



Research on the Operational Efficiency of Major Listed Port Enterprises Based on Two-Stage Network DEA in Series

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Abstract. Amid the deepening global trade and intensifying port competition, port operational efficiency has become a critical factor for corporate sustainable development. This study employs a network Data Envelopment Analysis (DEA) approach to decompose port operations into logistics operations and profit transformation phases, systematically evaluating the operational efficiency of 12 listed Chinese port enterprises from 2018 to 2023 and exploring the impact of logistics investment strategies. Based on this, some suggestions are put forward: deepening the application of digitalization and automation technology to optimize logistics operation efficiency; Focus on high value-added business and high value-added services to improve profitability; Formulate differentiated investment plans for bulk cargo and comprehensive ports. The research results provide theoretical basis and practical reference for port enterprises to optimize resource allocation, balance scale expansion and efficiency improvement, and help the port industry to transform to a high-quality and sustainable direction.

Keywords: Efficiency research, Network DEA, Logistics input, Digital input

1 Introduction

Under the background of global trade integration and regional economic coordinated development, ports, as the core node of the international supply chain, face the operational dilemma of "high input and low efficiency". While infrastructure investment continues to expand, the traditional extensive model has led to rising costs, intensifying homogenized competition, and shrinking profit margins. Most of the existing studies use the traditional DEA model, ignoring the phased characteristics of port value creation and the influence of emerging factors such as digital technology.

The current research direction of port efficiency is mainly to study the technical efficiency of ports, that is, the maximum output under a given input or the minimum input under the same output level. At present, the commonly used analysis tools can be divided into two categories: parametric method and non-parametric method. The parameterization method mainly constructs a clear production function model with input and output, and then analyzes the sample data with econometric methods to determine the

parameters of the function model^[1]. Non-parametric method is a comparison of the input-output ratio of ports, and domestic and foreign scholars widely use DEA to measure the relevant efficiency of ports^[2]. Since this paper studies the operation efficiency of port enterprises, which still belongs to technical efficiency, data envelopment analysis (DEA) is used to analyze the operation efficiency of port enterprises.

Starting from the main body of the port, the traditional DEA model is used to evaluate the static and single-stage efficiency of the port in the early stage. Based on the BCC and CCR models, most scholars at home and abroad select data related to port production, including dock area, number of production equipment, dock length^[3], etc. Feng Feng et al.^[4] used the DEA-SBM model to study and evaluate the efficiency of 17 selected ports, pointing out that scale efficiency seriously affects the comprehensive efficiency of ports, and the development of port scale cannot be ignored in the process of port development. Mostafa^[5] made a comparative analysis of the technical efficiency of ports in South Asia and the Middle East and ports in East Asia.

For port enterprises, operation efficiency is only port efficiency. Previous studies on port enterprises often lack the research on profit conversion of goods, or study on profit efficiency from the perspective of enterprises, lacking the output efficiency of throughput after the input of port infrastructure. Liu et al.^[6] used the super-efficiency DEA model to measure the operational efficiency of 20 container terminal enterprises in China in 2018. Wang Min^[7] respectively measured the operational efficiency of listed port enterprises.

The traditional DEA method regards each DMU as a "black box", does not consider its internal structure, and studies the systematic process of the lack of "port - goods - profit" for port enterprises. This measurement principle makes DEA method widely used to evaluate systems with complex internal network structure. Han Bing et al.^[8] used multi-stage network DEA to conduct an empirical analysis with listed port companies as an example, and concluded that the value added efficiency of listed port enterprises in China is generally low due to homogenization competition. Halvor Schøyen et al.^[9] used the basic CCR-DEA model to measure the impact of logistics efficiency delivery performance success and container liner connectivity on port efficiency. Evelin Krmac et al.^[10] compared the environmental efficiency of one-stage DEA with that of two-stage DEA. At present, there are few researches on the application of network DEA method to ports. With the deepening of researches, network DEA is gradually emerging, which regards port production as a multi-stage process and can analyze each sub-stage and the overall collaborative efficiency. Liu Dan et al.^[11,12] measured the port efficiency and the port enterprise efficiency of multiple periods through network DEA

This study innovatively constructed a two-stage network DEA model, deconstructed port operation into a chain structure of "logistics operation-profit conversion", and studied the operation efficiency of port enterprises based on the data of 12 listed ports from 2018 to 2023.

2 Results

By summarizing the previous studies on ports in domestic and foreign literatures, the input-output indicators used in the literatures are summarized and sorted out. Finally, the number of berths, output value of logistics equipment assets, logistics cost, number of employees and digital input are selected as input indicators, throughput and container throughput as intermediate variables, and net profit and output variables of main business income.

In order to facilitate data acquisition, this paper selects 12 representative port enterprises listed on Shanghai and Shenzhen stock exchanges as samples. The data mainly comes from the annual reports of listed enterprises and industry statistical yearbook.

2.1 Multi-stage DEA Efficiency Analysis

In this paper, the serial network DEA model is adopted to disassemble the port operation process, which is divided into logistics operation stage and port operation stage. logistics operation stage is the formation process of port core production capacity, reflecting the supporting role of logistics input on cargo handling capacity. Profit conversion stage is the process of transforming logistics processing capacity into economic benefits, reflecting the level of port market operation. The overall operational efficiency is the product of the efficiency values of the two stages, and the overall efficiency is affected by the double effects of the two stages.

2.1.1 Logistics Operation Stage Efficiency Analysis

The logistics operation stage reflects the basic operational efficiency of port operation. The key of this stage is to maximize the output (throughput) of logistics operation by optimizing resource allocation and technology application, and lay the foundation for subsequent logistics conversion (revenue and profit).

(1) comprehensive efficiency

In the logistics operation stage, the logistics input of a port enterprise is the beginning of the entire port operation, and the comprehensive efficiency reflects whether the port has the optimal allocation of resources such as berths, equipment, manpower and digital investment. As shown in Figure 1, the overall comprehensive efficiency of a port changes from the time dimension, and the comprehensive efficiency of most ports has a rising trend, indicating that as time goes by, the overall efficiency of a port will increase. Most ports have gradually optimized their logistics operations, and the input-output relationship has improved.

During the period of 2018-2023, the comprehensive efficiency value of Beiwan Port, Lianyungang Port and Tangshan Port has always been maintained at 1, maintaining an efficient operation state from the beginning. For example, the comprehensive efficiency value of Shanghai Port, Guangzhou Port, Xiamen Port, Rizhao Port and Dalian Port gradually increased to 1, while the comprehensive efficiency value of Ningbo Zhoushan Port and Tianjin Port fluctuated somewhat, but the overall value remained at 0.9-1.

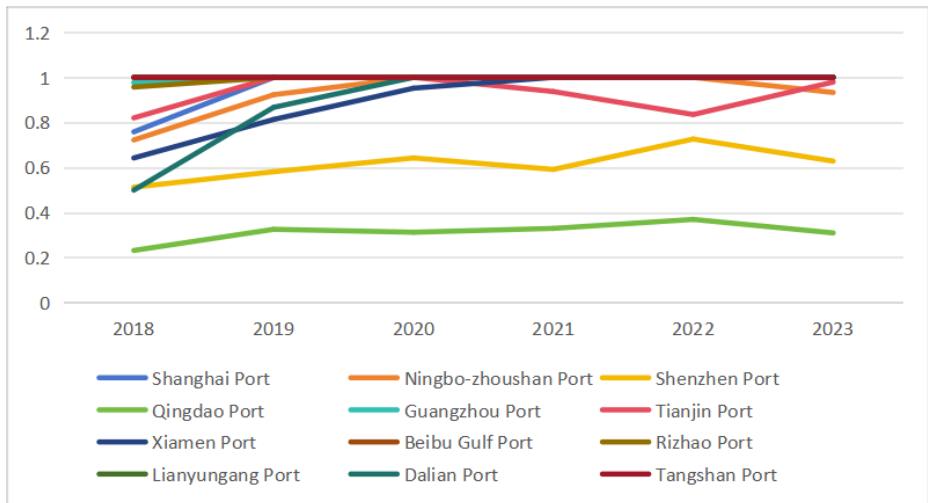


Fig. 1. The pure technical efficiency value of each port logistics operation stage in 2018-2023

(2) Pure technical efficiency

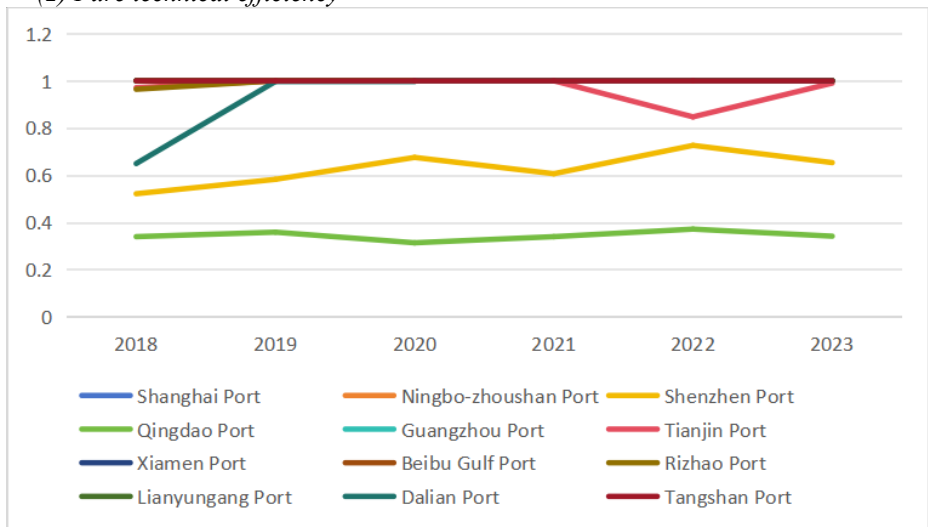


Fig. 2. The pure technical efficiency value of each port logistics operation stage in 2018-2023

The pure technical efficiency of the logistics operation stage reflects the efficiency of the port in cargo handling, throughput and other logistics operations, excluding the impact of scale expansion, indicating whether the port has reached the optimal level in terms of logistics input, technology application and process optimization. As can be seen from Figure 2, except for Shenzhen Port and Qingdao Port, the pure technical efficiency values of other ports from 2018 to 2023 have remained at a high level, which means that DEA is effective in all ports in recent years. The pure technical efficiency

value of Shenzhen Port fluctuates between 0.5-0.8, with a large fluctuation, which may be due to a series of positive improvement measures taken by Shenzhen Port during this period, so that the operation efficiency of the port can be gradually improved for a short time.

(3) Scale efficiency

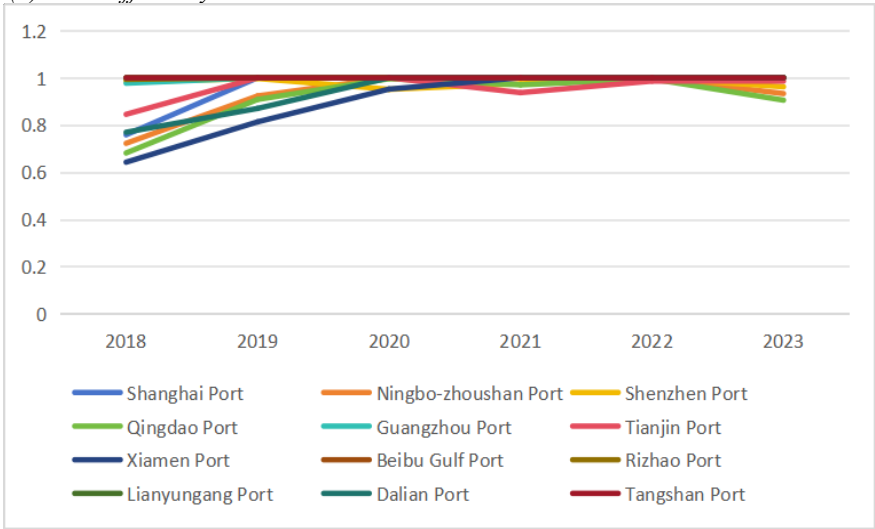


Fig. 3. The scale efficiency of each port logistics operation stage from 2018 to 2023

The scale efficiency of logistics operation stage reflects whether the logistics investment of port enterprises is reasonable and whether the throughput can be effectively improved through scale expansion under the same technical level and management ability. As can be seen from Figure 3, scale efficiency generally presents an upward trend. Since 2020, the scale efficiency of most ports is 1, indicating that under the current input scale, the cargo has obtained the optimal resource allocation and input scale in the turnover process of the port.

2.1.2 Profit Conversion Stage Efficiency Analysis

The logistics conversion stage is that the port enterprise as the main body converts the actual logistics handling into financial profit, the core is the mapping from the logistics scale to the financial value, and its efficiency reflects the comprehensive management ability of the port enterprise. Through the network DEA model, the port can quantify how to transform the physical advantage of "throughput" into sustainable profitability, and provide decision-making basis for improving the operational efficiency of the port.

(1) Comprehensive efficiency

According to Figure 4, it is found that the comprehensive efficiency of most ports in the logistics conversion stage shows a gradual decline. There are significant differences in the efficiency values of various ports. Since 2020, the efficiency values of Shenzhen port and Lianyungang port have remained at 1, indicating that the ability of goods to

transform into economic value is relatively good. From the perspective of time, it may be affected by the epidemic, and most ports have a significant decline in efficiency in 2020.

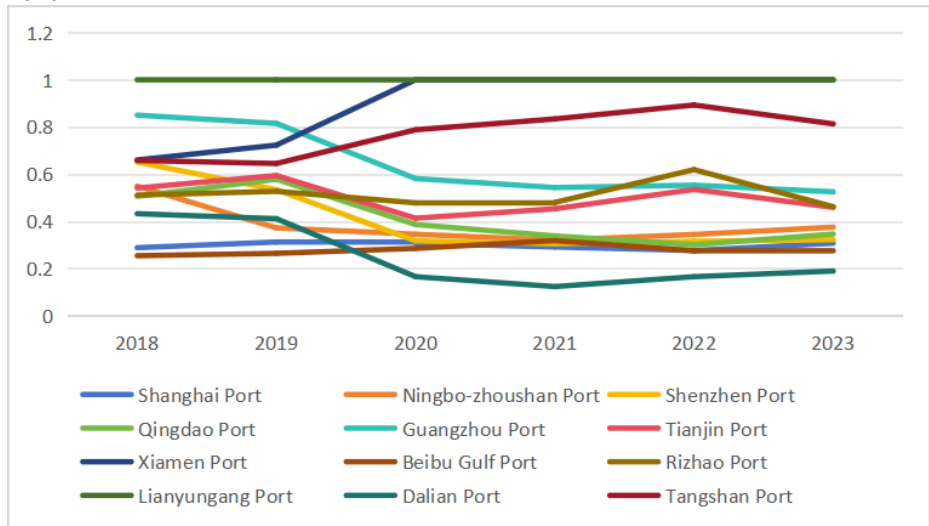


Fig. 4. The comprehensive efficiency of each port profit conversion stage from 2018 to 2023

(2) Pure technical efficiency

On the one hand, the pure technical efficiency of the logistics conversion stage indicates whether the operation mode of the port enterprise is correct, that is, the technical adaptation of the port logistics operation and the technical demand for high value-added services; on the other hand, it indicates the management level of the port enterprise, that is, the cost control level. As can be seen from Figure 5, most ports have certain fluctuations in different years, but the overall level remains at a certain level.

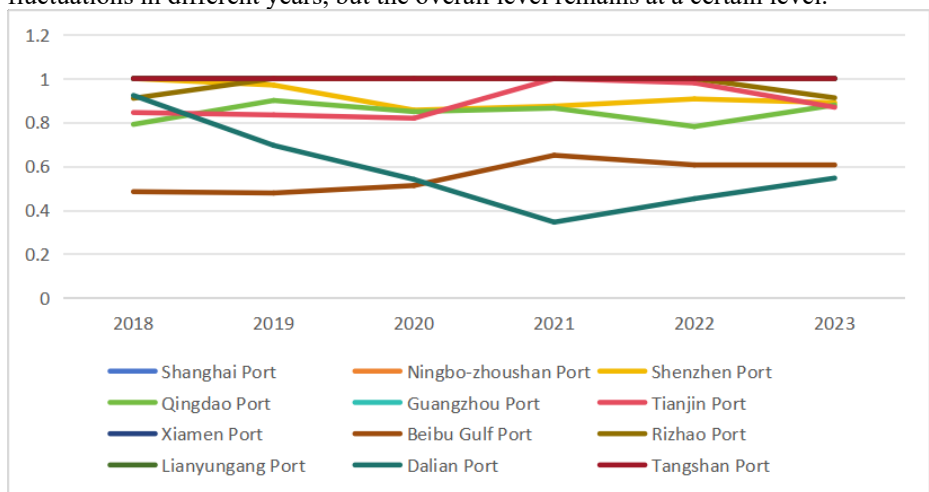


Fig. 5. The pure technical efficiency of each port profit conversion stage from 2018 to 2023

(3) *Scale efficiency*

Scale efficiency reflects the scale match between throughput and revenue in the profit conversion phase. Fig. 6 shows that there is a significant difference in scale efficiency among ports. Xiamen Port and Lianyungang Port continue to maintain DEA effectiveness after 2020, indicating that their scale and revenue reach the optimal state, while other ports have DEA ineffectiveness to varying degrees and efficiency values decline. Most of the ports have decreased the scale efficiency value in 2020, which may be due to the fluctuation of seaborne trade demand caused by the epidemic, resulting in port capacity unable to match in time. As the port industry is an asset-heavy industry, port companies often cannot receive timely profit feedback when investing in ports, and introduce automation equipment and upgrade technology in digital construction investment.

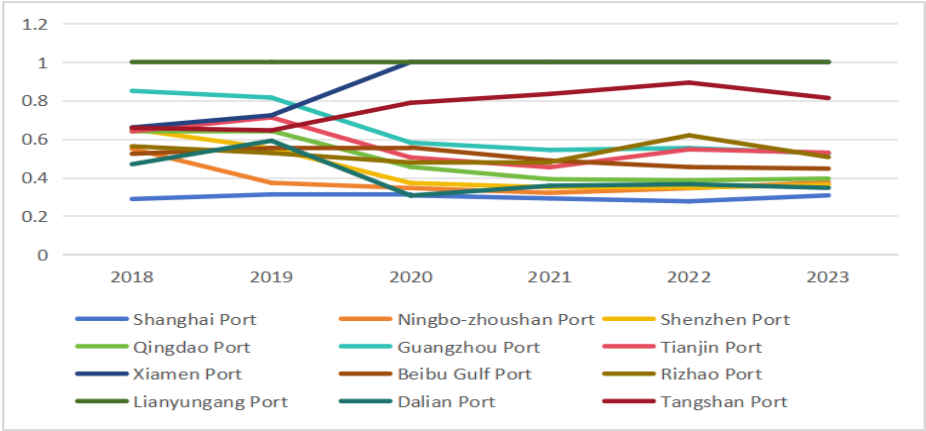


Fig. 6. The scale efficiency of each port profit conversion stage from 2018 to 2023

2.1.3 *Overall Port Operational Efficiency Analysis*

The operational framework of ports is decomposed into two sequential stages: the logistics operational stage and the profit conversion stage. Port efficiency is modeled as the product of the efficiency values from these two stages, reflecting their synergistic interplay. This multiplicative relationship underscores that inefficiency in either stage directly diminishes overall operational performance.

(1) *Comprehensive efficiency*

The results of port operation efficiency of each port are affected by the logistics conversion stage, and there are significant differences among ports. Among them, as we can see in Figure 7, the efficiency value of Lianyungang port and Xiamen Port has always maintained 1 after 2021, and they can have the optimal allocation and management of logistics input, which is the benchmark of other ports. The port operation efficiency of Shenzhen Port, Guangzhou Port and Dalian Port will decrease significantly in 2020, and the life port resources have not been well allocated.

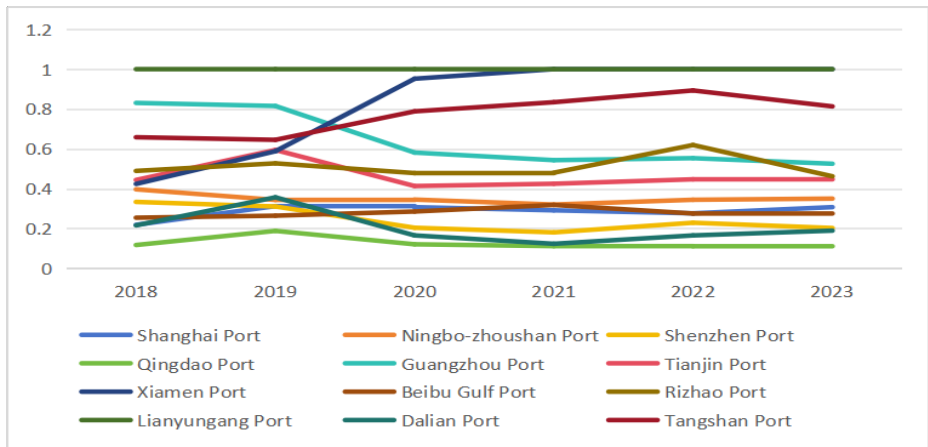


Fig. 7. The comprehensive efficiency of each port overall operation from 2018 to 2023

(2) Pure technical efficiency

In the actual operation of port enterprises, pure technical efficiency is often related to technological innovation and management level. According to Figure 8, it is not difficult to find that the pure technical efficiency value of Shanghai Port, Ningbo Zhoushan Port, Guangzhou Port, Xiamen Port, Lianyungang Port and Tangshan Port from 2018 to 2023 has always been, that is, DEA effective, indicating that these ports may have technical advantages, can maximize the utilization of input resources, and their management level is in the leading level in the industry. However, Qingdao Port is in an inefficient state for a long time, and the pure technical efficiency value is maintained between 0.26 and 0.32, and it is in a technical invalid state for a long time.

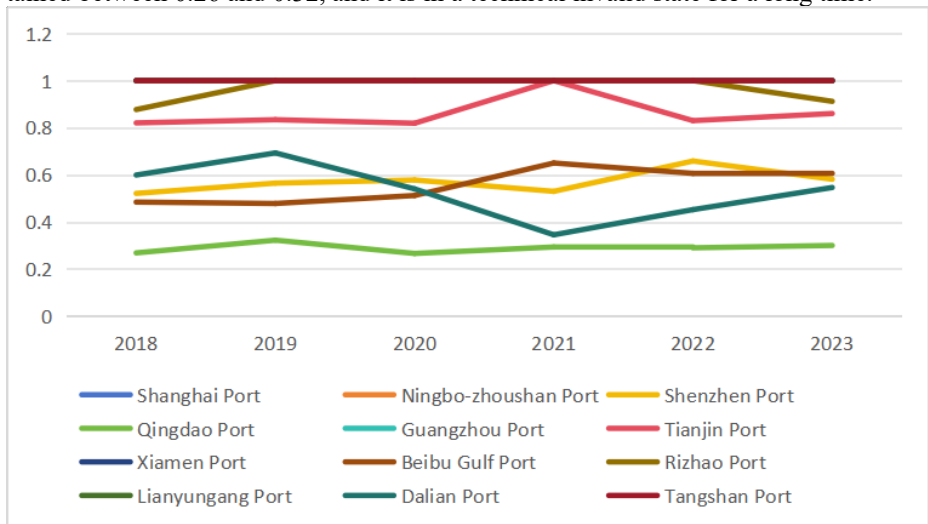


Fig. 8. The pure technical efficiency of each port overall operation from 2018 to 2023

(3) *Scale efficiency*

In Figure 9, Lianyungang Port and Xiamen Port have outstanding performance. The scale efficiency value of Lianyungang Port is 1 for six consecutive years, indicating that its input-output is in the optimal state of scale efficiency and is a benchmark for other ports. Most of the ports had a trough period of decline in 2020 and 2021, and recovered to a certain extent in 2022, while the scale efficiency of Tangshan port and Xiamen port was on the rise even during the epidemic.

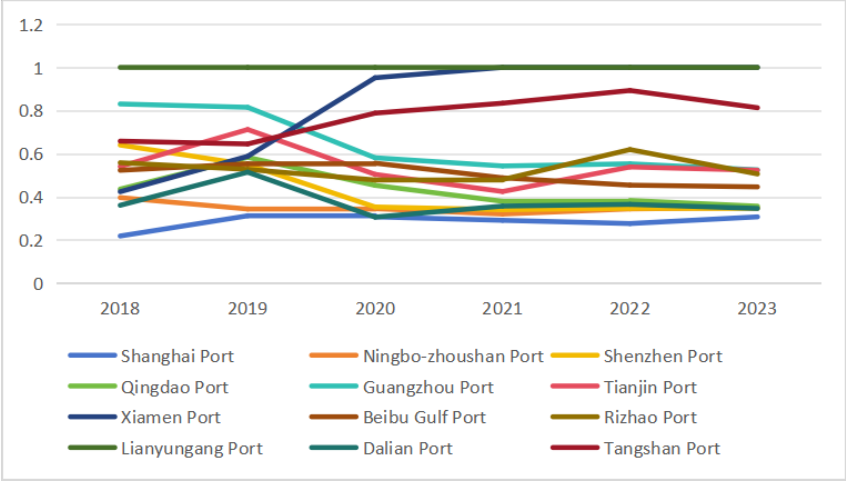


Fig. 9. The scale efficiency of each port overall operation from 2018 to 2023

2.2 The Impact of the Two Stage on the Overall Operational Efficiency

2.2.1 The Impact of Logistics Operation Stage on Overall Operational Efficiency

Figure 10 compares the average comprehensive efficiency of logistics operation stage and port operation. From 2018 to 2023, the efficiency of logistics operation continues to improve, and the efficiency value is close to 1, indicating that the operation management of logistics operation in the port has been continuously optimized, and the efficiency of resource utilization has been continuously improved, indicating that the logistics input of port enterprises is used more effectively. Or digital construction has greatly improved efficiency.

The overall level of port operation efficiency is low, fluctuating between 0.4-0.6, and the mean value of logistics operation efficiency is significantly higher than the overall port operation efficiency, indicating that logistics operation is the core link of port operation, and its efficient operation provides basic support for the overall port efficiency. Although the efficiency of logistics operation has improved year by year, it has not been fully translated into port operation efficiency, which may be because the improvement of logistics efficiency cannot make up for the decline in profit conversion efficiency.

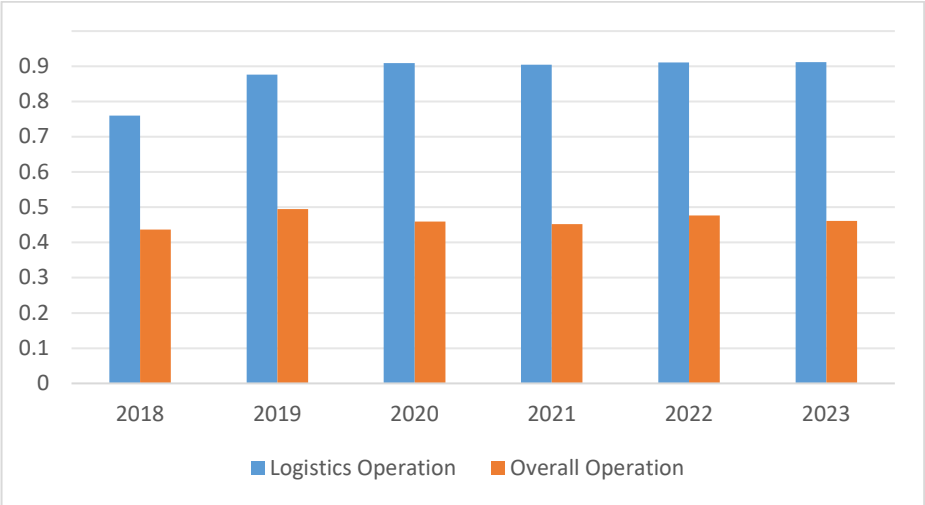


Fig. 10. Comparison of logistics operation stage and port operation efficiency value

2.2.2 The Impact of Profit Conversion Stage on Overall Operational Efficiency

Figure 11 compares the average comprehensive efficiency of the profit conversion stage and the port operation efficiency. It is not difficult to find that the profit conversion efficiency is slightly higher than the port operation efficiency, but the average profit conversion efficiency is in a slightly declining state, from 0.575 to 0.506, which indicates that although the port has the cargo handling capacity, the capacity to convert throughput into revenue and profit is insufficient.

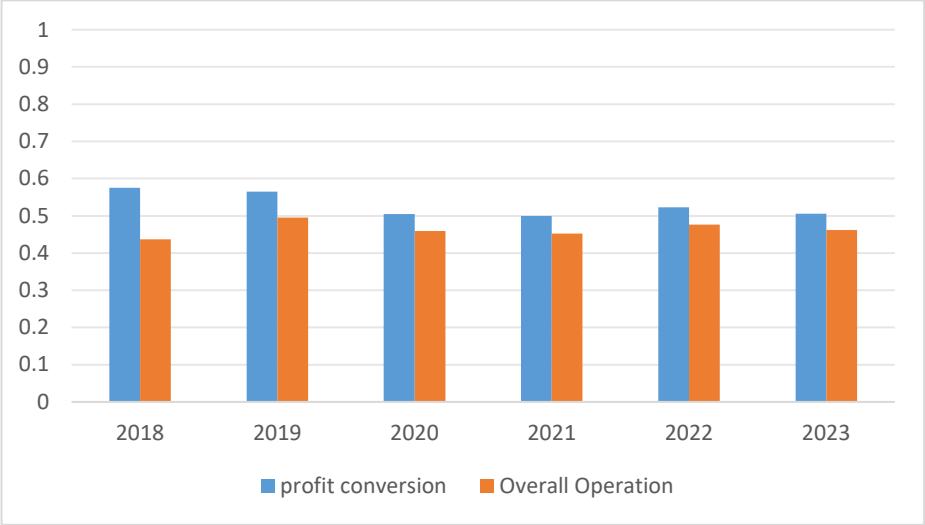


Fig. 11. Comparison of profit conversion stage and port operation efficiency value

Comparing the impact of the two stages on port operation, the profit efficiency began to decline while the logistics efficiency was greatly improved, and the improvement of logistics efficiency was offset by the decline of profit conversion efficiency, resulting in the comprehensive efficiency of port operation stagnating in the range of 0.4-0.5. Therefore, it can be concluded that the loss of port operation efficiency occurs in the profit conversion link. China's port has a long-term problem of light weight and price, the pursuit of cargo throughput and container throughput improvement, the lack of attention to high-priced goods, high value-added services, resulting in small profit space for port enterprises. Therefore, the port enterprises should adjust the logistics investment strategy according to the actual situation.

3 Conclusions

This study conducts an in-depth analysis of the operational efficiency of listed port enterprises based on the network DEA model, aiming to explore the inherent relationship between logistics input strategies and operational efficiency. The findings reveal that the efficiency of logistics operations in port operations significantly surpasses that of profit conversion stages, with insufficient synergy between these two-stage efficiencies being a critical constraint on the overall operational efficiency of listed ports.

Comprehensive analysis: Although enhanced logistics operation efficiency provides fundamental support for port operations, the simultaneous decline in profit conversion efficiency has prevented overall operational efficiency from achieving synchronous improvement. The failure of logistics efficiency gains to offset profit efficiency losses has resulted in long-term stagnation of comprehensive port operational efficiency within the 0.4-0.6 range. This phenomenon primarily stems from the persistent "volume-for-price strategy" in Chinese ports, which severely compresses profit margins for port enterprises.

Based on the research conclusions, the following recommendations are proposed to optimize the logistics investment strategies of listed port enterprises:

- 1) Deepen the investment in digitalization and automation technologies. To deepen investments in digitalization and automation technologies, drive technological advancements in ports, achieve real-time sharing of cargo logistics information and intelligent allocation, enhance logistics operational efficiency, improve management capabilities, strengthen the integration of technological applications with management models, and elevate overall port operational efficiency.
- 2) Focus on high-value-added services by expanding port business models and diversifying cargo types to boost high-margin revenue streams and optimize the income structure. Consolidate logistics resources to elevate the proportion of containerized cargo, develop dedicated international logistics routes, and strengthen multimodal transport networks. This approach will reduce logistics costs for port enterprises while enhancing profitability through operational synergies and expanded service coverage.
- 3) Based on port types, implement differentiated investment strategies. For bulk cargo ports, focus on concentrated technological investments to research and

develop specialized handling equipment, aiming to enhance the efficiency of bulk cargo processing and reduce cargo damage rates.

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