Efficiency evaluation of main ports in Jiangsu Province Based on DEA model

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Abstract. Jiangsu Province is an important port province close to the river and the coast. Its port efficiency plays an important role in the development of regional economy. This paper analyzes the efficiency of major ports in Jiangsu Province in 2017 and 2019 by using DEA model. The results show that some inland ports have some problems such as excess input, insufficient output and unreasonable resource allocation. On this basis, suggestions for improvement are put forward to promote the efficiency of ports in Jiangsu Province.

1. Introduce
As an important node of integrated transportation system, port plays an important role in shipping economy and social development. Under the new background of promoting domestic and international double circulation, higher requirements are put forward for the operation efficiency of the port, which affects the smoothness of the economic cycle. Jiangsu Province is located in the north wing of the Yangtze River Delta. It is a veritable port province with rich resources along the river and coast. Therefore, this paper studies and evaluates the efficiency of the main ports in Jiangsu Province, and puts forward suggestions to improve the port efficiency and promote economic development.

As early as in the 1980s, the evaluation research of port efficiency was started, which has been basically mature now. The DEA model is one of the most important research methods. Cullinane[1] used DEA-BCC model to evaluate the efficiency of major container ports in the world, taking shoreline length and other inputs as indicators. Wu et al. [2] used DEA model to analyze the relationship between port loading and unloading equipment capacity and port operation efficiency. Seo et al. [3] selected 32 ports as samples as decision making units to study port efficiency. DEA model was adopted to analyze and point out that improving port infrastructure can effectively improve port operating efficiency. Wang Xuanhuang [4] evaluated the dynamic efficiency of major inland river container ports in China based on the DEA-Malmquist model, and established the DEA-Tobit model to explore the factors affecting port operation efficiency. Zheng Yan et al. [5] took Lianyungang Port as an example and analyzed the logistics efficiency of the port system with the DEA model. On the basis of previous studies, this paper further applies DEA model to analyze and evaluate the operation efficiency of main ports in Jiangsu Province in 2017 and 2019, and puts forward relevant suggestions for the planning, construction and development of ports in Jiangsu Province.
2. Models and Data

2.1 Model theory

This paper applies DEA model to study port efficiency, because DEA, as a nonparametric estimation method, is different from other evaluation methods. The weight of each input and output in the DEA model does not need to be assigned manually. The model calculates the weight according to the optimality principle according to the actual data of input and output, which not only simplifies the processing process, but also enhances the objectivity and authenticity. It is more suitable for the efficiency evaluation of multi-input and multi-output, so it has more advantages in the evaluation of port efficiency.

CCR model and BCC model are the two most typical models in DEA method. CCR model with constant return to scale calculates the value of technical efficiency on the premise of assuming constant return to scale. The study of technical efficiency can minimize the input or maximize the output under certain input. By improving the setting of return to scale in CCR model, the BCC model with variable return to scale is obtained. This solves the confusion between technical efficiency and scale efficiency in the CCR model. The BCC model calculates the technical efficiency and pure technical efficiency under the condition of variable returns to scale. Technical efficiency can evaluate whether port output is optimal under certain input conditions. The pure technical efficiency can evaluate whether the output structure and input conditions of a port are reasonable under the condition of constant input. Scale efficiency refers to the phenomenon that product cost decreases and income increases with the expansion of production scale. Scale efficiency (SE) is equal to technical efficiency (TE) divided by pure technical efficiency (PTE), that is, SE = TE / PTE. By comparing and analyzing the two models, we choose the BBC model which is more suitable for evaluating port efficiency. The model is shown as follows:

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\begin{align*}
\min_{\theta} & \sum_{j=1}^{n} x_j \lambda_j + S^- = \theta x_0 \\
\text{s.t.} & \sum_{j=1}^{n} y_j \lambda_j - S^+ = y_0 \\
& \sum_{j=1}^{n} \lambda_j = 1 \\
& S^-, S^+, \lambda_j \geq 0
\end{align*}
\]

2.2 Data selection

Based on the above DEA-BBC model, when selecting input and output indicators, this paper refers to the indicators selected from relevant domestic and foreign literatures, considers the availability and scientificity of data, and combines with the characteristics of ports in Jiangsu Province. The specific input indexes are wharf length, number of berths and number of berths above ten thousand tons. Output indicators are cargo throughput and container throughput. Port efficiency evaluation indexes are shown in Table 1.

| category          | Specific indicators                  |
|-------------------|--------------------------------------|
| Input index       | Wharf length                         |
|                   | Number of berths                     |
|                   | Number of berths above ten thousand tons |
| Output indicators | Cargo throughput                     |
|                   | Container throughput                 |
The eight major ports in Jiangsu Province are selected as decision-making units, and the input and output indicators are based on the relevant data of major ports in Jiangsu Province in 2017 and 2019. The DEA-BBC model is used to study the operation efficiency of ports in Jiangsu Province. The data are mainly from the China Statistical Yearbook and the China port Yearbook. The original index values of input and output are shown in Tables 2 and Tables 3.

### Table 2 Original index values of input and output of major ports in Jiangsu Province in 2017

| Port              | Wharf length/m | Number of berths /pcs | Number of berths above ten thousand tons/pcs | Cargo throughput/ten thousand tons | Container throughput / ten thousand TEU |
|-------------------|----------------|-----------------------|---------------------------------------------|-----------------------------------|----------------------------------------|
| Lianyungang Port  | 16760          | 81                    | 70                                          | 22840.5                           | 471                                    |
| Nanjing Port      | 27642          | 240                   | 59                                          | 24215                             | 316.7                                  |
| Suzhou Port       | 45031          | 292                   | 129                                         | 60455.9                           | 587.5                                  |
| Nantong Port      | 18399          | 113                   | 54                                          | 23572                             | 100.7                                  |
| Jiangyin Port     | 14191          | 96                    | 31                                          | 15970.5                           | 54.1                                   |
| Zhenjiang Port    | 22623          | 173                   | 55                                          | 14203                             | 40.5                                   |
| Yancheng Port     | 9546           | 91                    | 19                                          | 9016.6                            | 20.8                                   |
| Yangzhou Port     | 30900          | 346                   | 60                                          | 13223                             | 51                                     |

### Table 3 Original index values of input and output of major ports in Jiangsu Province in 2019

| Port              | Wharf length/m | Number of berths /pcs | Number of berths above ten thousand tons/pcs | Cargo throughput/ten thousand tons | Container throughput / ten thousand TEU |
|-------------------|----------------|-----------------------|---------------------------------------------|-----------------------------------|----------------------------------------|
| Lianyungang Port  | 17540          | 84                    | 60                                          | 24432                             | 478                                    |
| Nanjing Port      | 27694          | 223                   | 63                                          | 26566                             | 330.5                                  |
| Suzhou Port       | 45579          | 298                   | 130                                         | 52274.7                           | 626.7                                  |
| Nantong Port      | 20860          | 127                   | 59                                          | 33639.3                           | 154.2                                  |
| Jiangyin Port     | 16721          | 108                   | 39                                          | 23128.5                           | 53.9                                   |
| Zhenjiang Port    | 23339.7        | 176                   | 58                                          | 34009.3                           | 41.5                                   |
| Yancheng Port     | 10362          | 85                    | 22                                          | 7917.81                           | 26.45                                  |
| Yangzhou Port     | 28000          | 249                   | 64                                          | 13917                             | 52.34                                  |

### 3. Results and Discussion

Based on the BCC model, DEAP2.1 software is used to compare and analyze the 8 major ports in Jiangsu Province in 2017 and 2019. Through studying the influence of pure technical efficiency and scale efficiency on the comprehensive technical efficiency, efficiency analysis is conducted, and the comprehensive technical efficiency, pure technical efficiency, scale efficiency and scale efficiency are calculated. The specific values are shown in Table 4.

### Table 4 Efficiency evaluation of major ports in Jiangsu Province in 2017 and 2019

| Port             | 2017     | 2019     |
|------------------|----------|----------|
|                  | TE       | PTE      | SE     | TE       | PTE      | SE     |
| Lianyungang Port | 1.000    | 1.000    | 1.000  | -        | 1.000    | 1.000  |
| Nanjing Port     | 0.994    | 1.000    | 0.994  | 0.895    | 0.897    | 0.998  |
| Suzhou Port      | 1.000    | 1.000    | 1.000  | 0.845    | 1.000    | 0.845  |
| Nantong Port     | 0.977    | 1.000    | 0.977  | 1.000    | 1.000    | 1.000  |
| Jiangyin Port    | 1.000    | 1.000    | 1.000  | 1.000    | 1.000    | 1.000  |
The results show that the average comprehensive technical efficiency, average pure technical efficiency and scale efficiency of the main ports in Jiangsu Province in 2017 are 0.856, 0.876 and 0.972 respectively. In 2019, the average comprehensive efficiency is 0.842, and the average pure technical rate is 0.920. The scale efficiency is 0.910. Generally speaking, the average efficiency of the main ports in Jiangsu Province is above the level.

From the perspective of returns to scale, increasing returns to scale means that increasing input can bring more output, diminishing returns to scale means that increasing input will bring less output, and constant returns to scale means that increasing the same proportion of input can increase the same proportion of output. In 2017, the returns to scale of Nanjing Port, Nantong Port, Zhenjiang Port, Yancheng Port and Nantong Port in Jiangsu Province increased, while the returns to scale of Lianyungang Port, Suzhou Port and Jiangyin Port remained unchanged. In 2019, the returns to scale of Suzhou port will decrease, while those of Nanjing port, Yancheng port and Yangzhou port will increase, while those of other ports will remain unchanged.

From the perspective of comprehensive technical efficiency, the efficiency gap between ports in Jiangsu Province is large. In 2017, the comprehensive technical efficiency of Zhenjiang Port and Yangzhou Port was far lower than the average. In 2019, the combined technical efficiency of Yancheng Port and Yangzhou Port was lower than the average. Among them, the comprehensive technical efficiency of Nanjing Port, Suzhou Port and Yangzhou Port in 2019 was slightly lower than that in 2017, while the comprehensive technical efficiency of Yancheng Port decreased significantly. Among them, the comprehensive technical efficiency of Zhenjiang Port has improved significantly, reaching 1. In 2019, Lianyungang Port, Nantong Port, Jiangyin Port and Zhenjiang Port will reach the forefront of efficiency. Comprehensive technical efficiency changes shown in Figure 1.

![Changes in port comprehensive technical efficiency](image)

From the perspective of pure technical efficiency and scale efficiency, the decrease of comprehensive technical efficiency of Nanjing Port from 2017 to 2019 is due to the decrease of pure technical efficiency. However, the comprehensive technical efficiency of Suzhou Port and Yancheng Port is reduced because the scale efficiency is lower than the pure technical efficiency. The comprehensive technical efficiency of Zhenjiang Port reached 1 in 2019, because both pure technical efficiency and scale efficiency reached the forefront. The pure technical efficiency of Yangzhou Port in 2017 and 2019 was far below the scale.
efficiency, resulting in the overall technical efficiency being consistently below the average. Changes in pure technical efficiency and scale efficiency are shown in Figure 2 and Figure 3.

![Changes in port pure technical efficiency](image1)

Figure 2 Changes in port pure technical efficiency

![Changes in port scale efficiency](image2)

Figure 3 Changes in port scale efficiency

From the perspective of ports, Nanjing port, as one of the largest inland ports in Asia, has a variety of intermodal transport modes, such as rivers, rivers and seas, and land and water. The comprehensive technical efficiency in 2017 and 2019 is higher than the average, which fully reflects the good development prospect of Nanjing port. Nanjing port should make good use of its own hardware advantages to maximize port efficiency. Zhenjiang port and Yangzhou port are both located at the intersection of the Beijing Hangzhou Grand Canal and the Yangtze River. There is only a river gap between the two ports. In 2017, the comprehensive technical efficiency of the two ports has a small difference, but by 2019, the comprehensive technical efficiency gap between the two ports will be very large. In the case of roughly the same input index, the cargo throughput of Zhenjiang port is much higher than that of Yangzhou port. This shows that Yangzhou port has not made full use of its own port resources and advantages. It should make full use of the port's infrastructure and give full play to its own advantages to improve the port's cargo throughput. The scale and output of Lianyungang, Jiangyin and Nantong ports are in balance. Their comprehensive technical efficiency is very high in two years, and their fluctuation is very small. They should continue to develop, extend the port industrial chain, expand the economic influence of hinterland, and promote the development of port scale.
4. Conclusions
In this paper, DEA-BCC model is used to compare and analyze the operating efficiency of eight major ports in Jiangsu Province in 2017 and 2019. Through the analysis, it is concluded that the average efficiency of major ports in Jiangsu Province is good and has a good development prospect. The vast majority of ports in Jiangsu Province have reached the optimal pure technical efficiency, but there are also a few ports lack of technological innovation, resulting in low capacity and low efficiency of port operation. In addition, the inland ports of the Yangtze River in some provinces are crowded, and the lack of output leads to the waste of port resources. At the same time, some ports have not reached the best scale efficiency and have not yet formed scale effect.

According to the results of the analysis, combined with the characteristics of the ports in Jiangsu Province. Improving port efficiency and forming scale effects require scientific allocation of port resources, optimizing input and output, and avoiding waste of resources; combining the industrial structure of the city where the port is located and the development layout of the port industry, adapting measures to local conditions, optimizing the port layout, clarifying the port positioning, and realizing the port's misplaced development, To avoid vicious competition; to promote the development of technological innovations such as intelligent construction, the Internet of Things, port automation operations, and intelligent logistics to reduce operating costs, thereby improving port efficiency and promoting regional economic development.

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