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RESEARCH ON GREEN ECONOMIC EFFICIENCY OF CHINA'S BOHAI RIM PORTS CONSIDERING UNDESIRABLE OUTPUT – BASED ON CCR-SBM AND MALMQUIST MODEL

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Abstract. *The ecological and green development of ports has always been an important aspect of China's green transportation construction. In this paper, five ports including Yingkou Port, Dalian Port, Jinzhou Port, Rizhao Port and Tianjin Port will be statically compared using the CCR-SBM model. And use Malmquist index for dynamic analysis. The empirical results show that the static efficiency evaluation shows that after considering the undesired output, the green economic efficiency of China's Bohai Rim ports has a clear downward trend, and SO_2 has a negative impact on the green economic efficiency of the ports. The dynamic efficiency evaluation shows that the fluctuation of Malmquist index is mainly affected by the efficiency of technological progress, and the overall analysis shows that pure technical efficiency has a more significant impact on technical efficiency.*
Keywords: Bohai Rim ports, CCR-SBM model, Malmquist index, Green economic efficiency

1. **Introduction.** Vigorously promoting ecological protection, preventing global warming and reducing greenhouse gas emissions have become the technological pursuit, political goal and social responsibility of all countries in the world. During China's "14th Five-Year Plan" period, it is necessary to speed up the green transformation of the development mode, and coordinate the promotion of high-quality economic development and high-level protection of the ecological environment. This shows that energy conservation and emission reduction policies centered on reducing energy intensity and carbon intensity have also become one of the key elements of our country's energy strategy. Ports are an important part of the transportation industry, and the energy consumption and pollutant emissions of port enterprises are also the focus of attention. Ports in the Bohai Rim region of China are an important part of ports, and it is necessary to implement the concept of green development in all aspects of port design, construction and operation, and promote the establishment of a green and low-carbon port system. This paper selects Dalian Port, Yingkou Port, Tianjin Port, Rizhao Port and Jinzhou Port as the research objects, and uses the CCR-SBM model to carry out a comparative analysis of static efficiency. Dynamic comprehensive evaluation provides optimization suggestions for accelerating the construction of a green port development model. Although some achievements have been made in the research on the evaluation of port green economic efficiency, the research on the port environment only focuses on analyzing one of the static or dynamic aspects, and it is easy to ignore the other aspect. Based on the above considerations, this paper attempts to use CCR-SBM to conduct a static comparative analysis of China's Bohai Rim ports, and use the Malmquist index as a theoretical tool to conduct an overall and

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sub-port dynamic analysis on the green economic efficiency of ports, from both static and dynamic aspects. Research on the evaluation of green economic efficiency of ports around the Bohai Sea in China.

2. Literature Review.

For the research objects with multiple inputs and multiple outputs, most of them adopt a non-parametric frontier efficiency analysis method developed by American operations researchers Charnes et al. [1] on the basis of "relative efficiency evaluation", namely DEA model. In the environmental efficiency evaluation system, the traditional DEA model will make the measured results inaccurate, so some scholars begin to use the DEA model that considers undesired outputs. When Hailu and Veeman [2] analyzed the environmental efficiency of the Canadian paper industry, they also treated pollutants as input variables. Although this method can minimize undesired output, it also has certain disadvantages, and it cannot reflect the actual production process. Therefore, there are other DEA models that consider undesired output. Tao et al. [3], Lu and Zhao [4] all used the SBM (i.e., Slacks-Based Measure) model to evaluate the environmental efficiency of each province and found that the introduction of environmental variables is obvious. The average efficiency level of each region has been reduced, indicating that the conclusions drawn by introducing undesired outputs more reflect the real situation. You et al. [5] used the environmental Malmquist index to evaluate the dynamic environmental efficiency of the power industry in the BRICS countries (China, India, Russia and Brazil). Yuan and Sun [6] proposed an improved model based on undesired output preference based on the traditional DEA model. Taking the listed port enterprises in China as an example, the environmental efficiency of port enterprises is objectively evaluated using the model proposed in this paper. For the dynamic evaluation of port efficiency, Martinez-Budria et al. [7] and Valentine and Gray [8] used the Malmquist total factor productivity index to evaluate port efficiency changes. When Wu et al. [14] used the data envelopment analysis method to measure the green development efficiency of the Yangtze River Delta urban agglomeration, they calculated and evaluated the green economic efficiency of the Yangtze River Delta urban agglomeration based on the BCC model. And the DEA-Malmquist index was introduced to analyze the decomposition of green development efficiency, which dynamically measured the change trend of the decomposition of green development efficiency in each region of the Yangtze River Delta.

3. Research Methods.

3.1. CCR-SBM model.

This paper considers the establishment of a DEA model based on slack variables to evaluate the green economic efficiency of five ports in China's Bohai Rim with undesired outputs. The hypothetical decision-making unit has three input-output vectors: input, expected output and undesired output. According to the processing method of SBM-DEA model proposed by Tone [11], the SBM-DEA model of undesired output can be written as

$$\rho^* = \min \frac{1 - \frac{1}{m}\sum_{i=1}^{m} \frac{s_1^-}{x_{i0}}}{1 + \frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1} \frac{g_r^g}{y_{r0}^g} + \sum_{r=1}^{s_2} \frac{s_r^b}{y_{r0}^b}\right)} \tag{1}$$

s.t.

$$\begin{cases} x_0 = X\lambda + s^- \\ y_0^g = Y^g\lambda - s^g \\ y_0^b = Y^b\lambda + s^b \\ s^- \geq 0,\ s^g \geq 0,\ s^b \geq 0,\ \lambda \geq 0 \end{cases}$$

Among them, s represents the slack of input and output; λ is the weight vector. The objective function ρ^* is strictly decreasing with respect to s^-, s^g, s^b, and $0 \leq \rho^* \leq 1$. For a particular evaluated unit, it is efficient if and only if $\rho^* = 1$, that is, $s^- = 0$, $s^g = 0$, $s^b = 0$. The difference between SBM-DEA and the traditional DEA model puts the slack variable directly into the objective function.

3.2. **Malmquist index.** The Malmquist index can be used to measure the dynamic change index of green economic efficiency including undesired output from period t to period $t-1$. The expression for the Malmquist exponent is as follows:

$$\text{tfpch} = \frac{D_t^u(x_t, y_t)}{D_{t-1}^u(x_{t-1}, y_{t-1})} * \left[\frac{\dfrac{D_t^C(x_t, y_t)}{D_{t-1}^C(x_{t-1}, y_{t-1})}}{\dfrac{D_t^u(x_t, y_t)}{D_{t-1}^u(x_{t-1}, y_{t-1})}}\right] * \left[\frac{D_{t-1}^C(x_{t-1}, y_{t-1})}{D_t^C(x_{t-1}, y_{t-1})} * \frac{D_{t-1}^C(x_t, y_t)}{D_t^C(x_t, y_t)}\right]^{\frac{1}{2}} \tag{2}$$

From Formula (2), x_t, y_t and x_{t-1}, y_{t-1} respectively represent the input and output of period t and period $t-1$, D_t and D_{t-1} respectively represent the period t and period $t-1$ distance function. From period $t-1$ to period t, when $M > 1$, total factor productivity presents an upward trend; when $M < 1$, total factor productivity presents a downward trend; when $M = 1$, total factor productivity remains unchanged. Malmquist index = Pech × Sech × Techch, which are technical efficiency index, pure technical efficiency index and scale efficiency index, respectively.

4. Empirical Analysis.

4.1. **Indicator selection and data sources.** Input variables set the three factors of main business cost (yuan), labor force (people), and berth length (meters) as input variables. Set the main business income of each port (yuan), container throughput (TEU) as the expected output variable. To understand the impact of port pollutants on efficiency, SO_2 emissions (tons of SO_2) were set as undesired outputs. The indicator data in this article are taken from the "Annual Report" of each port from 2011 to 2019, and the "China Port Yearbook". The missing sulfur dioxide emission data in some years is calculated according to the formula in the port fuel combustion process: SO_2 emission = raw coal consumption × sulfur content × 0.8 × 2 × (1-desulfurization rate) [9].

Table 1. Green economy efficiency evaluation index system

Indicator category	Indicator name	Unit
Input indicator	Main business cost	Yuan
	Labor force	People
	Berth length	Meter
Output indicator	Main business income	Yuan
	Container throughput	TEU
	SO_2 emissions	Ton

4.2. **Static efficiency analysis.** This research uses DEAP 2.1 and python software to calculate the green economic efficiency of China's Bohai Rim ports from 2011 to 2019, and uses SPSS software to perform statistical analysis on the efficiency measurement results. The calculation results are shown in Table 2.

1) Comparison of comprehensive efficiency and green economic efficiency

It can be seen from Figure 1 that the mean value of comprehensive efficiency is greater than or equal to the mean value of green economy efficiency (Figure 1), indicating that the port's green economy efficiency has declined after considering the undesired output, indicating that environmental pollution is the main reason for this gap. The reason also reflects the necessity of green economy efficiency evaluation considering undesired output.

Table 2. Analysis results of average comprehensive efficiency and green economic efficiency of Bohai Rim ports

Annual	Comprehensive efficiency	Ranking	Green economic efficiency	Ranking
Dalian Port	1.000	1	0.897	3
Yingkou Port	1.000	1	1.000	1
Tianjin Port	1.000	1	1.000	1
Rizhao Port	0.897	5	0.750	5
Jinzhou Port	0.979	4	0.772	4

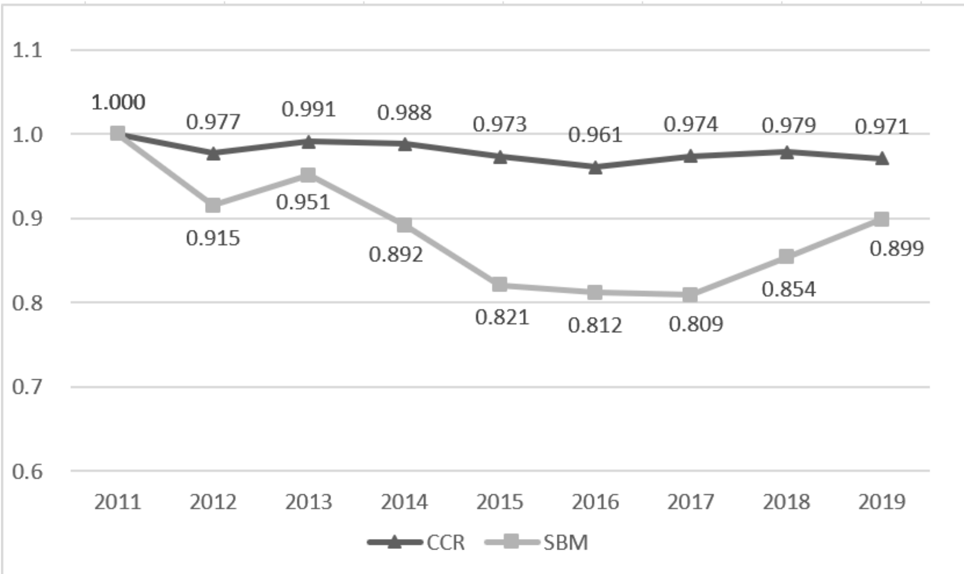

Figure 1. Annual efficiency trend of ports around the Bohai Sea

(Note: SBM is the green economic efficiency considering undesired outputs; CCR is the comprehensive efficiency without considering undesired outputs.)

2) Analysis results of green economic efficiency of Bohai Rim ports

It can be seen from Table 2 that during the measurement period, the green economic efficiency and comprehensive efficiency of Yingkou Port and Tianjin Port were both at the forefront. The green economic efficiency and comprehensive efficiency of Rizhao Port are ranked low, because the rapid development of the port and the uncoordinated control of pollutant discharge restrict the green economic efficiency of Rizhao Port. The green economic efficiency of Dalian Port and Jinzhou Port is at a moderate level among China's Bohai Rim ports, but the green economic efficiency of the two ports has improved to a certain extent in 2019, indicating that environmental protection policies introduced in recent years have promoted energy conservation and emission reduction levels has been further improved.

4.3. **Dynamic efficiency analysis.** This paper uses DEAP 2.1 to calculate the average Malmquist index of the green economic efficiency of China's Bohai Rim ports and its corresponding decomposition items. The results are shown in Table 3. Among them, Effch stands for "Technical Efficiency Change Index", Techch stands for "Technical Progress Change Index", Pech stands for "Pure Technical Efficiency Change Index", and Sech stands for "Scale Efficiency Change Index".

1) Malmquist index calculation

It can be seen from Table 3 that the Malmquist index has increased year by year since 2011, exceeding 1 in 2014, but dropped to 0.962 in 2018, with an average value of 1.021.

TABLE 3. Malmquist index and decomposition of green economic efficiency of Bohai Rim ports in China from 2011 to 2019

Period	Effch	Techch	Pech	Sech	Malmquist
2011-2012	0.982	0.980	1.000	0.982	0.963
2012-2013	1.017	0.980	1.000	1.017	0.997
2013-2014	1.001	0.990	1.000	1.001	0.991
2014-2015	0.976	1.121	1.000	0.976	1.094
2015-2016	0.987	1.110	1.000	0.987	1.095
2016-2017	1.003	1.023	0.968	1.036	1.026
2017-2018	1.020	1.021	1.033	0.987	1.041
2018-2019	0.979	0.982	0.966	1.014	0.962
Mean	0.996	1.026	0.996	1.000	1.021

The reason is that the cargo throughput of the five ports in 2018 showed an upward trend. The development of the port has been accelerated, but the energy conservation and emission reduction measures after the increase in energy consumption have not kept pace with the development, resulting in a downward trend in green economic efficiency. Among them, the technical progress index caused the Malmquist index to increase by 2.40%, and the technical efficiency index caused the Malmquist index to decrease by 0.4%, indicating that the fluctuation of the Malmquist index was mainly affected by the technical progress efficiency, which was positively correlated. Green economy efficiency creates a disincentive. Among them, the pure technical efficiency index caused a decrease of 0.4%, and the scale efficiency index had no obvious impact on the technical efficiency index. It can be seen from Table 3 that the scale efficiency of China's Bohai Rim ports from 2011 to 2019 was generally good, with all values between 0.976 and 1.036, and the scale efficiency index in more than half of the years was greater than or equal to the average value of 1. The overall management level of ports has improved; while the pure technical efficiency index (0.996), another dimension that constitutes technical efficiency, decreased by 0.4%, and the years lower than the average 1 were concentrated in 2016-2017 and 2018-2019, indicating that during this period, the technical level of China's Bohai Rim ports restricted the growth of green economic efficiency to a certain extent.

2) Difference analysis of port Malmquist index

From the perspective of the total factor input-output efficiency of each port, the Malmquist index varies among ports. The average value of Dalian Port, Rizhao Port and Yingkou Port is less than 1, and the average value of Tianjin Port and Jinzhou Port is greater than 1. The average value of Tianjin Port (1.193) is the highest, and the average value of Rizhao Port (0.975) is the lowest (Figure 2). From the dynamic analysis, the green economic efficiency of various ports around the Bohai Sea in China is not balanced. Tianjin Port and Jinzhou Port are relatively high, while the green economic efficiency of the other three ports is relatively low, and the level of green conservation and emission reduction needs to be improved.

5. **Conclusion.** On the basis of constructing the input-output index system of port green economic efficiency, this study uses the CCR-SBM model to conduct a static comparative analysis, and uses the Malmquist index to conduct a dynamic empirical analysis of the green economic efficiency of the five major ports around the Bohai Sea in China from 2011 to 2019.

5.1. **Main conclusions.** The static evaluation results show that first, the green economic efficiency levels of Yingkou Port and Tianjin Port are relatively high and relatively stable, the efficiency value of Rizhao Port ranks low during the measurement period, and Dalian Port and Jinzhou Port are at a medium level; second, the results of this study show that

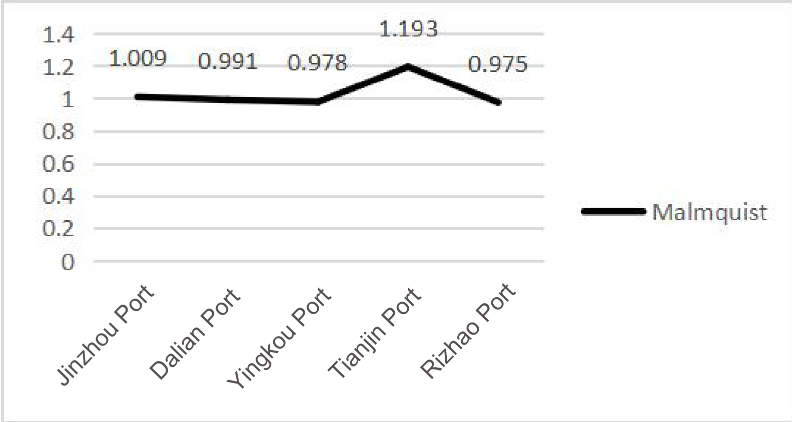

FIGURE 2. The average value of Malmquist index of ports in China's Bohai Rim ports

the mean value of green economic efficiency is less than the mean value of comprehensive efficiency, and it can be seen that SO_2 has a negative impact on the green economic efficiency of ports.

The results of the dynamic efficiency evaluation of the Malmquist index show that first, the Malmquist index of China's Bohai Rim ports increased first and then decreased during the selected calculation year. Due to the development of ports, energy conservation and emission reduction measures have not kept up with the increase in energy consumption, resulting in a decline in the efficiency of the green economy; second, the Malmquist index of each port is greatly affected by the technological progress index, so it is particularly important to improve the technological innovation capability of port enterprises.

5.2. **Key recommendations.**

1) Establish a government supervision mechanism.

The government should improve policy mechanisms, implement management policies, increase law enforcement and supervision, prevent companies from "drilling policy loopholes", and ultimately achieve an efficient atmospheric environmental protection system by improving the corresponding energy structure adjustment policies, economic policies, and management policies. Goulielmos and Pardali also pointed out the source of port environmental pollution, and believed that the establishment of a supportive port culture should be incorporated into port environmental protection [13]. Laws and regulations are binding conditions for the implementation of policies and important guarantees for the smooth progress of green economy work.

2) Deeply promote the emission reduction of major pollutants.

As an enterprise that consumes more energy, the waste gas generated by the port, especially SO_2, has a great restrictive effect on the improvement of energy saving and emission reduction efficiency. Therefore, the port should focus on the reduction of sulfur dioxide and nitrogen oxides, and the use of clean energy is the key to promoting energy conservation and emission reduction in ports. Strengthen the application of new technologies, reduce the proportion of traditional carbon energy use, speed up the construction of desulfurization facilities, accelerate the process of desulfurization and denitrification in non-key industries, improve the energy consumption structure, and reduce the proportion of coal consumption.

3) Increase investment in science and technology and cultivate technological innovation enterprises.

As a key participant in energy conservation and emission reduction, ports should be forward-looking, actively develop new energy technologies, ship shore power technology and frequency conversion energy conservation technologies, select fuels that meet the standards, and actively develop and apply clean energy, indicating that relevant port departments should increase research and development investment, provide more financial support in decontamination and emission reduction, improve the level of technological progress through technological innovation, and continuously upgrade and optimize to improve the efficiency of energy conservation and emission reduction of the port.

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