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REVIEW ARTICLE

CARBON EFFICIENCY OF PROVINCES IN PAN-YANGTZE RIVER DELTA, PAN-PEARL RIVER DELTA, AND CIRCUM-BOHAI REGION

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ABSTRACT

The IPCC (2006) method is used to estimate the carbon dioxide emissions of China's Pan-Yangtze River Delta, Pan-Pearl River Delta and Bohai Rim regions from 2014 to 2016.And the three-stage Super-DEA model is used to analyze the carbon emission efficiency of the provinces in the three economic circles. The empirical results show that China's carbon emission efficiency shows upward trend with volatility, but the improvement is slow, and the overall efficiency is not high. The inter-provincial gap is obvious, showing the pattern of "Pan-Pearl River Delta> Pan-Yangtze Triangle> Circum-Bohai region".

KEYWORDS

Three-stage Super-DEA model, Carbon Emissions, Carbon Efficiency.

1. INTRODUCTION

In recent years, countries have attached great importance to climate change issues, and it is urgent to reduce greenhouse gas emissions. China proposes that by 2020, China's carbon dioxide emissions per unit of GDP will fall by 40-45 percentage points. By 2030, the proportion of non-fossil energy consumption will increase to 20% of primary energy consumption. Energy shortage is also an unavoidable problem in China's economic development. Under the dual pressure of emission reduction and energy shortage, China needs to improve its technology level, energy efficiency to reduce industrial carbon dioxide emissions in the next decade. As the most important three economic circles in China, the Pan-Yangtze River Delta, the Pan-Pearl River Delta and the Circum-Bohai region have different development models, resulting in significant differences in regional carbon emission efficiency. Under the requirements of energy conservation, emission reduction and green development, studying the carbon emission efficiency of provinces and cities within the three major economic circles will help provide reference for development experience and policy formulation in other regions.

2.PREVIOUS EMPIRICAL RESEARCH: AN OVERVIEW

There are two general methods for measuring carbon emission efficiency: one is the parametric method, the most representative is the SFA (stochastic frontier analysis). A group of scholars used SFA to measure the carbon emission efficiency of each country, the results showed that China's overall carbon emission efficiency is far lower than other developed countries [1]. Other scholar found that foreign trade and optimizing energy structure and industrial structure could help improve carbon emission efficiency [2]. Based on a study, the carbon emission efficiency of each province in China has an upward trend, and at the same time the transition shows great regional differences [3,4]. The other type is non-parametric methods, the most representative of which is Data Envelopment Analysis (DEA). A scholar studied the carbon efficiency of 18 major carbon emission countries in the world. The results showed that technical efficiency promoted the improvement of efficiency [5]. Other scholar found the carbon emission efficiency of each province showing a downward trend and obvious regional differences [6]. According to research, the DEA and SBM methods found that the carbon emission efficiency in the eastern region is significantly higher than that in the central and western regions, and the productivity growth mainly depends on technological progress [7].

3.THE EMPIRICAL FRAMEWORK

This paper uses a three-stage super-DEA model, which is divided into the following three steps:

1. The first stage. The basic idea of super-DEA is to make the input and output variables of the unit linearly represented by the variables of other remaining decision-making units. When evaluating the h^{th} decision-making unit, it's supposed that the evaluation system is composed of n decision-making units, there are m kinds of inputs, s kinds of outputs. DMU_j represents the j^{th} decision-making unit. X_{ij} represents the i^{th} input of DMU_j and Y_{rj} represents the r^{th} output of DMU_j. The input-oriented model is:

$$\min\theta$$

$$\begin{cases} \sum_{\substack{j=1 \\ j\neq k}}^{n} x_{ij}\lambda_j \leq \theta x_{ik} \quad i = 1,2 \ldots \ldots \mathrm{m} \\ \sum_{\substack{j=1 \\ j\neq k}}^{n} y_{rj}\lambda_j \leq y_{rk} \quad r = 1,2 \ldots \ldots \mathrm{s} \\ \lambda_j \geq 0 \\ \lambda_j \geq 0, \forall i, j, r \end{cases} \qquad (1)$$

2. The second stage. Due to the influence of environment, random factors and management inefficiency, the results of the first stage cannot reflect the true efficiency of each unit. Therefore, the slacks of the input variables in the first stage are used as the dependent variables, and the selected environmental variables are used as the independent variables. Then SFA regression is carried out to eliminate the impact of environmental and random factors on inputs.

$$S_{ij} = f(Z_k, \beta) + \upsilon_{ik} + \mu_{ik} \quad i = 1,2 \ldots \ldots \mathrm{m}; \ j = 1,2 \ldots \ldots \mathrm{n} \qquad (2)$$

S_{ij} represents the slack variable of the i^{th} output of DMU_j; Z_k represents the k^{th} environmental variable; β is the regression coefficient of the environmental variable; $\upsilon_{ik} + \mu_{ik}$ is a mixed error term, which indicates random error and management inefficiency, υ~N(0, σ_υ^2), μ~N^+ (0, σ_μ^2). The adjustment formula is as follows:

$$X_{ij}^{A} = X_{ij} + \left[\max\left(f(Z_k,\hat{\beta})\right) - f(Z_k,\hat{\beta})\right] + [\max(v_{ik}) - v_{ik}] \qquad (3)$$

X_{ij} and X_{ij}^{A} represent the inputs before and after adjustment, $\max\left(f(Z_k,\hat{\beta})\right) - f(Z_k,\hat{\beta})$ is the adjustment of inputs, $[\max(v_{ik}) - v_{ik}]$ is the adjustment of random factors.

3. The third stage. According to the adjusted input of the second stage and original output, the super DEA model can be used to obtain the relative true efficiency considering the environment and random factors. According to the energy value-carbon model proposed by IPCC, Carbon dioxide emissions= $\alpha \sum E_i * C_i$, $E_i$is the energy consumption, C_i is the coefficient of various energy sources converted to standard coal, α is the carbon emission coefficient of standard coal, α = 2.7. Carbon dioxide emissions is an input. In addition, labor and capital stock as other inputs, GDP is taken as the output. Labor is the number of employees at the end of the year, and capital stock is calculated based on the results of a scholar [8]. Based on the research of other scholars, this paper chooses environmental regulation and industrial structure, R&D investment, urbanization level and green area proportion [9,10].

4.EMPIRICAL RESULTS

According to the input-output index system, the relevant data are brought into the first-stage model, and the results are shown in Table 1.

Table 1: Results of the first stage

	2014	2015	2016		Average	Ranking
Shanghai	0.510	0.524	0.547		0.527	10
Jiangsu	0.433	0.446	0.446		0.442	14
Zhejiang	0.400	0.417	0.430		0.415	16
Anhui	1.057	1.027	1.022		1.035	2
Beijing	0.771	0.854	0.899		0.842	4
Tianjin	0.442	0.431	0.432		0.435	15
Hebei	0.688	0.675	0.675		0.679	5
Liaoning	0.547	0.580	0.503		0.544	9
Shangdong	0.439	0.447	0.451		0.446	13
Fujian	0.937	0.935	0.928		0.933	3
Jiangxi	0.326	0.356	0.385		0.356	18
Hunan	1.295	1.269	1.238		1.267	1
Guangdong	0.435	0.461	0.461		0.452	12
Guangxi	0.563	0.554	0.552		0.556	8
Hainan	0.374	0.370	0.368		0.371	17
Guizhou	0.442	0.515	0.585		0.514	11
Sichuan	0.681	0.679	0.662		0.674	6
Yunnan	0.530	0.576	0.580		0.562	7
Average	0.604	0.618	0.620		0.614	
Range	0.969	0.913	0.870		0.911	

From Table 1, the average efficiency of the three major economic circles in 2014-2016 is 0.614, and the efficiency still has room to improve. Without considering environmental factors and random factors, the efficiency of various provinces is relatively stable, and there is a trend of increasing year by year. However, the efficiency difference between provinces is very large, but it shows a narrowing trend. From the regional perspective: The Pan-Pearl River Delta region has the highest efficiency, followed by the Pan-Yangtze River Delta region, and the Circum-Bohai region has the lowest efficiency; From the perspective of time, only Anhui and Hunan are on the frontier of efficiency, and there is plenty of scope for other provinces to push that further.

Taking the slacks of the input obtained in the first stage as dependent variables, the SFA regression analysis is performed with the five environmental variables as independent variables. The regression results are as follows:

1. Return result of carbon emissions
S_1=11871.382+43084.886*Z_1-744.926*Z_2-551.73*Z_3+31.04*Z_4+30054.124*Z_5
2. Return result of labor force
S_2=-223.4-5.38*Z_1+1.747*Z_2+0.014*Z_3+0.121*Z_4+55.117*Z_5
3. Return result of capital stock
S_3=4089.881-682.92*Z_1-434.207*Z_2-51.209*Z_3-6.687*Z_4+13599.721*Z_5

Z_i respectively represent environmental regulation, industrial structure, urbanization level, green coverage, and R&D investment. When the regression coefficient is greater than 0, that represents the slack also increases with the increase of environmental variables, and the distance to $\max\left(f(Z_k,\hat{\beta})\right)$is small, it just need to adjust a little when using formula(2), so the efficiency is underestimated, and the efficiency is overestimated conversely. From the regression results, environmental variables have different effects on different input variables, and the differences are quite large. Therefore, it is necessary to adjust the original input variables and eliminate the influence of environment and random factors on efficiency evaluation.

Table 2: Results of the third stage

	2014	2015	2016	Average	Ranking
Shanghai	0.638	0.674	0.712	0.675	8
Jiangsu	0.847	0.86	0.803	0.836	3
Zhejiang	0.717	0.721	0.689	0.709	7
Anhui	1.08	1.113	1.091	1.094	1
Beijing	0.792	0.819	0.816	0.809	4
Tianjin	0.457	0.451	0.43	0.446	15
Hebei	0.668	0.655	0.654	0.659	9
Liaoning	0.543	0.553	0.474	0.523	11
Shangdong	0.643	0.599	0.567	0.603	10
Fujian	0.742	0.713	0.722	0.726	6
Jiangxi	0.366	0.384	0.341	0.364	16
Hunan	1.09	1.041	0.959	1.03	2
Guangdong	0.776	0.799	0.748	0.774	5
Guangxi	0.476	0.467	0.47	0.471	13
Hainan	0.163	0.162	0.157	0.161	18
Guizhou	0.251	0.281	0.267	0.267	17
Sichuan	0.515	0.526	0.526	0.522	12
Yunnan	0.462	0.47	0.421	0.451	14
Average	0.624	0.657	0.633	0.648	
Range	0.927	0.951	0.934	0.933	

From table 2, it can be seen that after removing the influence of environmental and random factors, the carbon emission efficiency of most provinces has improved to some extent, and the efficiency is also relatively stable, but there is still a lot of room for improvement. Horizontally, the carbon emission efficiency difference between provinces is relatively stable, but the difference is very large. Hainan Province has the lowest efficiency in various years and Anhui Province has the highest efficiency. It needs to attract attention, implement the idea of low-carbon development and green development. Longitudinal, only Anhui Province and Hunan Province are on the frontier of efficiency. Other provinces still have a long way to go and need to implement tasks of emission reduction for a long time. From a regional perspective, the Pan-Pearl River Delta region has the highest efficiency, the circum-Bohai region has the lowest efficiency, and the development gap between regions is relatively large. At the same time, it can be seen that the efficiency of Beijing, Jiangsu, Anhui and Hunan is above 0.8. Beijing and Jiangsu are located along the coast, gaining economic growth by virtue of geographical advantages and early good development opportunities, and their carbon emission efficiency is at the national leading level. Anhui Province and Hunan Province, as latecomers in economic development, make full use of regional advantages based on gaining development experience of the eastern region. The focus of their emission reduction is on optimizing the proportion of energy structure and technology-intensive industries and promoting the development of low carbon industries. However, the efficiency of Jiangxi, Guizhou and Hainan is below 0.4, which are greatly different in resource endowment, but they are in the primary stage of economic and social development. Compared with other developed regions, they pay more attention to GDP growth and the industry structure is dominated by high energy-consuming industries which have formed a natural disadvantage in terms of carbon emissions. These regions need to adapt to local conditions, fully exploit the advantages of the region, actively improve the energy structure and industrial structure while developing the economy, and strive to develop clean energy, knowledge-intensive and capital-intensive industries to promote healthy economic development.

5.CONCLUSION

The three-stage DEA model is used to measure the carbon efficiency of each province in the three economic circles. According to the results, it is found that the carbon emission efficiency of the first and third stage of each province does have significant differences, and the efficiency is improved by eliminating the influence of environmental and random factors. Among the three economic circles, the Pan-Pearl River Delta region has the highest efficiency, the Bohai Rim region has the lowest efficiency, and the efficiency is significantly different among provinces. Except for Tianjin and Hainan, other coastal provinces are more efficient; in terms of time, most provinces' efficiency is rising. Regional differences are issues that must be considered in the development of regional economic. The same is true for achieving emission reduction targets. China should implement different emission reduction strategies according to local conditions, focusing on areas with low carbon efficiency and economically underdevelopment areas. The results show that the carbon emission efficiency of economically developed provinces is generally higher than that of economically underdeveloped regions. Therefore, it is necessary to strengthen exchanges and cooperation between provinces and learn effective energy saving and emission reduction measures. At the same time, the government needs to strengthen emission reduction support in economically underdeveloped regions, including policy, technology and financial support. Economically developed provinces should play a leading role in guiding other regions to reduce technological progress. The key to reducing emissions is to improve energy efficiency and develop new energy. China should support independent innovation and international technology cooperation to promote innovation and application of emission reduction technologies and promote economic growth shift to the mode of "low input, low consumption, low pollution".

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