Research on Logistics Efficiency of Chinese Ports above Designated Size Based on DEA-Malmquist Index

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ABSTRACT
The port is no longer a docking point for ships, but a multi-functional platform for sorting, warehousing, transportation and distribution due to the wide application of e-commerce logistics platforms. The continuous functioning and the efficiency have to be paid large attention to, which can promote faster exotic product delivery and lasting international commercial relationships. In order to measure the logistics efficiency of the port and identify defections, this paper selects provinces and cities where 11 important ports are located in China by the utilization of DEA-Malmquist index. The results show that the bottleneck of the growth rate of my country's port throughput appears. Taking the Qinling and Huaihe River as the boundary, the port transportation efficiency in the north is generally not as efficient as that in the south and even has a tendency to retreat. The improvement of port logistics efficiency should focus on increasing scale efficiency, improving resource allocation and management capabilities, finding new revenue growth points and reducing costs to break through bottlenecks.

Keywords: *Malmquist index, Logistics efficiency, Economic growth, Data envelopment analysis (DEA)*

1. INTRODUCTION

The efficiency of port logistics is required to be improved constantly so as to catch up with the international trade and regional economic integration. The development of logistics is the pulse of the national strategy. With the continuing application of 5G technology and Internet of Things (IoT) in the field of logistics, more transparent and fluent markets are emerging which gives new momentum to seaports. However, the situation in the global market is not favorable. On the one hand, the outbreak of the COVID-19 epidemic has fully exposed the shortcomings of the lack of coordination and weak elasticity of China's supply chain service system. On the other, under the influence of the slowdown in the growth rate of international trade, due to the international trade frictions, the development of ports may be hindered. To adapt to this macro-environment, the operation of port logistics should be transformed from "interconnection" to "supply chain", making full use of the advantages of the customs bonded area and the rapid development of the hinterland economy, which need the full support of government and leading enterprises. Therefore, it is necessary to take the provinces and cities where the ports above designated size in China are located as the research objects, and comprehensively use the data envelopment analysis (DEA) model to make static analysis in combination with the Malmquist index to evaluate the development level of their logistics efficiency dynamically. Ports above designated size are those ports that have an annual throughput of more than 10 million tons and are included in the "Above Designated" list of the Ministry of Transport of China. In view of the collectability and representativeness of data, research on ports above designated size is more valuable for reference.

DEA model has been widely used to investigate the logistics efficiency of ports. Ni et al. (2017) found that port efficiency is greatly affected by the level of port logistics informatization and land transportation capacity by using DEA-Tobit model[1]. It is recommended to further promote port cooperation, improve the level of informatization, and the portland transportation collection and distribution system to improve the port logistics efficiency; Nhu-Ty and Thanh-Tuyen (2018) provide the optional decision rules about the number of container traffic by applying DEA model to measure the relative efficiencies of container ports and terminals[2]. Jiang et al. (2019) used PCA to reduce the dimensions of the evaluation data while considering more indicators and the DEA method to evaluate the logistics efficiency of port enterprises in China.[3].

DEA model has also been widely used from various perspectives including enterprises, provinces, cities and countries, and has been discussed in the development of the logistics industry by collecting different input-output indicators. Cui et al. used the DEA model to study logistics efficiency from the enterprise perspective[4]; Cui Wangni studies the differences in logistics efficiency between regions from the perspective of provinces and selects industry GDP as an input variable in finance[5]; Isotilia (2018) uses a kind of variant from a national perspective that is multi-modal, four-legged transportation solution to measure the transportation efficiency between China and Poland[6]; Hong Gyun Park(2016) et al examine the efficiency and operations of logistics providers employing the DEA method to analyze a five-year panel data[7]. Theophilus Lartey et al.(2021)utilize the three-stage DEA to examine the influences of bank risk exposures and interbank fundings over the operational efficiency and found that overall bank performance management is achieved through a delicate complement of risk, funding and financial performances[8]. All in all, due to the deviation in research scope, dimension and research method, there are also differences in research results and there is no rigid standard regarding the selection of research indicators.

The paper is composed of 4 sections. In the first part, a brief introduction about the necessity of the research and the analysis is presented. The second section includes a description of the methods used in the research, consisting of an explanation of the DEA model and the Malmquist index. Section 3 includes the empirical process of the research. In section 4, the conclusions and relevant suggestions are given. This paper is supplemented by a list of references.

This paper chooses the gross regional product (GRP) of the province and city where the port is located as the output variable, as a measure of the contribution of port logistics development to the economic development of the hinterland. To the best knowledge of the author, there is no reference using local GRP as an output factor for the measurement of logistics efficiency. By studying the development of the Hinterland where the ports are located, it may be found that the economic development of the inland areas is closely related to the port logistics platform, which leads to another suggestion that the cooperation between the government and leading enterprises of port logistics could be a future tendency.

2. THE RESEARCH MODEL

2.1 DEA Model

The DEA technique was applied based on standard linear programming to provide optional amendments of multiple inputs and outputs, resulting in the optimal efficiency of decision making units(DMUs). The model adopted is the input-oriented BCC-DEA model. As DEA method avoids the influence of subjective factors to the greatest extent by using linear programming to automatically generate weights, which would be intimidating for decision-makers to assign numbers for measuring efficiency. The principle of the DEA method is mainly to determine the relatively effective production frontier by means of Operations Research and Mathematical Statistics through the inputs and outputs of the DMUs that do not change and to evaluate the degree of deviation of each DMU from the DEA frontier[9].

BCC-DEA models can deal with variable returns to scale(BCC, also known as VRS)[10], which is frequently used in the analysis of port logistics efficiency where returns to scale are not constant. Through DEAP2.0 software, the technical efficiency of each port can be decomposed into scale efficiency and pure technical efficiency, which can further explore the bottlenecks restricting the improvement of technical efficiency and propose optional improvement plans.

2.2 Malmquist Productivity Index

According to the above calculation principle of DEA model, the result obtained by DEA-BCC model is the efficiency value within the certain time range, that is, the static value of the target decision-making unit. The Malmquist index makes up for the flaw that the DEA model can only analyze static efficiency by addressing panel data from multiple periods to assess the logistic efficiency over time. It can also decompose the Malmquist index to more accurately determine the main factors that fluctuate the efficiency value over time[11]. In this study, the provinces and cities where ports above designated size in China are located are regarded as a decision-making unit (DMU), and the Malmquist index can represent the change of efficiency of each DMU dynamically from time t to time t+1. The formula for calculating the Malmquist index is:

$$M(x^{t+1}, y^{t+1}, x^t, y^t) = \left[\frac{D^t(x^{t+1}, y^{t+1})}{D^t(, x^t, y^t)} \times \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^{t+1}(, x^t, y^t)}\right]^{\frac{1}{2}} = \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^t(, x^t, y^t)}\left[\frac{D^t(x^{t+1}, y^{t+1})}{D^{t+1}(, x^{t+1}, y^{t+1})} \times \frac{D^t(x^t, y^t)}{D^{t+1}(, x^t, y^t)}\right]^{\frac{1}{2}} = effch \times techch \quad (1)$$

Where variable M refers to the Malmquist productivity index, x and y are the input and output values of the object being evaluated; t is the period, which is the year in this article; Dt and Dt+1 are the distance from the DEA frontier of the time point. M index > 1 indicates that the total factor productivity (tfpch) in period t+1 is rising relative to period t, and the logistics technology and management level are both improving over time; when effch > 1, it indicates that the application efficiency of logistics technology is improving. Under the assumption of the BCC model, the effch index can be decomposed into the pure technology change index (pech) and the scale efficiency change index (sech), namely:

$$\text{effch} = \text{pech} \times \text{sech} \quad (2)$$

The decomposition of the Malmquist index can comprehensively and completely analyze the dynamic changes of port logistics efficiency:

$$\text{tfpch} = \text{effch} \times \text{techch} = \text{pech} \times \text{sech} \times \text{techch} \quad (3)$$

3. EMPIRICAL ANALYSIS

3.1 Construction of the Indicator System and Selection of Data Indicators

To better understand the contribution of logistics development made to the local economy, this article chooses GRP and logistics industry freight turnover as output variables to measure the quality of the logistics and the influences on regional economic development. According to the traditional production operation theory, the development of the industry requires the input of various resource elements, generally including three types of human, financial and material resources. This paper selects the number of staff directly related to the logistics industry (transportation, warehousing and postal services) as the labor input, the added value of the logistics industry as the monetary input, and the total mileage. Among them, the total mileage is used as material input, which is the sum of railway mileage, inland waterway mileage and highway mileage. The variables used are presented in Table 1.

Table 1. Port Logistics Input-Output Index System

Criterion layer	Dimension	Indicator layer
Input	Labor	Transportation, Warehousing and Postal Employment
	Finance	Value added in the transport, warehousing and postal industries
	Material	Total mileage (10,000 kilometers)
Output	Quantity	Freight turnover (100 million ton-kilometers)
	Quality	Gross regional product

The data used in this paper are from China Statistical Yearbook, China Logistics Yearbook, and China Statistical Abstract. In order to study the dynamic changes of logistics efficiency, this paper selects the data of 11 provinces and cities from 2016 to 2018 for analysis.

3.2 Static Analysis of DEA Model

Using DEAP2.0 to investigate the logistics efficiency of 11 provinces and cities in China from 2016 to 2018 using the input-output indicator system, the comprehensive efficiency value, pure technical efficiency value and scale efficiency value of port logistics were calculated. The results are presented in Table 2.

Table 2. Distribution of port logistics efficiency in 11 provinces and cities in 2016 and 2018

	2016				2018			
	crste	vrste	scale	Returns to scale	crste	vrste	scale	Returns to scale
DMU1	0.751	0.763	0.984	irs	0.736	0.769	0.957	irs
DMU2	0.801	0.891	0.9	drs	0.591	0.662	0.892	drs
DMU3	1	1	1	-	1	1	1	-
DMU4	0.931	0.935	0.996	drs	0.789	0.836	0.944	drs
DMU5	1	1	1	-	1	1	1	-
DMU6	1	1	1	-	1	1	1	-
DMU7	1	1	1	-	1	1	1	-
DMU8	0.692	0.753	0.92	drs	0.956	0.961	0.995	drs
DMU9	1	1	1	-	1	1	1	-
DMU10	0.821	0.852	0.964	irs	0.791	0.85	0.931	irs

DMU11	0.782	1	0.782	irs	0.743	1	0.743	irs
MEAN	0.889	0.927	0.959		0.873	0.916	0.951	

Comprehensive technical efficiency (crste) is the production efficiency of DMU's input elements at a certain (optimal scale), which can measure and evaluate the DMUs' resource allocation capability, resource utilization efficiency and other capabilities comprehensively. Because Comprehensive technical efficiency = pure technical efficiency (vrste) × scale efficiency (scale).

Vrste is the efficiency determined by the system and management level, and the efficiency of the enterprise due to factors such as management and technology. If vrste=1, it demonstrates that at the current technical level, the research object is efficient in using the input resources. Scale measures whether a business is currently operating at an optimal scale.

(1) As for comprehensive technical efficiency value(crste), the average total efficiency of the entire logistics industry dropped from 0.889 in 2016 to 0.873 in 2018, with large differences within the industry. Among them, five provinces and cities in 2016-2018 achieved DEA effectiveness in port logistics efficiency, and DMU3, DMU5, DMU6, DMU7, DMU9 were at the forefront of efficiency, indicating that both technical and scale The utilization of resources in these areas has reached the optimal state. These provinces and cities should shed lights on the development of the economic scale of the port hinterland and the improvement of the management level, and optimize the structure of the port logistics industry to realize the integration of port logistics. These regions should improve the service level, so as to achieve economies of scale, industrial clusters and logistics networking.

(2) The pure technical efficiency of port logistics is generally in a state of decline, mainly due to the decline in the technical efficiency of DMU2, from 0.891 in 2016 to 0.662 in 2018. There is a lot of space for improvement, and the sharp decline in pure technical efficiency in recent years shows that the main reason why the province's comprehensive efficiency has not reached full effectiveness is the scale efficiency is low, and the scale of investment should be adjusted to further improve the scale benefit. The comprehensive efficiency of the remaining four provinces is very close to the technical efficiency, indicating that the main reason for the comprehensive efficiency not reaching full effectiveness is the limitation of pure technical efficiency, just not as prominent as DMU2.

(3) The pure technical efficiency of DMU11 has been 1 for three years, but the overall efficiency and scale efficiency have not been reached, indicating that DMU11 still needs to improve in terms of scale efficiency, which can be classified as weak DMU efficiency; areas with increasing scale efficiency such as DMU1, DMU10, DMU11 can reasonably increase capital investment in port infrastructure, while other areas with diminishing returns to scale have obvious efficiency losses, and attention should be paid to the allocation of funds and the rational use of resources.

3.3 Dynamic Analysis of Malmquist Index

The Malmquist index can dynamically reflect the trend of logistics efficiency in various regions. This paper uses DEAP2.0 to run the data of port logistics in 11 provinces and cities in China from 2016 to 2018 to identify movements in total factors production rate and make necessary comparisons, as shown in Table 3 and Table 4.

Table 3. Total factor productivity of logistics industry from 2016 to 2018

year	Effch	techch	pech	sech	tfpch
2016-2017	0.95	1.014	0.97	0.979	0.963
2017-2018	1.029	1.057	1.016	1.013	1.087
mean	0.988	1.035	0.993	0.996	1.023

3.3.1 Analysis of Changes in Overall Efficiency

The average value of the logistics efficiency index in all regions of China from 2016 to 2018 was 1.023, with an average annual growth rate of 2.3%, showing an overall upward trend, and the total factor productivity index in each year was greater than 1 , indicating that the port logistics efficiency is in a continuous upward trend. From the decomposition of the total productivity index, the technological progress efficiency (techch) is 1.035, with an average increase of 3.5%, indicating that the growth of total factor productivity is mainly caused by technological progress efficiency; pure technical efficiency, technical efficiency and scale efficiency Productivity are moving passively. From the perspective of the time trend, due to the small number of years collected, it can only be seen that each efficiency value is on the rise, and the technical efficiency increases rapidly, from 0.95 to 1.029. The scale efficiency is less than 1 in

2016-2017, and this value is smaller than other efficiency values in 2017-2018, and effch=sech×pech. Therefore, growth of technical efficiency is limited by the growth rate of scale efficiency.

Table 4. Logistics Malmquist index and its decomposition

	firm	effch	techch	pech	sech	tfpch
Northern of China	DMU1	0.99	1.023	1.004	0.986	1.013
	DMU2	0.859	1.04	0.862	0.996	0.893
	DMU3	1	0.931	1	1	0.931
	DMU4	0.92	1.035	0.946	0.973	0.952
Southern of China	DMU5	1	1.082	1	1	1.082
	DMU6	1	1.055	1	1	1.055
	DMU7	1	1.058	1	1	1.058
	DMU8	1.175	1.015	1.13	1.04	1.192
	DMU9	1	1.043	1	1	1.043
	DMU10	0.982	1.059	0.999	0.983	1.04
	DMU11	0.975	1.056	1	0.975	1.03
	mean	0.988	1.035	0.993	0.996	1.023

3.3.2 Comparison of Changes in Efficiency among Provinces

From Table 4, it can be seen that except for DMU3, the technological progress index of other provinces is greater than 1, which has promoted the improvement of logistics efficiency primarily; The top two provinces and cities are DMU8 and DMU5, because DMU8 is positioned as the core strategic fulcrum of maritime cooperation, which brings important development opportunities for the development of coastal ports there. DMU5 benefits from the crisscrossing logistics supply chain and the developed hinterland economy and is also the most economically developed city in China. The technological progress efficiency and total factor productivity of the remaining provinces are basically the same, indicating that technological efficiency and technological progress factors play a synergistic role in promoting the total factor production rate.

3.3.3 Comparison of Regional Differences (Perceive Qinling-Huaihe as the Boundary, Dividing China into Northern and Southern Regions)

The overall logistics development in various regions is in the rising stage. The logistics economy in the south of China is developing rapidly, mainly due to the technological progress index (techch). The development of the logistics economy in the areas of the north is relatively backward. Except for DMU3, other provinces and cities are mainly limited by scale efficiency. Therefore, provinces and cities can appropriately expand the business scale on the existing basis, flexibly apply new technologies of the Internet of Things and big data, and develop smart logistics. In order to maintain the growth of scale efficiency value, optimize the logistics market structure, increase the utilization rate of resources, and avoid blind investment in infrastructure.

4. CONCLUSION

This study uses the DEA-Malmquist index to conduct an empirical study on the logistics production efficiency of Chinese ports above designated size. According to the analysis results, it can be seen that:

From the static analysis of the DEA model, it can be concluded that nearly half of the provinces and cities have reached the DEA effect, DMU11 has reached the DEA weak effect, and the scale efficiency of the remaining coastal provinces and cities is still It needs to be improved; By using Malmquist index, it can be seen that the average value of China’ s port logistics efficiency index from 2016 to 2018 is 1.023, indicating that the port logistics production efficiency has shown a steady upward trend in recent years, but only driven by technological progress. Pure technical efficiency and scale efficiency have a negative impact on overall production efficiency. From the perspective of spatial distribution, the economic development of the areas south of China is generally faster than that in the north of China. All regions should make contributions to the improvement of scale efficiency. According to the development situation of each region, realize the application of emerging technologies to reduce economic costs, optimize the market structure and form a more complete logistics service network.

Standing from the empirical results, this paper specifically investigates the logistics efficiency of ports above designated size, but there are still some problems that need to be improved in the future. First, China's classification of the logistics industry is not clear enough, so when selecting input data, only the data of the transportation, warehousing and postal industries can be selected, which is one-sided. Secondly, regarding the construction of a smart logistics platform, the circulation of logistics networks and the embedding of new technologies, the realization of these activities and the time and cost relating to these are huge, and the requirements for the economy of the port hinterland and the support of the government are very rigid. These suggestions are not general and practical for the solution of such problems. Lastly, although the DEA model can be used to evaluate multi-input-output DMUs, there are limitations in the number of indicators. Future work will involve choosing a more complete input index, while not affecting the reliability and accuracy of the calculation results, as well as considering the influence of external factors and random errors.

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