Evaluation of Energy Ecological Efficiency in the Yellow River Basin Based on Super-SBM

Jian Lu

School of Finance, Anhui University of Finance and Economics, Bengbu 233030, China

Abstract

With the rapid development of my country's economy, energy consumption and environmental problems have become increasingly prominent. Therefore, based on the Super-SBM model, this paper measures the energy eco-efficiency of 9 provinces in the Yellow River Basin from 1997 to 2019. On this basis, by measuring and decomposing the Malmquist-Luenberge (ML) index to study the impact of technical efficiency and technological progress on energy eco-efficiency Finally, the convergence is analyzed by using σ convergence and absolute β convergence. The empirical results show that the energy eco-efficiency of the Yellow River Basin is low and there are large regional differences; the improvement of energy eco-efficiency in the river basin is more dependent on technological progress; the Yellow River Basin as a whole and its upper, middle and lower reaches do not converge. In the future, all localities should adjust the energy consumption structure and industrial structure, accelerate scientific and technological innovation, and pay attention to the coordinated development between regions.

Keywords

Yellow River Basin; Super-SBM; Energy eco-efficiency; Malmquist-Luenberger Index.

1. Introduction

Since the reform and opening up, China's economy has made great achievements that have attracted worldwide attention. At the same time, it has also caused a series of problems such as environmental pollution, biodiversity reduction, resource depletion, and ecological imbalance, which have brought enormous pressure to the ecological environment. Against the background of the slowdown of the national economic growth, China's economy is undergoing a transition from high-speed growth to high-quality development. In this transformation process, it is necessary to improve energy efficiency, reduce pollutant emissions, and achieve high-quality economic development in my country. Since the 18th National Congress of the Communist Party of China, the construction of ecological civilization has been raised to an unprecedented strategic height. General Secretary Xi Jinping pointed out that "lucid waters and lush mountains are invaluable assets", and has repeatedly emphasized the need to take the path of ecological protection and high-quality development. With the popularization of the "two mountains" theory, the research on energy eco-efficiency has also received widespread attention from scholars from all walks of life. As an important energy base in China and an ecological barrier in North my country, the Yellow River Basin is rich in mineral resources, with reserves of raw coal, crude oil and natural gas ranking among the top in the country. In addition, the population of the Yellow River Basin accounts for more than 30% of the country's total population and contributes 25% of the country's gross domestic product. It has a pivotal strategic position in my country's economic development. On the other hand, the industrial structure of the provinces in the Yellow River Basin is unreasonable, and the development model of high energy consumption and high pollution is relatively common. In addition, its own ecological environment is fragile and the carrying capacity of resources and environment is low, which greatly affects the development of local social economy. Therefore, improving energy ecological efficiency is a necessary move for the long-term development of the Yellow River Basin, and it is also the only way to achieve high-quality development

Based on the existing domestic literature in recent years, the research on energy eco-efficiency at this stage tends to be mature, and the hotspots of concern are mainly concentrated in two aspects. One is the calculation and evaluation of energy eco-efficiency. Meng Fansheng (2018) and Zhou Min (2019) used the PP-SFA dynamic evaluation model and the TOPSIS-RSR algorithm to evaluate the energy eco-efficiency of 30 provinces in my country [1,2]; Chen Junfei (2021) based on the Super-SBM model Based on the panel data of prefecture-level cities in Shaanxi Province[3], Liu Yinge (2018) used the SBM-TOBIT model to study energy ecological efficiency level [4]. The second is the influencing factors of energy eco-efficiency. For example, Sun Wei (2020) used the GML index of energy eco-efficiency to analyze its internal influencing factors, and used spatial econometric test to study the influence of external factors [5]; Dong Huizhong (2022) took the middle and lower reaches of the Yellow River as an example to investigate the impact of technological innovation on the impact of technological innovation. The impact of energy eco-efficiency [6].

Although the above studies have achieved beneficial results, there are still shortcomings: First, the selection of input and output indicators is subjective and not comprehensive. For example, some researches do not include human capital input or undesired output into the research scope. Second, most of the existing literature focuses on the national or inter-provincial level, and there are few studies on the energy ecological efficiency of the Yellow River Basin. further analysis. In view of this, the author uses the Super-SBM model that considers unexpected excess and has fixed returns to scale to study the energy eco-efficiency of the Yellow River Basin in my country, which is of great significance for improving the energy eco-efficiency in the basin and promoting high-quality economic development.

2. Research Methods, Index System Construction and Data Sources

2.1. Research Methods

2.1.1. Super--SBM Model

As a non-parametric technical efficiency analysis method, the Data Envelope Model (DEA) can evaluate the relative efficiency of the decision-making unit (DMU) through the input-output situation, but the traditional DEA model (such as the BBC or CCR model) does not take the input into account. The problem of slack in output, which often does not correspond to reality. To avoid this defect, Tone [7] introduced slack variables and proposed a non-radial-based SBM model, but the SBM model may have multiple DMUs in effect at the same time, resulting in the inability of decision-making units to compare and sort. Therefore, Tone [8] proposed a Super-SBM model to further distinguish the effective evaluation units, and solved the problem of slack in the input-output variables and the ranking of decision-making units. The formula of the model is as follows:

Among them:ρ represents the value of energy eco-efficiency; m represents the number of evaluation units; n represents input elements; o_1 and o_2 represent expected output and undesired output respectively; x_k and y_k represent input and output indicators respectively; x and y are used to characterize input and output slack variables; λ envelope multipliers.

$$\begin{aligned} &\rho = \min \frac{1 - \frac{1}{n}\sum_{i=1}^{n} \frac{\overline{x}}{x_{ik}}}{1 + \frac{1}{o_1 + o_2}\left(\sum_{s=1}^{S} \frac{\overline{y^d}}{y_{sk}^d} + \sum_{p=1}^{P} \frac{\overline{y^v}}{y_{pk}^v}\right)} \\ &\overline{x} \ge \sum_{j=1,\ne k}^{m} (x_{ij}\lambda_j) \qquad (\mathrm{i} = 1,2,\cdots n) \\ &\overline{\mathrm{y}^d} \le \sum_{j=1,\ne k}^{m} (y_{sj}^d \lambda_j) \qquad (s = 1,\cdots o_1) \\ &\overline{y^v} \ge \sum_{j=1,\ne k}^{m} (y_{pj}^d \lambda_j) \qquad (p = 1,\cdots o_2) \\ &\overline{x} \ge x_k ; \overline{y^d} \le y_k^d ; \overline{y^v} \ge y_k^v ; \lambda_j > o \end{aligned} \tag{1}$$

2.1.2. ML Index

The theoretical basis of the Malmquist-Luenberger index (ML index) is the environmental technical feasibility set and the directional distance function theory [9], which is mainly used to evaluate the change of total factor productivity.Considering the impact of undesired output, referring to the research of CHUNG (1997) [10] and FARE (2001) [11], this paper adopts the geometric mean of the ML index in the t period and t+1 period to construct the ML index to measure the energy eco-efficiency dynamic changes. The ML index during the period from t to t+1 can be expressed as equation (2).

$$\mathrm{ML}_t^{t+1} = (\mathrm{ML}_0^t \mathrm{ML}_0^{t+1})^{1/2} = \left[\frac{1 + D_0^t(x^t, y^t, b^t; y^t, -b^t)}{1 + D_0^t(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})} \times \frac{1 + D_0^{t+1}(x^t, y^t, b^t; y^t, -b^t)}{1 + D_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})}\right]^{1/2} \tag{2}$$

In the formula, $D_0^t(x^t, y^t, \mathrm{b}^t; y^t, -b^t)$ is the distance function of production technology in period t, and the ML index can be decomposed into technical efficiency change index (EC) and technological progress index (TC), the formula is shown in formula (3)

$$\begin{aligned} \mathrm{ML}_{\mathrm{t}}^{t+1} &= \left[\frac{1 + D_0^{t+1}(x^t, y^t, b^t; y^t, -b^t)}{1 + D_0^t(x^t, y^t, b^t; y^t, -b^t)} \times \frac{1 + D_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})}{1 + D_0^t(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})}\right]^{1/2} \times \left[\frac{1 + D_0^t(x^t, y^t, b^t; y^t, -b^t)}{1 + D_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1})}\right] \\ &= \mathrm{EC} \times \mathrm{TC} \end{aligned} \tag{3}$$

If ML>1, it indicates that the energy eco-efficiency increases; if ML<1, it means that the energy eco-efficiency decreases.

2.2. Construction of Indicator System

After reviewing a large number of literatures and materials on energy ecological efficiency, this paper sorts out the ideas of domestic and foreign scholars to construct the evaluation index system of energy and ecological total factor productivity, and follows the principles of scientificity, effectiveness and data availability. To construct the evaluation index system of energy ecological efficiency in the Yellow River Basin from two aspects. We take the total energy consumption as the energy input, measure the labor input by the number of urban employed persons in each province (autonomous region) at the end of the year, and select the fixed asset investment in 1997 as the base period as the proxy variable of the capital stock to measure the capital input, and the expected output is It is characterized by the added value of the secondary and tertiary industries in each province (autonomous region), and the influence of price factors is excluded from the base period of 1997; the discharge of industrial wastewater, industrial sulfur dioxide (SO2), industrial smoke (dust) and carbon dioxide are used as indicators. (CO2) emissions are used to describe the undesired output, and the data of the four indicators are fitted into a comprehensive value by the entropy method as the undesired output. The details are shown in Table 1.

Table 1. Evaluation index system of energy eco-efficiency

Primary variable	Secondary variable	Tertiary variable
Input	Energy input	Total energy consumption
	Labour input	Total number of employed persons in urban units at the end of the year
	Capital investment	Actual fixed asset investment
Output	Expected output	Actual added value of secondary and tertiary industries
	Undesirable output I	industrial wastewater discharge
		Industrial sulfur dioxide (SO2) emissions
		Industrial smoke (powder) dust emissions
		Carbon dioxide (CO2) emissions

2.3. Data Sources

This paper mainly selects the relevant data from 1997 to 2019 of the nine provinces through which the Yellow River flows to calculate the energy ecological efficiency and analyze its convergence. The research data used are all from the authoritative data published by government statistics departments such as the National Bureau of Statistics, the Energy Statistical Yearbook of the 9 provinces (autonomous regions) where the Yellow River flows, and the Bulletin of the State of the Environment. For individual missing data, multiple imputation, modeling prediction and other methods were used to fill in.

3. Empirical Analysis

3.1. Analysis of Energy eco-efficiency based on Super-SBM Model

We use the software MaxDEA6.0 to measure the energy eco-efficiency of the Yellow River Basin, and calculate the energy eco-efficiency values of the 9 provinces (autonomous regions) in the Yellow River Basin from 1998 to 2019 by using the Super-SBM model considering undesired output and fixed returns to scale. , and the results are shown in Table 2.

As far as the entire river basin is concerned, since 1997, the energy eco-efficiency value of the Yellow River Basin has not exceeded 1, and its average value is only 0.727, indicating that the energy eco-efficiency in this region is not high and is ineffective. From 1997 to 2019, the energy eco-efficiency value generally showed a rising trend, and reached a peak in 2018. After 2018, its value fluctuated between 0.7 and 0.8, and there were signs of "recovery" in the past two years. Compared with 1997, the energy ecological efficiency of the Yellow River Basin has been improved to a certain extent in 2019. At the inter-provincial level, only Shandong Province maintains a mean value of energy eco-efficiency above 1, and all other provinces are less than 1. Provinces with effective energy eco-efficiency in the past decade include Inner Mongolia, Shandong and Sichuan. In terms of change trends, compared with the base period, the values of Gansu, Henan, Inner Mongolia, Shaanxi and Sichuan have increased in different ranges, among which Sichuan and Inner Mongolia have the largest increases, indicating that the quality and benefits of development in the two places have been significantly improved. However, in the remaining four provinces, the energy eco-efficiency has declined, the most obvious of which is Shanxi Province, which dropped from 1.037 in 1997 to 0.425 in 2019.

Table 2. Energy eco-efficiency values of provinces in the Yellow River Basin

Province	Gansu	Henan	Inner Mongolia	Ningxia	Qinghai	Shandong	Shanxi	Shaanxi	Sichuan	Regional Average
1997	0.414	0.628	0.475	0.385	0.399	1.235	1.037	0.583	0.529	0.632
1998	0.412	0.629	0.513	0.369	0.421	1.214	1.033	0.585	0.559	0.637
1999	0.409	0.604	0.481	0.365	0.380	1.217	1.031	0.625	0.554	0.629
2000	0.443	0.608	0.529	0.346	0.397	1.257	1.028	0.667	0.575	0.650
2001	0.448	0.586	0.522	0.332	0.403	1.234	1.031	0.632	0.553	0.638
2002	0.479	0.635	0.649	0.348	0.446	1.258	1.031	0.642	0.601	0.677
2003	0.500	0.674	1.007	0.342	0.475	1.210	1.010	0.673	0.605	0.722
2004	0.533	0.669	1.017	0.350	0.488	1.189	0.873	0.717	0.624	0.718
2005	0.594	0.733	1.044	0.342	0.426	1.149	0.780	0.748	0.683	0.722
2006	0.606	0.754	1.082	0.338	0.434	1.139	0.667	0.765	0.721	0.723
2007	1.002	0.803	1.115	0.341	0.442	1.107	0.660	0.760	0.770	0.778
2008	1.012	0.850	1.154	0.361	0.465	1.077	0.607	0.794	0.788	0.790
2009	1.040	1.003	1.183	0.334	0.443	1.082	0.587	0.833	0.850	0.817
2010	0.699	1.003	1.193	0.353	0.470	1.054	0.577	0.918	1.078	0.816
2011	0.605	0.815	1.212	0.332	0.428	1.029	0.546	0.781	1.143	0.765
2012	0.580	0.791	1.202	0.328	0.410	1.029	0.502	0.748	1.178	0.752
2013	0.557	0.800	1.201	0.351	0.420	1.050	0.497	0.732	1.169	0.753
2014	0.569	0.806	1.199	0.337	0.436	1.074	0.499	0.734	1.171	0.758
2015	0.614	1.006	1.210	0.324	0.455	1.105	0.518	0.752	1.174	0.795
2016	0.525	0.858	1.208	0.324	0.425	1.136	0.475	0.671	1.274	0.766
2017	0.497	0.710	1.194	0.281	0.360	1.025	0.415	0.630	1.243	0.706
2018	0.491	0.721	1.194	0.313	0.355	1.050	0.411	0.612	1.272	0.713
2019	0.512	1.013	1.196	0.319	0.388	1.108	0.425	0.596	1.302	0.762
mean	0.589	0.769	0.990	0.340	0.425	1.132	0.706	0.704	0.888	0.727

3.2. Energy Eco-Efficiency Analysis based on ML Index

The ML index measures the rate of change of energy eco-efficiency relative to the previous year, and can be used here to study the change trend of energy eco-efficiency and its decomposition terms in the Yellow River Basin and various provinces. Therefore, based on the input and output data of the provinces in the Yellow River Basin from 1997 to 2019, we use software to continue to dynamically measure and decompose the ML index of energy eco-efficiency, and decompose the ML index into technological progress changes (TC) and technological efficiency changes. (EC), and analyze the internal influencing factors of energy eco-efficiency accordingly. The ML index of energy eco-efficiency in each province and the mean value of its decomposition items are shown in Table 3.

Table 3. ML index and decomposition of energy eco-efficiency in the Yellow River Basin from 1997 to 2019

province	Changes in energy eco-efficiency (ML Index)	Ranking	Technological Efficiency Change (EC)	Technological Progress Changes (TC)
Gansu	1.124	4	0.995	1.063
Henan	1.144	3	0.960	1.213
Inner Mongolia	1.204	1	1.042	1.073
Ningxia	1.062	8	1.022	1.120
Qinghai	1.081	7	1.043	1.155
Shandong	1.058	9	1.010	1.113
Shanxi	1.165	2	1.001	1.115
Shaanxi	1.117	6	0.992	1.071
Sichuan	1.118	5	0.999	1.082
Yellow River Basin	1.118	-	1.007	1.111

It can be seen from the table that the ML indices of the 9 provinces (autonomous regions) are all greater than 1, indicating that the total factor productivity of all provinces (autonomous regions) has improved. Among them, the most obvious improvement is in Inner Mongolia Autonomous Region. In addition, Shanxi, Gansu and other regions with low average energy ecological efficiency also rank higher, and the last place is Shandong Province with high average energy ecological efficiency. The ML indices of Gansu, Henan, Inner Mongolia and Shanxi all exceeded the geometric mean of the Yellow River Basin by 1.118. This is mainly because the provinces (autonomous regions) with high energy eco-efficiency have a better foundation in technology and economy, have a higher starting point, and play an obvious demonstration role in the entire river basin. ", through its own efforts and the radiation drive of the leading regions, it can play a "catch-up effect" and has great development potential. From the perspective of technological progress change (TC), the value of each region is greater than 1, indicating that the technical level has improved; and in terms of technical efficiency change (EC), the indicator values of Gansu, Henan, Shaanxi, and Sichuan are all less than 1, indicating that In these regions, the technical efficiency has a weak role in improving the economy, and the resource utilization efficiency is not high. Comparing the values of technical efficiency and technological progress, it can be found that the value of technological progress changes in 9 provinces is higher than that of technical efficiency. From this, we can conclude that the growth of energy ecological efficiency in the Yellow River Basin as a whole is more dependent on the role of technological progress.

Next, we conduct a dynamic analysis of the ML index of energy eco-efficiency and its decomposition terms in the Yellow River Basin from 1997 to 2019. As can be seen from Figure 1, the ML index of the Yellow River Basin dropped from 1.215 to 1.063 in 2019, the average annual growth rate of the technical efficiency index was 0.229%, and the technical progress index fluctuated and declined above the level of 1, and the average annual growth rate was -0.833%, from the perspective of the entire Yellow River Basin, the decrease in the ML index of energy eco-efficiency is mainly due to insufficient development momentum for technological progress.

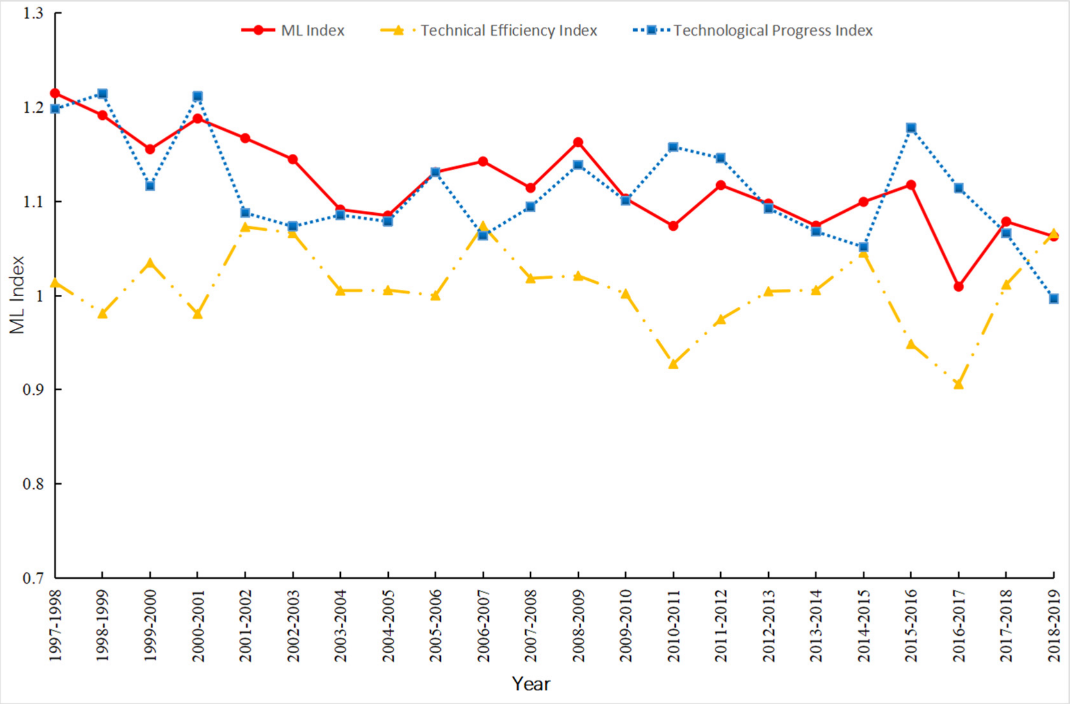

Figure 1. The trend of energy eco-efficiency ML index and its decomposition items in the Yellow River Basin

4. Conclusion and Implications

Through the above empirical analysis, this study draws the following conclusions: The energy ecological efficiency levels of the provinces in the Yellow River Basin are quite different, and the degree of fluctuation over time is obvious, which has great potential for improvement; technical efficiency is the driving force for total factor productivity in the region. The main driver of improvement, while the downward trend of technological progress has led to the decline of the ML index.

Based on the above research conclusions, this paper puts forward the following policy suggestions on how to improve the energy ecological efficiency of the Yellow River Basin:

(1) Change the traditional energy consumption pattern and vigorously develop clean energy. China's energy consumption structure has long been dominated by coal, especially the Yellow River Basin as an important output base for coal and other fossil energy. However, under the environment of strengthening energy conservation and emission reduction, environmental protection and coping with climate change, the model of the Yellow River Basin relying on traditional energy to develop economy will definitely be abandoned. Therefore, all provinces should actively change the way of energy consumption, adjust the energy consumption structure, vigorously develop renewable energy and clean energy such as solar energy, wind energy, hydropower, realize the large-scale application of new energy as soon as possible, and build a new energy consumption system.

(2) Adjust the industrial structure and promote industrial transformation. Most of the provinces in the Yellow River Basin belong to traditional industrial cities, and their economic development is overly dependent on the exploitation and utilization of energy, which is an extensive economic development model of "high energy consumption" and "high pollution". Therefore, it is necessary for all localities to change the economic development model, accelerate the transformation and upgrading of traditional industries with overcapacity such as minerals and steel, and cultivate and develop green emerging industries. According to their actual situation, adjust the proportion of industrial structure, develop characteristic industries, and reduce energy consumption and environmental pollution.

(3) Strengthen regional exchanges and narrow the development gap. Due to the unbalanced development of energy eco-efficiency among the provinces in the Yellow River Basin, all regions need to strengthen exchanges between regions, promote the flow of production factors between regions, give full play to their respective advantages, learn from each other's strengths and complement their weaknesses, promote the formation of a regional coordinated development pattern, and fully develop high-efficiency regions. Advantages drive the development of low-efficiency regions and reduce the imbalance of development among regions.

(4) Improve the innovation-driven development strategy, taking into account technical efficiency and technological progress. Increase investment in scientific and technological research and development to stimulate the initiative and enthusiasm of scientific research personnel; encourage scientific and technological innovation of enterprises from the perspectives of taxation and subsidies, especially related technologies in energy conservation and emission reduction, and continue to make use of technological progress to improve the quality of economic development. Build a government-led scientific and technological research and development system with the participation of universities, research institutes, enterprises and other subjects, increase the cooperation and exchanges between enterprises and universities and scientific research institutions, improve the technology conversion rate, and realize the integration of production, education and research.

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