zone's upstream, midstream, and downstream eco-economic efficiency differs noticeably. The downstream region has the greatest average eco-economic efficiency value, at 1.018. The distribution of regional eco-economic efficiency is unequal, as seen by the average eco-economic efficiency of the upstream and midstream, which are 0. 840 and 0. 841, respectively. From the perspective of specific provinces and cities, the average efficiency value is more than 1, and there are five provinces and cities in the high efficiency area, among which Shanghai ranks first. The average value of eco-economic efficiency is 1.605, and Chongqing and Guizhou Province rank second and third. There are 2 provinces and cities with higher efficiency and 3 provinces and cities with lower efficiency, and Sichuan Province is in the low efficiency area all the year round. In terms of the range of change, from 2011 to 2020, More than half of the 11 provinces and cities have improved their eco-economic efficiency to varying degrees. Among them, Hunan Province, Hubei Province and Shanghai have the highest growth rates, with an increase of 132.49%, 84.8% and 20.69% respectively. It shows that in the past eight years since the implementation of the development strategy of the Yangtze River Economic Zone, we have insisted on joint protection and not on large-scale development. Adhering to ecological priority and green development, great achievements have been made in ecological environment protection and restoration.

Table 2. Eco-economic efficiency of the Yangtze River Economic Zone from 2011 to 2020

Provinces	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Mean value
Shanghai	1.479	1.455	1.471	1.508	1.528	1.515	1.757	1.748	1.803	1.785	1.605
Jiangsu	1.064	1.073	1.013	1.011	1.009	1.010	1.015	1.010	1.033	1.027	1.027
Zhejiang	1.009	1.010	1.006	0.567	0.502	0.472	0.463	0.515	1.007	0.545	0.710
Anhui	0.558	0.634	1.004	1.010	1.004	0.592	0.634	0.549	0.666	0.651	0.730
Downstream average	1.028	1.043	1.124	1.024	1.011	0.897	0.967	0.956	1.127	1.002	1.018
Jiangxi	1.090	1.086	1.047	1.046	1.012	1.003	1.011	1.012	1.002	0.688	1.000
Hubei	0.421	0.452	0.465	0.542	0.508	0.444	0.505	1.009	1.016	0.778	0.614
Hunan	0.434	0.488	1.021	1.027	1.033	1.030	1.030	1.020	1.011	1.009	0.910
Midstream average	0.648	0.675	0.844	0.872	0.851	0.826	0.849	1.014	1.010	0.825	0.841
Chongqing	1.047	1.062	1.054	1.050	1.050	1.096	1.056	1.067	1.103	1.093	1.068
Szechwan	0.367	0.399	0.366	0.359	0.357	0.341	0.333	0.350	0.489	0.344	0.371

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Guizhou	1.067	1.040	1.042	1.034	1.046	1.047	1.033	1.034	1.026	1.029	1.040
Yunnan	1.004	1.003	0.690	0.776	0.686	0.604	1.007	1.015	1.020	1.029	0.883
Upstream average	0.871	0.876	0.788	0.805	0.785	0.772	0.857	0.867	0.910	0.874	0.840
Regional average	0.867	0.882	0.925	0.903	0.885	0.832	0.895	0.939	1.016	0.907	0.905

B. Dynamic Malmquist Index Decomposition of Eco-economic Efficiency

To gain additional insight into the dynamic growth of the efficiency of eco-economic development, The Yangtze River Economic Zone's eleven provinces and cities' eco-economic input-output data are computed and broken down using the Malmquist index. The outcomes are displayed in Tables 3 and 4.

Table 3. Eco-economic efficiency Malmquist index of the Yangtze River Economic Zone from 2011 to 2020

Year	TFP	EC	pech	pech	TC
2011-2012	1.021	1.036	1.081	0.975	0.986
2012-2013	0.989	1.111	1.085	0.973	1.187
2013-2014	1.131	0.987	1.084	0.969	0.977
2014-2015	1.163	0.972	1.085	0.967	0.990
2015-2016	1.324	0.933	1.031	1.047	1.182
2016-2017	1.304	1.087	1.029	1.046	0.941
2017-2018	1.370	1.094	1.019	1.051	1.235
2018-2019	1.221	1.149	1.104	1.053	1.004
2019-2020	1.036	0.878	1.097	1.057	0.937
Mean value	1.173	1.027	1.068	1.015	1.049

Table 3 shows that the average change in the index of total factor productivity during the study period was 1.173, with the exception of the 2012-2013 change in total factor productivity, which was less than 1. From the trend of change, the fluctuation of total factor productivity increased from 2011 to 2018, and began to show a downward trend in 2019. It demonstrates that as we move forward, we should focus on the innovative technology's driving force and wisely use the resources that are already available. From the decomposition results, the trend of technological progress change index is similar to that of total factor productivity change index. Technological improvement is the primary cause of the change in total factor productivity in the Yangtze River Economic Zone. The scale efficiency change index increased gradually from 2015 to 2016, but it was always lower than the pure technical efficiency. It shows that the technological progress in the Yangtze River Economic Zone from 2011 to 2020 is mainly caused by the change of pure technical efficiency.

Table 4. Eco-economic efficiency Malmquist index of 11 provinces and cities in the Yangtze River Economic Zone

Area	TFP	EC	pech	sech	TC
Shanghai	1.086	1.022	0.572	0.555	1.060
Jiangsu	1.305	0.996	1.000	0.996	1.308
Zhejiang	1.430	0.997	1.001	0.996	1.530

Anhui	1.265	1.049	1.027	1.058	1.289
Jiangxi	0.958	0.956	0.989	0.967	1.002
Hubei	1.395	1.110	1.154	1.075	1.272
Hunan	1.197	1.134	1.130	1.001	1.113
Chongqing	1.023	1.005	1.016	0.992	1.017
Szechwan	1.234	1.007	1.330	1.100	1.240
Guizhou	0.993	0.996	0.949	1.052	0.996
Yunnan	1.022	1.029	1.028	1.000	1.012
Mean value	1.173	1.027	1.018	0.981	1.167

From Table 4, we can see that, on the whole, the total factor productivity has increased by 17.3% annually. It demonstrates that throughout the study period, the Yangtze River Economic Zone's eco-economic efficiency maintained a high average yearly growth rate. From the decomposition results, the change index of technical efficiency is 1.027, and the change index of technical progress is 1.167. It demonstrates that the primary driver of the shift in eco-economic efficiency is technological advancement. With the exception of Jiangxi and Guizhou, all provinces and cities have average annual change indices of total factor productivity that are higher than 1. In the Yangtze River Economic Zone, the majority of provinces and cities have increasing eco-economic efficiency as the years go by, and their eco-economic development is in good shape.

V. CONCLUSIONS

The conclusions of this paper are summarized as follows: (1) The eco-economic efficiency of the Yangtze River Economic Zone shows a fluctuating upward trend in general, and there are spatial non-equilibrium characteristics, with the downstream area having the highest mean ecological and economic efficiency, followed by the middle reaches, and the upstream area having the lowest ecological and economic efficiency. (2) Based on the dynamic Malmquist index of eco-economic efficiency, the Yangtze River Economic Zone's total factor productivity has a robust upward trend. Additional examination of the decomposition results reveals that technical advancement is the primary cause of the change in total factor productivity. With the exception of Jiangxi and Guizhou, all other areas exhibit an average annual change index of total factor productivity more than 1, indicating a state of good eco-economic development.

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