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Study on the Efficiency Evaluation of Port Green Technology Innovation Based on Ultra-Efficiency DEA and DEA-Malmquist Index Model

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Introduction

China's current economy is shifting from high-speed growth to high-quality development, which is a deep-seated adjustment of the concept and model of development. In this process, green development is particularly important and has become a key direction for economic transformation and upgrading. This is not only in line with the needs of domestic sustainable development, but also in line with the trend of global green economy.

China's economy is transitioning from rapid growth to quality-focused development, reflecting a profound shift in development philosophy. Green development is crucial in this shift, aligning with domestic sustainability needs and global green economy trends.

The "green" goal is essential for implementing the new development concept, promoting high-quality development, and balancing economic growth with environmental protection. Environmental degradation makes green technology innovation crucial for China to address resource and environmental constraints.

The Data Envelope Analysis (DEA) model measures the relative efficiency of decision-making units. However, traditional DEA models have limitations when evaluating port efficiency, lacking depth in analyzing efficiency gaps and conducting static analysis. To address these issues, a super-efficiency CCR-DEA (Charnes-Cooper-Rhodes-Data Envelope Analysis) mode is introduced to evaluate the efficiency of ports achieving an effective state. The DEA-Malmquist index model shows port efficiency changes over years, and total factor productivity decomposition identifies the root causes of these changes.

The organization of this paper focuses on the study of sustainable development in the port industry. Green indicators are incorporated into the port efficiency evaluation system, combined with the super-efficiency DEA and DEA-Malquist index mode for static and dynamic analysis, respectively, to measure the green technological innovation efficiency of 10 ports, in order to comprehensively assess the efficiency status of green technological innovation in ports. The calculation results are also analyzed in depth to find out the important factors affecting the efficiency of green technological innovation in ports, and analyze the inherent pattern of change. Finally, based on the results of the above analysis, suggestions are put forward, aiming to provide strong theoretical support and decision-making reference for the sustainable development of China's ports.

The core contribution of this study is to conduct a systematic and in-depth research on the efficiency of green technology innovation by using the super-efficiency DEA model and DEA-Malmquist index model analysis with the port industry as the key research object.

Methodologies

1) Ultra-efficiency DEA model.

The ultra-efficiency DEA model is a powerful tool to evaluate the efficiency of enterprise technology innovation. It is difficult to evaluate the advantages and disadvantages of traditional DEA models when multiple decision units show efficiency. To answer this problem, Anderson and Petersen (1993) proposed the input-oriented ultra-efficiency CCR-DEA model. The efficiency value evaluation result of the "non-DEA effective" decision unit is the same as that of the traditional DEA model, but the efficiency value of the "DEA effective" decision unit is higher than the measurement results of the traditional DEA model.

2) DEA-Malmquist index model.

The Malmquist index was proposed by MALMQUIST in 1953 to analyze the growth of total factors at two different time points. In 1994, FÄRE et al. combined it with the DEA method to decompose total factor productivity into efficiency changes and technological changes. The DEA-Malmquist index evaluates the dynamic productivity of different time periods by calculating input-output efficiency. Based on the input vector, output vector and distance function values, it calculates the Total Factor Productivity Change Index (TFPCH), the Technological Efficiency Change Index (EFFCH), the Technological Progress Change Index (TECHCH), the Scale Efficiency Change Index (SECH) and the Pure Technology Efficiency Change Index (PECH).

Mathematical Formulas

$$Minimize\theta$$

$$Subject\ to$$

$$\sum_{\substack{j=1\\ j\neq o}}^{n} xi_j\lambda_j \le \theta x_{io}, i = 1,2...,m$$

$$\sum_{\substack{j=1\\ j\neq 0}}^{n} y_{rj}\lambda_j \ge y_{ro}, 1,2,...,s,$$

$$\lambda_j \ge 0, j \neq o.$$

$$m_0(x_{t+1}, y_{t+1}, x_t, y_t) = [\frac{d_t(x_{t+1}, y_{t+1})}{d_t(x_t, y_t)} * \frac{d_{t+1}(x_{t+1}, y_{t+1})}{d_{t+1}(x_t, y_t)}]^{\frac{1}{2}} \quad (3)$$

$$I_{tfpch} = I_{effch} \times I_{tech} \square\ I_{effch} = I_{sech} \times I_{pech} \square\ I_{tfpch} = I_{tech} \times I_{sech} \times I_{pech} \quad (4)$$

Research Questions

This paper explores the efficiency of green technology innovation in China's ports and analyzes the factors influencing the green technology innovation of port enterprises.

Tables

Table 1. Ultra-efficiency values of China's top ten ports from 2015 to 2022

Port	Mean	2015	2016	2017	2018	2019	2020	2021	2022
Yantian port	1.065	1.121	1.997	0.892	0.862	0.867	1.068	0.904	0.806
Beibu gulf port	0.130	0.160	0.157	0.142	0.161	0.094	0.103	0.111	0.113
Xiamen port affairs	0.116	0.137	0.109	0.104	0.110	0.110	0.113	0.123	0.120
Rizhao port	0.208	0.157	0.161	0.177	0.222	0.216	0.229	0.244	0.260
Sipg	0.226	0.098	0.093	0.113	0.155	0.138	0.301	0.438	0.468
Port of tianjin	0.332	0.337	0.189	0.173	0.500	0.192	0.507	0.494	0.261
Port of tongxhan	0.519	0.463	0.596	0.676	0.415	0.446	0.484	0.515	0.554
Lianyungang	0.192	0.162	0.191	0.143	0.159	0.180	0.190	0.226	0.281
Dalian port	0.184	0.182	0.172	0.170	0.174	0.176	0.173	0.215	0.207
Ningbo zhoushan port	0.158	0.153	0.156	0.164	0.177	0.144	0.142	0.151	0.179
Mean		0.297	0.382	0.275	0.293	0.256	0.331	0.342	0.325

Figure

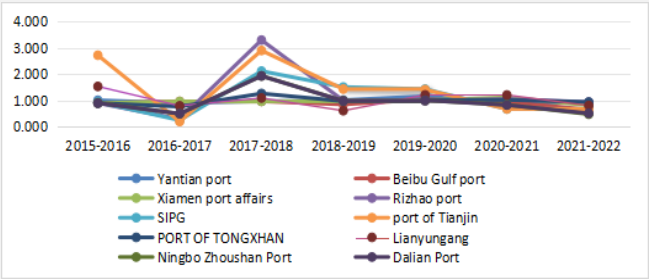

Figure 1. The techch index of China's top ten major ports

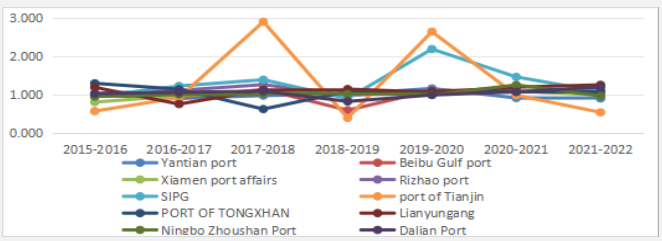

Figure 2. The Malmquist index of China's top ten major ports

Conclusion

From a static point of view, the overall innovation efficiency of green technology in China's ports is low, but it maintains a sustained and slow growth trend.

From a dynamic perspective, the efficiency of green technology innovation in China's ports has maintained a relatively stable trend, indicating that with the development of ports, the green technology innovation in ports is also making continuous progress. In this process, the TFPCH index of each port is significantly influenced by the Technical Progress Index, while the pure technical efficiency Index also plays a crucial role.