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Research on Logistics Efficiency Evaluation of Dalian Port Based on Three-stage DEA

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Abstract

Northeast China is an important industrial and agricultural base in China. In the 14th Five-Year Plan of China, General Secretary Xi pointed out that it is necessary to promote the comprehensive revitalization of Northeast China. Dalian Port, as the largest port in Northeast China, undertakes the important task of regional revitalization. Based on this background, relevant data are selected, and the logistics efficiency of Dalian Port from 2011 to 2020 is analyzed by using three-stage DEA method. The results show that the final comprehensive efficiency of Dalian Port in 10 years, the average values of pure technical efficiency and scale efficiency are 0.978, 0.997 and 0.981 respectively, which are 0.048, 0.031 and 0.022 higher than those of the first three efficiency values excluding environmental factors and statistical disturbance factors, indicating that Dalian Port logistics efficiency is indeed affected by environmental factors and statistical disturbance factors, and scale efficiency has obvious constraints on Dalian Port logistics efficiency. Based on this, Finally, the paper puts forward some suggestions on port technology innovation and scale adjustment.

Keywords

Three-stage DEA, logistics efficiency, Dalian Port, Northeast China

1. Introduction

As an important industrial and agricultural production base in China, Northeast China is an important guarantee for safeguarding China's national security, food security, environmental security, energy security and the safety of various industries, which is related to the overall situation of national development. In the 14th Five-Year Plan of China, General Secretary Xi pointed out that it is necessary to promote the comprehensive revitalization of Northeast China, adhere to the general tone of seeking progress while maintaining stability, base on the new development stage, completely, accurately and comprehensively implement the new development concept, construct a new development pattern, and promote high-quality development as the theme. To deepen the supply-side structural reform as the main line, to reform and innovation as the fundamental driving force, to meet the people's growing needs for a better life as the fundamental purpose, overall development and security.

Nowadays, more and more port cities begin to vigorously develop port logistics as a breakthrough to promote urban development. The concept of vigorously developing port logistics trade to promote urban economic development is accepted by more and more port cities. In addition, vigorously developing port trade can also fully promote the development of a large number of industries around the port and the surrounding areas of the port hinterland. At the same time, the industrial and economic development of the surrounding areas of the port will have a positive impact on the

development of port logistics trade, and thus achieve a virtuous circle. Dalian Port is the largest deep-water port and ice-free port in Northeast China, and its cargo throughput ranks first in the northeast port all the year round, which plays an important role in the economic development and foreign exchanges in Northeast China. Therefore, it is very necessary to study the logistics efficiency of Dalian Port, and improve the logistics efficiency of Dalian Port through the research and analysis results. Better drive the hinterland of Dalian Port economic and industrial development (Lu Lin, 2021).

2. Literature review

Through the study of many scholars at home and abroad in the logistics efficiency of the literature, the mainstream of research is mainly divided into parametric and non-parametric methods, in which non-parametric methods mainly use data envelopment analysis (Data Envelopment Analysis, DEA), its advantage is that only the input and output data can be used to objectively express the results of the study. At present, many scholars have adopted the DEA method, such as Elisa using the PCA-DEA model to evaluate the logistics efficiency of Brazil ports for 8 years. It is found that due to improper management, Brazilian ports are generally inefficient. Damage to the export of Brazil agricultural and sideline products (Elisa P & Guilherme R, 2020). Quintano et al. used the DEA-SBM model to evaluate the port logistics efficiency, and proposed a solution to the problem based on the research results to achieve the green development of the port (Quintano C, Mazzocchi P, & Rocca A, 2020). Dyck used the DEA-BCC model to study the logistics efficiency of six major ports in western Africa. It was found that the ports with low logistics efficiency mainly had the problem of waste of resources. And there are great problems in the port operation management mode (Dyck G, 2015). Zhang Li used the DEA-BCC model to analyze the logistics efficiency of Xuzhou City, and used the Tobit regression model to analyze several factors that have an impact on logistics efficiency. The results show that the weak infrastructure leads to the low logistics efficiency of Xuzhou City (Zhang Li, 2020). Jiang Jianhong et al. used the PCA-DEA method to evaluate the logistics efficiency of several port groups in China in the face of multiple evaluation indicators (Jiang Jianhong & Yang Jianbo, 2019). The parameter method is mainly stochastic frontier analysis, The advantage of Stochastic Frontier Analysis (SFA) is that it can exclude the influence of external environmental factors. Yu Lijing and others used SFA to calculate the logistics efficiency of all cities in Shandong Province. The results showed that the average value of comprehensive logistics efficiency in Shandong Province was not high, and there was a waste of resources (Yu Lijing, Wang Haifeng, & Jiang Yongqiang, 2017). Fan Yuan and others used SFA to analyze the logistics efficiency of 30 provinces, municipalities and autonomous regions in China. The results show that there is a huge gap in logistics efficiency between provinces and cities in China, and the overall situation is high in the east and low in the west, high in the south and low in the north (Fan Yuan & Ma Limei, 2011).

In 2002, Fried et al. proposed that there are three factors affecting the performance of decision-making units, namely, management inefficiency, environmental factors and statistical disturbance. The traditional DEA model only considers the impact of management inefficiency on efficiency, and does not separate the impact of environmental factors and statistical disturbance factors on decision-making units. Using three-stage DEA method can effectively separate the three factors on the logistics efficiency, making the results more accurate.

This paper will use the three-stage DEA method, this paper synthesizes the two environmental factors of Dalian City and the total import and export volume, and use the three-stage DEA model based on VRS-BCC to systematically analyze and evaluate the logistics efficiency of Dalian Port in the past ten years.

3. Study design

3.1 Three stage DEA model

The three-stage DEA model was first proposed by Fried et al. In the first stage, the traditional DEA model was used to analyze the initial efficiency of DMUs. In the second stage, the SFA regression method was used to eliminate the influence of environmental and statistical disturbance factors on the analysis results. In the third stage, the DEA efficiency analysis was carried out on the adjusted input-output variables.

3.1.1 first-stage BCC model

The BCC model with variable returns to scale is adopted in the first stage, as shown in Formula (1):

$$\min \theta - \varepsilon \left(\hat{e}^T S^- + e^T S^+ \right)$$
$$s.t. \begin{cases} \sum_{j-1}^{n} X_j \lambda_j + S^- = \theta X_0 \\ \sum_{j-1}^{n} Y_j \lambda_j - S^+ = Y_0 \\ \lambda_j \geq 0, S^-, S^+ \geq 0 \end{cases} \tag{1}$$

wherein, $j = 1, 2, \cdots, n$ Indicates a decision unit, X, Y S^+ and S^- are output slack variables and input slack variables, respectively; n is the number of decision making units, λ_j is the decision variable; ε is a non-Archimedean infinitesimal; θ is the overall efficiency of the DMU.

3.1.2 Second stage SFA model

The theoretical model formula (2) is established by collecting data with two indexes of environmental explanatory variables and slack variables as shown below:

$$S_{ij} = f^i \left(Z_j, \beta^i \right) + v_{ij} + u_{ij}$$
$$i = 1, 2, \ldots, m; \quad j = 1, 2, \ldots n \tag{2}$$

where β^i is the parameter vector of the environment variable to be estimated. $f^i \left(z_j, \beta^i \right) = z_j, \beta^i$ denotes the way the environment variable affects the slack variable s_{ij}. $v_{ij} + u_{ij}$ is a mixed error term, where, v_{ij} is a random error term, u_{ij} indicating management inefficiency. Estimation of conditions by managing inefficiencies $E\left[u_{ij} \middle| v_{ij} + u_{ij} \right]$ As shown in formula (3):

$$E\left[v_{ij} \middle| v_{ij} + u_{ij} \right] = s_{ij} - z_j \hat{\beta}^i - \hat{E}\left[u_{ij} \middle| v_{ij} + u_{ij} \right]$$
$$i = 1, 2, \ldots, m; \quad j = 1, 2, \ldots n \tag{3}$$

Finally, the input amount of other provinces is adjusted according to the input amount of the province with the best efficiency, as shown in Formula (4):

$$x_{ij}^* = x_{ij} + \left[Max_j \left(z_j \hat{\beta}^n \right) - z_j \beta^n \right] + \left[Max_j \left(\hat{v}_{ij}^{\wedge} \right) - v_{ij} \right]$$
$$i = 1, 2, \ldots, m; \quad j = 1, 2, \ldots n \tag{4}$$

Where: x_{ij}^* and x_{ij} are the calculated corrected input value and the initial input value respectively, is the estimated value of the parameters of environment variable $\hat{\beta}^n$, $\left[Max_j \left(z_j \hat{\beta}^n \right) - z_j \beta^n \right]$ indicates that so the decision unit is under the same environmental constraints indicates that so the decision unit is under the same environmental constraints, $\left[Max_j \left(\hat{v}_{ij}^{\wedge} \right) - v_{ij} \right]$ Representing that the logistics efficiency of each decision making unit is in the same natural state.

3.1.3 The third stage BCC model

The adjusted input data obtained in the second stage are combined with the original output data collected in each year and put into the BCC model for calculation.

3.2 Selection of evaluation indicators

As a cargo transfer station, the port does not produce substantive goods, and the value it provides is mainly logistics services. Therefore, the selection of various indicators of the port also has certain particularities. Through consulting the relevant research literature, there are two methods for selecting the port indicators: indirect method and production method. The production method evaluates the port as a production enterprise, and the input indicators are mainly infrastructure. This paper evaluates the port efficiency by taking the cargo throughput as the main output index. The indirect method is based on the financial data published by the company behind the port, such as the investment in science and

technology, the number of employees and other indicators as the input index, and the business income and profit margin as the output index. Based on the availability of data, this paper uses the production method to evaluate the port efficiency.

Therefore, this paper selects the number of production berths, regional highway freight volume and annual port capacity reflecting the scale of port infrastructure as input indicators, cargo throughput and container throughput reflecting the level of port logistics operations as output indicators, and regional GDP and regional total import and export volume reflecting the level of regional economic development as environmental indicators.

4. Analysis of empirical results

4.1 Empirical results of the first stage BCC model

The collected input and output data into the DEAP2.1 software for calculation and analysis, the results are summarized in Table 1.

The first stage DEA results initially show the logistics efficiency of Dalian Port from 2011 to 2020. According to the information shown in the table, before stripping environmental factors and random disturbances, the comprehensive technical efficiency of Dalian Port in 2011, 2012, 2014, 2015 and 2017 was 0.879, 0.768, 0.924, 0.850 and 0.875 respectively, indicating that under the existing input conditions. There is a large room for growth in the overall efficiency of Dalian Port in the past five years. From the perspective of DEA effectiveness, Dalian Port has remained at the forefront of efficiency in 2014, 2016, 2018, 2019 and 2020. The logistics efficiency of these five years has been at the forefront and the efficiency in all aspects is optimal. In addition, the pure technical efficiency in 2011 was 1, but its scale efficiency did not reach efficiency. This shows that the pure technical efficiency is not the main factor limiting the development of Dalian Port, but because this calculation result does not eliminate the influence of environment and random disturbance, it can not accurately show the logistics efficiency of Dalian Port in the past ten years, so it needs to be further adjusted and measured.

Table 1. Logistics efficiency of provinces and cities in the first stage of Yangtze River Economic Belt

Year	overall technical efficiency	pure technical efficiency	scale efficiency	scale efficiency characteristics
2011	0.879	1	0.879	irs
2012	0.768	0.897	0.856	irs
2013	0.924	0.945	0.978	irs
2014	1	1	1	-
2015	0.850	0.912	0.931	irs
2016	1	1	1	-
2017	0.875	0.926	0.945	irs
2018	1	1	1	-
2019	1	1	1	-
2020	1	1	1	-
Average	0.930	0.966	0.959	

4.2 Analysis of the Second Stage SFA Regression Results

The input variables of Dalian Port obtained in the first stage, namely, the number of berths for production, the amount of road freight and the slack of annual capacity, are taken as the explanatory variables of the three SFA models, and the environmental variables, namely, the regional GDP and the total import and export volume of the region, are taken as explanatory variables. The software Frontier4.1 is used to estimate the results, and the results are shown in Table 2.

Table 2. SFA Regression Table

Indicators	slack variable for production berths	Highway freight volume relaxation variable	annual capacity relaxation variable
constant term	9.42***(9.55)	1310.44***(1310.43)	1741.51***(1741.53)
Gross regional product	-0.35(-2.34**)	-0.06(-3.59***)	-0.10**(-2.58)
Total import and export volume/100 million yuan	-0.18***(-3.74)	-0.25**(-2.49)	-0.30***(-9.40)
σ^2	8.20***(9.37)	238556.55***(238556.55)	330410.70***(330410.70)
γ	1.00***(1213.40)	1.00***(211.71)	1.00***(439841.54)
log likelihood function	-16.88	-68.64	-70.29
LR test of the one-sided error	36.76***	44.07***	18.56***

Note: *, ** and *** indicate significance levels of 10%, 5%, and 1%, respectively; Values of t in parentheses

As can be seen from Table 2, the LR one-sided test of the SFA model corresponding to the three input slack variables passed the 1% significance test, indicating that the SFA regression is effective and the regression model is set correctly. At the same time, the σ of the three SFA models[2]The coefficients of the two environmental variables to the three input slack variables are significant at least at the level of 5%, which indicates that the GDP and the total import and export volume of Dalian Port have a significant impact on the input redundancy, indicating that the selection of environmental variables is reasonable.

Further analysis of the coefficient of environmental variables to input slack variables shows that: (1) GDP has a significant negative effect on the slack variables of berths, highway freight volume and annual port capacity, and the coefficients are -0.35, -0.06 and -0.10, respectively, indicating that the increase of GDP will reduce the input redundancy of Dalian Port, and the degree of influence is low; (2) The total import and export volume has a significant negative impact on the number of production berths, highway freight volume and port annual capacity slack variables, the coefficients are -0.18, -0.25 and -0.30, respectively, indicating that the increase of the total import and export volume will reduce the input redundancy of Dalian Port, and the degree of impact is low. The higher the level of economic development of the region, the stronger the consumption capacity of the port hinterland, promote the growth of import and export trade, is conducive to the development of the port, and the economically developed areas of the port production technology and management concepts, such as the use of a higher level, which can promote the port logistics efficiency.

4.3 DEA Efficiency Analysis after Adjusting Input in the Third Stage

Excluding the impact of environmental factors and random disturbances on the logistics efficiency measurement of Dalian Port, using the adjusted input data and DEAP2.1 software, the DEA model is used again to evaluate the efficiency. The efficiency value of Dalian Port in each year can more reasonably reflect the development of Dalian Port in each year. The results are shown in Table 3.

Table 3. DEA efficiency of Dalian Port in the third stage

Year	overall technical efficiency	pure technical efficiency	scale efficiency	scale efficiency characteristics
2011	0.913	1	0.913	Irs
2012	0.912	0.997	0.915	irs
2013	1	1	1	-
2014	1	1	1	-
2015	0.957	0.976	0.981	irs
2016	1	1	1	-
2017	0.996	0.997	0.999	irs
2018	1	1	1	-
2019	1	1	1	-
2020	1	1	1	-
Average	0.978	0.997	0.981	

Compared with the calculation results of the first and third stages, it can be seen that after eliminating the influence of environmental factors and random disturbances, the logistics efficiency of Dalian Port in the years before reaching the frontier has increased, the average comprehensive technical efficiency has increased by 0.048 after adjustment, the average pure technical efficiency has increased by 0.031 after adjustment, and the scale efficiency has increased by 0.022 after adjustment. It can be seen that in the calculation results of the DEA model without excluding the influence of environmental factors and random disturbances. The value of logistics efficiency of Dalian Port is low, and its real efficiency level is underestimated. From the results of the three stages, it can be seen that the first stage, that is, the years before the adjustment have been at the frontier of comprehensive technical efficiency, and after the adjustment of the third stage, they are still at the frontier, and 2013 has also reached the frontier after adjustment. In these four years where the comprehensive technical efficiency has not reached the frontier, it is in a state of diminishing returns to scale. In 2011 and 2012, which have the lowest comprehensive technical efficiency, the pure technical efficiency of the two years is 1 or close to 1, and its scale efficiency is low. According to the data, China's economy has developed rapidly in the past 10 years, and the infrastructure investment of ports and port hinterland cities is also in a blowout period. In a large number of infrastructure depreciation and renovation, hinterland road freight volume and other inputs have increased, and related investment and construction cannot be fully converted into actual effective output in the past two years. In this case, the port should be fully aware of the imbalance of input-output ratio, strengthen the management of the port group, reduce the scale of production and operation and control the input of resources. In the remaining six years, the comprehensive technical efficiency of Dalian Port has reached 1, indicating that the utilization rate of resources in Dalian Port is relatively high during this period, and it is only necessary to stabilize the scale of investment and construction. The average comprehensive technical efficiency of Dalian Port is 0.978 in the past 10 years, which is at a high level. However, there is still room for improvement in port investment scale and management mode.

5. Conclusion and countermeasure suggestion

This paper uses three-stage DEA to measure the logistics efficiency of Dalian Port from 2011 to 2020, and draws the following conclusions.

Environmental factors and random disturbance do have influence on the logistics efficiency measurement of Dalian Port, among which the input redundancy of GDP and the total import and export volume of port hinterland cities are negative, that is, the higher the GDP and the total import and export volume of the region, the more favorable it is for the construction of port berths, the improvement of the annual throughput capacity of the port and the increase of the total highway freight volume of the port hinterland cities. After the adjustment, the overall comprehensive efficiency, pure technical efficiency and scale efficiency of Dalian Port in the past ten years have increased. The average value is above 0.97, which indicates that the logistics efficiency of Dalian Port in the past ten years is generally high, but there is still room for improvement. After adjustment, the comprehensive technical efficiency has reached the optimal level in 6 years. However, the average pure technical efficiency is higher than the average scale efficiency in the past 10 years. Therefore, the port needs to learn from other advanced port management models and improve management technology. At the same time, it is necessary to pay attention to rationally adjust the port development scale so as to continuously improve the port logistics efficiency. Therefore, the following countermeasures are put forward from the aspects of improving the pure technical efficiency and scale efficiency of the port:

(1) To improve the pure technical efficiency of Dalian Port, the port should learn from the advanced technology and management concept of other ports at home and abroad, start with the equipment and personnel, introduce intelligent operation machinery and introduce high-level technical personnel and management personnel, optimize the management mode and equipment of the port group, and improve the pure technical efficiency of the port.

(2) To improve the scale efficiency of Dalian Port, Dalian Port should improve its service and innovation ability, find the balance point of port scale, strengthen the upgrading and maintenance of infrastructure, improve the service capacity of the port, control the cost to maximize the input and output efficiency of the port in the case of the best scale.

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Historical experience and enlightenment of the revitalization and development of Northeast China under the leadership of the Party

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