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RESEARCH ARTICLE

Frontier Analysis of the Container Ports in Taiwan During the COVID Pandemic

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Abstract

The COVID-19 outbreak has severely impacted global trade and cultural exchanges. Among its impacts are those on the international container shipping market, which is directly related to the national economy and trade and has naturally been affected. This market was in the doldrums during the pandemic. In general, COVID-19 has severely constrained shipping industry development in various countries. To this end, this study analyzes the frontier changes in the efficiency development of Taiwan's international container ports by collecting realistic operational data of the major container ports during the pandemic and combining them with measurements of the Malmquist Productivity Index and DEA theoretical methods. Finally, this study finds that the overall operating atmosphere during 2020−2021 was improved, which was directly related to the mitigation of the pandemic.

Keywords: Data envelopment analysis (DEA), Malmquist productivity index (MPI), Efficiency, Container ports

1. Introduction

Since March 2020, the novel coronavirus outbreak spread further across the world. Due to the impact of COVID-19, global economic activities have also been affected. Normal operating environments for all global sectors have been hampered, so the international shipping industry has also been affected. Additionally, business orders from global shipping companies have declined. The World Health Organization (WHO) upgraded the novel coronavirus to a "public emergency of global concern" and made relevant recommendations. Furthermore, since the novel coronavirus has a long incubation period, some countries have imposed a mandatory quarantine policy of 14 days for ships that had previously called on Chinese ports. This strict port quarantine policy has greatly reduced the efficiency of global shipping. As a public health emergency, COVID-19 adversely affected the production equipment of port enterprises and the normal operations management of ports. It has also significantly inconvenienced the supply and demand side, including the transportation of personnel and goods. The long-term shutdown has seriously weakened the development of the international shipping market, and many shipping companies have been forced to reduce shipping vessel numbers, liner transportation, ship leasing, port operations, etc. These sudden developments may directly affect the performance of relevant contracts, thus heavily damaging international shipping enterprises.

International maritime trade is closely related to the economic development of every country around the world, but the global pandemic has significantly blocked the main artery of international trade. COVID-19 has caused historic damage to the logistics supply of international shipping trade worldwide. For dry bulk transport, for example, the

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Chinese national shipping market remains heavily dependent on strong imports. Before COVID-19, China imported a lot of iron ore and coal for steel production, accounting for approximately 40% of global dry bulk shipments, and China's demand for agricultural imports was a major driver of the international dry bulk market. Members of the Baltic International Shipping Association (BIMCO) have stated that dry bulk freight rates have remained low because some Chinese buyers reduced or ceased their demand for seaborne commodities during the pandemic. Regarding international container transport, manufactured goods imported from China by developed economies remain the main driving force for the development of international container transport. In terms of container throughput, among the world's top ten international commercial ports, seven are Chinese ports. Affected by the epidemic, a wide range of factory closures slowed manufacturing and industrial production, and stringent quarantine measures at ports prevented workers from working normally. Furthermore, COVID-19 led to a sudden decline in the flow of international ocean container cargo. Maersk, the world's largest container shipping company, has stated that it is canceling two Asia–Europe routes due to a drop in China's demand for international container cargo during the pandemic. Additionally, it left 26,000 TEUs of cargo capacity empty and listed at least 27 empty voyages on its official website. The move to cancel international container shipping schedules is being followed by other international shipping companies, such as Mediterranean Shipping Company S.A., Hapag-Lloyd AG, and CMA CGM. The two companies also claim that they are continuing to reduce the number of ships on routes between China and the United States, Canada, India, and West Africa. Thus, since the global outbreak, the number of empty ships that cannot be loaded at their intended locations has increased daily. During the outbreak, third-party container shipping analysis companies estimated that approximately 600,000 20-foot boxes were removed from service because of the pandemic. Although rates may vary, an estimate of approximately $1000 per container means that shippers have to bear a huge loss of more than $600 million [1].

Taiwan is surrounded by the sea and global trade goods are transported by sea. Port development is an important economic pillar of Taiwan, and occupies a very important position. Therefore, Taiwan's shipping industry developed earlier and has formed a relatively complete international shipping industry chain, with major players occupying important positions in the global shipping industry. According to the latest global container shipping line capacity ranking by Alphaliner, the French shipping consultancy (1 May 2022), Taiwan has two Top 10 companies (Evergreen Shipping and Yangming Shipping) [2]. International container transport consists of mostly regular routes, carrying industrial finished products, and standardized packaging of goods directly to customer warehouses; therefore, its development is closely related to the global consumer market. Taiwan is China's largest single source of imports because of the close trade relationship between the two countries; far outstripping Japan and South Korea. Therefore, the COVID-19 pandemic has severely restricted the development of China's trade and international container transportation, which has also affected the operating environment of Taiwan's ports. Simultaneously, cultural exchanges between the two sides of the Taiwan Strait were interrupted during the epidemic, leading to a gradual widening of the psychological and emotional distance between the peoples on both sides. The sense of alienation and unfamiliarity among the populaces continued to grow, causing cultural exchanges between the two sides to also suffer a serious blow [3]. According to Taiwan's Business Times, Shanghai Shipping Exchange data revealed that the Taiwan Cross-Straits Container Composite Index (TWFI) was affected by the repeated COVID-19 outbreaks, and as a result, port disruptions fell 3.1% in September 2021, with the mainland southeast (Xiamen, Fuzhou) to Taiwan (Keelung, Taichung, Kaohsiung) line falling the most. This included the export index falling 9.1% and the import index falling 13.4% [4].

Simultaneously, due to competition from international container ports in Taiwan's neighboring waters and the impact of the pandemic, loading and unloading operation volumes at Taiwan's major ports have fallen short of operating targets for years. According to the research report released by Taiwan Port Co., LTD., the total revenue of "ports-loading and unloading" and "ports-container" business of Taiwan ports in 2020 was 5.33% less than the target (approximately NT $400 million). Among them, Kaohsiung Port, which ranks first in Taiwan in terms of throughput, was affected by the epidemic more than other ports. However, in 2021, due to the gradual recovery of the global economy, trade, and shipping market, the growth of container handling volume at the international commercial port slowed. Compared with the previous year, the container handling throughput increased by 100,000 charging tons, but the growth rate represented only 0.01%. Therefore, this study will use DEA theory and analysis of the Malmquist Productivity Index (MPI) to examine the frontier changes in container port development in Taiwan under the influence of the COVID-19 pandemic.

The remaining parts of this study are organized as follows: Section 2 reviews the literature on research about DEA applications on container ports and research combining MPI with DEA. In Section 3 the main evaluation model applied in this study is introduced and the process of calculating the MPI based on the DEA method is briefly described. Next, a real-world case example of international container ports in Taiwan (2018−2022) is presented in Section 4. Finally, Section 5 concludes with the evaluation results, and discusses some managerial implications.

2. Literature review

2.1. 2.1 DEA application on container ports

DEA is a non-parametric mathematical planning research method used to assess relative performance and is often applied to evaluate the operational performance of international container ports [5−9]. This can help port managers allocate and utilize their resources more rationally and effectively. To open the "black box" of the evaluated system and explore the relationship between the internal structural performance and the overall performance of the evaluated system, Gan et al. [10] stratified the parallel or serial structures of the international container port operation systems. They conducted a linked performance evaluation in two environments: vessel scheduling supervision and port working time control. Then, they proposed a new evaluation model based on the DEA theoretical approach and applied it to the performance evaluation practice of international container ports in Taiwan. Mustafa et al. [11] focused on comparing the technical efficiency of ports in South Asia and the Middle East with those in East Asia and identified methods to improve the efficiency and optimize the management of ports in different countries. They found that among the ports in the Middle East and South Asia, only one port each from India and the UAE was considered the most efficient. Meanwhile, Lianyungang Port in China was evaluated as the most efficient in East Asia. Overall, the average efficiency of ports in South Asia and the Middle East was found to be similar to those in East Asia. Since the size of container port services and the configuration of port facilities vary between countries Nikolaou and Dimitriou [12] considered comparing international container terminals based on port performance to be a complex task. They evaluated the performance of the Top 50 global container port terminals for five consecutive years by combining the theoretical approach of DEA and Tobit regression models and verified the impact of important port factors on port operational performance (e.g., size of terminal space, number of cranes, and port shoreline length). As the three largest central hub cities in the Pearl River Delta region of China, Hong Kong, Shenzhen, and Guangzhou ports always play important roles in the regional growth of China. However, due to problems associated with port environmental protection and complex transportation system coordination, Liu et al. [13] used the SBM-DEA model to evaluate the efficiency of the main container terminals in these three cities from 2018 to 2019. They found that Guangzhou's main container terminals were less efficient than those in Hong Kong and Shenzhen. They also provided some reliable reference information for future port investment and regional development policies in the Pearl River Delta region. The operation of ports is of vital economic importance because of their role in international trade. Striking a dynamic balance between increasing economic activities and reducing environmental impacts is crucial for the sustainable development of the ports. Djordjević et al. [14] proposed a novel two-stage non-radial DEA model to evaluate the environmental efficiency of both landward and seaward operations of the Berlin port. Their study found that two main factors (the number of terminals and capital expenditures) significantly impacted the port's environmental efficiency. They claimed that their new model would allow Berlin Port to continuously reduce its annual CO_2 emissions by reducing the combinations of variables controlled by engineering and policy measures.

2.2. MPI combined with DEA

Originally proposed in 1953 [15], MPI has since been popularized as one of the most practical methods to measure productivity changes. In 1992, Fare et al. [16] combined a non-parametric linear programming method with DEA theory, which led to the widespread use of MPI. Until today, this method has been widely used to measure production efficiency in industrial, financial, medical, and other sectors. It is useful to analyze the changes in the efficiency frontier according to the calculation results [17−21]. Cao et al. [22] argued that economic development is generally accompanied by ecosystems' consumption. For this reason, they selected 23 key ecological indicators and proposed a new DEA-Malmquist method to measure changes in ecoefficiency across Chinese provinces from 2009 to 2015. This new model explores the relationship between ecological environment and economic development. They also found that economy-ecosystem performance from 2012 to 2015 worsened compared to that of 2009–2012 and that technical efficiency was not the main factor restricting the economic and ecosystem development of 26 provinces. Energy security has always been an issue of great concern for many national managers and policymakers. Huang et al. [23] integrated the DEA, fuzzy best-worst model, and assurance regions approaches to conduct an assessment study on the energy security performance of 30 Chinese provinces from 2008 to 2017. Further, they explored the dynamic trends in the energy security performance of these evaluated provinces using MPI. They found that the energy security performance of China's provinces differed significantly and that the southern and eastern coastal provinces of China performed significantly better than the northwestern regions of China in terms of energy security. How to scientifically assess the sustainability of suppliers and selecting the best company from many suppliers has always been an important goal for supply chain managers. Therefore, sustainable supply chain management has been one of the most important concerns of management. Fathi and Sean [24] constructed a dual frontier network DEA model with a common set of weights (CSW). Based on this, a new CSW-based model for measuring MPI was proposed. They claimed that their new model could help supply chain managers determine the sustainability of the supply chains at the optimistic, pessimistic, and dual frontier levels. Khoshroo et al. [25] believed that how to accurately evaluate changes in energy productivity over relative time intervals is an important production management issue of many enterprises. To this end, they proposed three new methods of measuring MPI based on theoretical studies of optimism, pessimism, and general views of data envelopment analysis; then applied their new methods to the evaluation of productivity changes and efficiency to chickpea-producing farms in 16 Iranian provinces. To explore the disposability relationship between new energy inputs and CO_2 emissions, Zhu et al. [26] constructed a new Malmquist-Luenberger index to measure the total factor productivity change of carbon emissions. They concluded that their new model could effectively avoid distortion estimates caused by existing technologies that ignore the potential relationship between energy inputs and CO_2 emissions. By measuring the total factor carbon productivity of 41 industrial sectors in China from 2013 to 2016, they found that the growths and declines of the total factor carbon productivity indexes were mainly driven by technological progress or deterioration.

2.3. Discussion

According to this literature review, it can be seen that DEA is a non-parametric theoretical method for evaluating relative performance which can objectively reflect the level of daily operation and management of enterprises. Additionally, this method is often applied to evaluating the performance of international container ports by scholars. The traditional DEA model usually only reflects the static efficiency of decision-making units, and cannot evaluate changes in efficiency values during different periods. If combined with production efficiency index calculations, it could be used to analyze changes in the overall market environment from the perspective of technical efficiency changes and technological progress changes in multiple dimensions. Therefore, this study intends to evaluate the efficiency changes in Taiwan's international container freight market by collecting actual operation data of major container ports in Taiwan (2018–2022) by combining DEA and MPI.

3. Methods

To evaluate the efficiency of the container ports in Taiwan, we proposed the following method. According to the traditional CCR-DEA model [27], assume there are n ports. Each port has m inputs and s outputs. Let x_{ij}^t denote the i-th input of the j-th port at year t, and let y_{rj}^t denote the r-th output of the j-th port at year t. The efficiency of the k-th port at year t is computed using the following model (1):

$$
\begin{aligned}
& e_k^t = \min \theta \\
& s.t. \quad \theta x_{ik}^t \geq \sum\nolimits_{j=1}^{n} \lambda_j x_{ij}^t; \\
& y_{rk}^t \leq \sum\nolimits_{j=1}^{n} \lambda_j y_{rj}^t; \\
& \lambda_j \geq 0, j = 1, \cdots, n.
\end{aligned}
\tag{1}
$$

The evaluated efficiency $e_k^t = \theta^*$ in period t can determine the amount by which the observed inputs can be proportionally reduced while producing a given level of output. Similarly, letting period t change to $t+1$ for model (1), we obtain the technical efficiency for the k-th port in period $t+1$.

To calculate the change in productivity efficiency, two mixed-period measures should be constructed. The first computes the optimal value $e_k^{t,t+1}$, which denotes the efficiency of DMU in period t evaluated by the efficient frontier of period t+1 for the k-th port. The following linear programming problem (2) demonstrates this measurement model:

$$\begin{aligned} & e_k^{t,t+1} = \min \theta \\ & s.t.\quad \theta x_{ik}^{t} \geq \sum\nolimits_{j=1}^{n} \lambda_j x_{ij}^{t+1}; \\ & y_{rk}^{t} \leq \sum\nolimits_{j=1}^{n} \lambda_j y_{rj}^{t+1}; \\ & \lambda_j \geq 0, j = 1, \cdots, n. \end{aligned} \tag{2}$$

where $e_k^{t,t+1^*}$ denotes the efficiency of the k-th port at year t relative efficient frontier at t+1. Similarly, the other (3) computes the optimal value $e_k^{t+1,t}$, which denotes the efficiency of DMU in period t+1 evaluated by the efficient frontier of period t.

$$\begin{aligned} & e_k^{t+1,t} = \min \theta \\ & s.t.\quad \theta x_{ik}^{t+1} \geq \sum\nolimits_{j=1}^{n} \lambda_j x_{ij}^{t}; \\ & y_{rk}^{t+1} \leq \sum\nolimits_{j=1}^{n} \lambda_j y_{rj}^{t}; \\ & \lambda_j \geq 0, j = 1, \cdots, n. \end{aligned} \tag{3}$$

Based on Färe et al. [16], the Malmquist Productivity Index can be defined as (4):

$$MPI_k^{t,t+1} = \left[\frac{e_k^{t+1,t+1}}{e_k^{t,t+1}} \times \frac{e_k^{t+1,t}}{e_k^{t,t}}\right]^{1/2} = \frac{e_k^{t+1,t+1}}{e_k^{t,t}} \times \left[\frac{e_k^{t,t}}{e_k^{t,t+1}} \times \frac{e_k^{t+1,t}}{e_k^{t+1,t+1}}\right]^{1/2} \tag{4}$$

where the MPI can be decomposed into two parts. The ratio $\frac{e_k^{t+1,t+1}}{e_k^{t,t}}$ can reflect the change in technical efficiency, while the ratios inside the bracket $\left[\frac{e_k^{t,t}}{e_k^{t,t+1}} \times \frac{e_k^{t+1,t}}{e_k^{t+1,t+1}}\right]^{1/2}$ can measure the shift of frontiers between periods t and t+1. Therefore, in this study, the frontier change measure by port k can be measured by (5):

$$F_k^{t,t+1} = \left[\frac{e_k^{t,t}}{e_k^{t,t+1}} \times \frac{e_k^{t+1,t}}{e_k^{t+1,t+1}}\right]^{1/2} \tag{5}$$

According to (5), the overall frontier progress from year t to year $t+1$ can be measured by

$$F^{t,t+1} = \left[\prod\nolimits_{k=1}^{n} F_K^{t,t+1}\right]^{1/n} \tag{6}$$

If $F^{t,t+1} < 1$, it signifies that the performance of all container ports in Taiwan recedes from year t to year $t+1$. If $F^{t,t+1} > 1$, it signifies that the performance of all container ports in Taiwan makes progress from year t to year $t+1$. If $F^{t,t+1} = 1$, it signifies that the performance of all container ports in Taiwan remains the same from year t to year $t+1$. In this study, we have employed models 1–3 to measure the changes in the frontiers of the container ports in Taiwan from 2018 to 2022.

To ensure the convenience of using this MPI application, this study provides an unambiguous flowchart in Fig. 1. The flowchart for the MPI application with the DEA model is as follows.

4. Empirical study

4.1. Data collection and variables

Taiwan's major international commercial ports include those of Kaohsiung, Keelung, Taipei, Taichung, Taoyuan, Hualien, and Su'ao. Among them, Kaohsiung Port is the largest commercial port in Taiwan, always ranking among the Top 10 international commercial ports in the world, and having the capability to dock 100,000-ton freighters. The port hinterland of Kaohsiung is wider, which is the center of Taiwan's heavy chemical industry base and export processing. In terms of throughput, Keelung Port can be regarded as the second largest port in Taiwan, with more than 60 terminals. Taipei Port was originally intended to be an auxiliary port to Keelung Port, but its area is larger than that of Keelung. Thus, this port now houses Taiwan's Free Trade Port Zone, which has contributed to the

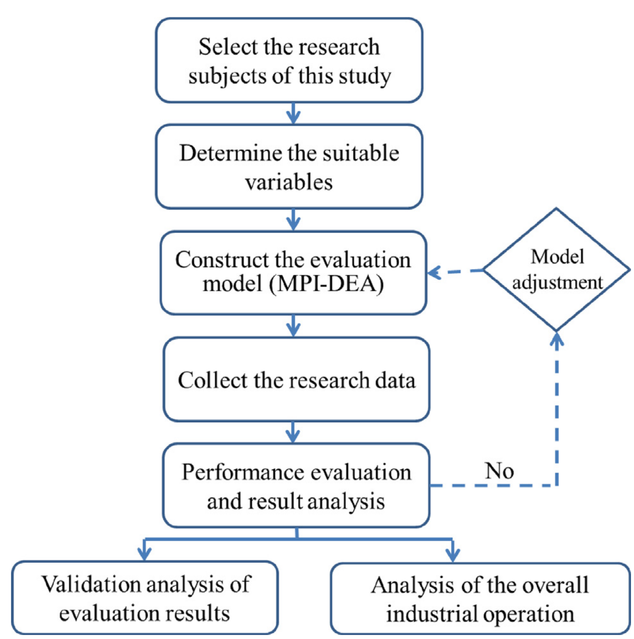

Fig. 1. Flowchart for applying MPI application with DEA model.

growth of the port's international trade volume. Taichung Port, located on the central west coast of Taiwan, is a new international commercial port in Taiwan. It is designed to relieve the operating pressure of the ports of Kaohsiung and Keelung [28].

Thus, to explore recent changes in the efficiency frontier of the operating environment of international container ports, this study collected updated daily operational data from Taiwan Port Group Companies from 2018 to 2022 through expert interviews and visitation research, which covers all pandemic impact phases. Four representative international container ports in Taiwan were selected as research objects. These included the Kaohsiung Port, Taichung Port, Taipei Port, and Keelung Port. Meanwhile, the important evaluation parameters for this study are summarized in Table 1 and the research database is presented in Table 2.

4.2. Evaluation results

According to the methods described above, the total evaluation results for this study are summarized in Table 3. In Table 3, the results of the Malmquist Productivity Index are calculated in the last column, TFPCH is short for "Total Factor Productivity Change Index", which is the product of EFFCH and TECHCH (TFPCH = EFFCH × TECHCH). Additionally, EFFCH denotes the change in efficiency change $\frac{e_k^{t+1,t+1}}{e_k^{t,t}}$, while TECHCH denotes the technological change, which can reflect the frontier change $F^{t,t+1^*}$; thus, it is also referred to as "Frontier-shift Effects" or "Innovation". Next, PECH and SECH are short for "Pure Technical Efficiency Change" and "Scale Efficiency Change", respectively, and the product of these results yields the result "EFFCH" (EFFCH = PECH × SECH).

Table 2. Research data in this study.

Time	Ports	*Input variables*			*Output variables*
		Bridge Cranes	Berth Number	Port Area (km^2)	Throughput (TUE)
2018	Keelung	33	56	572	1,471,865
	Taipei	13	27	3091	1,659,999
	Taichung	16	78	11,285	1,744,126
	Kaohsiung	75	137	17,736	10,445,726
2019	Keelung	33	56	572	1,455,293
	Taipei	13	27	3091	1,620,392
	Taichung	16	78	11,285	1,793,966
	Kaohsiung	75	137	17,736	10,428,634
2020	Keelung	33	56	572	1,532,792
	Taipei	13	27	3091	1,618,131
	Taichung	16	78	11,285	1,820,986
	Kaohsiung	75	137	17,736	9,621,662
2021	Keelung	33	56	572	1,601,392
	Taipei	13	27	3091	2,009,132
	Taichung	16	78	11,285	1,979,295
	Kaohsiung	75	137	17,736	9,864,439
2022	Keelung	33	56	572	1,622,706
	Taipei	13	27	3091	1,789,998
	Taichung	16	78	11,285	1,785,212
	Kaohsiung	75	137	17,736	9,491,575

Table 3. Evaluation results.

	EFFCH	*TECHCH* ($F^{t,t+1^*}$)	PECH	SECH	*TFPCH* (*MPI*)
2018–2019	1.002	0.996	1.011	0.991	0.998
2019–2020	1.045	0.954	1.006	1.038	0.996
2020–2021	0.974	1.126	0.972	1.002	1.097
2021–2022	1.011	0.930	1.000	1.011	0.941
Average	**1.008**	**0.999**	**0.997**	**1.010**	**1.006**

To further analyze the dynamic recent changes in the development trend of international container ports, the "TFPCH", "EFFCH", and "TECHCH" values were converted from Table 3 to Fig. 2.

Table 1. Descriptions for selected variables in this study.

Name	Descriptions
Throughput	•Container throughput is the sum of the number of imported and exported containers in a port over a period, usually in TEU. Container throughput usually can effectively reflect the important role played by ports in international material exchange and foreign trade transportation and is an important basis for port planning and development construction. This was chosen as the key output variable in this study.
Bridge Cranes	•Bridge cranes are the lifting equipment that are erected over containers in the port for lifting material. As their ends are located in tall concrete columns or metal brackets, they are shaped like bridges and thus named. Bridge cranes bridge along track laid on both sides of elevated longitudinal runs, and can fully utilize the space under the bridge to lift containers without obstruction of ground equipment. They are the most widely used and most numerous container port transport tools and were selected as the input variable for this study.
Berths Number	•The determination of berth numbers not only directly affects the throughput capacity of a port and the required construction investment, but also affects the condition of ships in port, loading and unloading costs, and loading and unloading wait times. Thus, it was selected as the second input variable for this study.
Port Area	•Port area usually determines the size of a port, the storage capacity for containers, and other factors. Port area size is directly related to the land cost of the port; therefore, it is a relatively important input resource in the operation of a port.

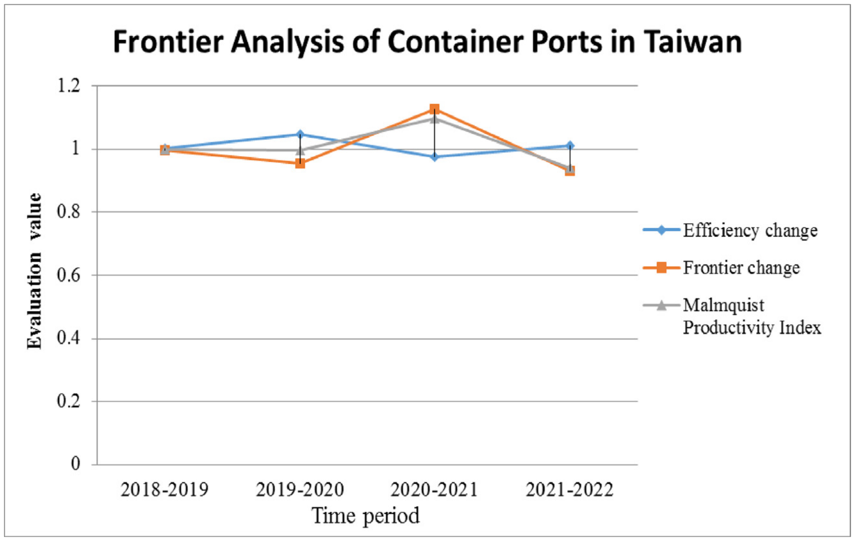

Fig. 2. Frontier analysis of container ports in Taiwan.

In Fig. 2, the dynamic change process of frontier change (TECHCH) remains the same as the MPI (TFPCH) change. Affected by COVID-19, the operating environment and international competitiveness of Taiwan's international container ports revealed a process of first decline (2018–2020) and then gradual recovery (2020–2021), while during 2021–2022, the upward trend in productivity had fallen again.

In analyzing the change of efficiency frontier of operations using the MPI index, if the value of TECHCH ($F^{t,t+1^*}$) was >1, it meant that the performance of all container ports in Taiwan made progress from year t to year t+1. Thus, only 2020–2021 was found to obtain a satisfactory result (with an evaluation score of 1.097), and due to the adverse effects of the pandemic, the remaining periods showed decreasing results (with evaluation scores <1). Under the dual impact of the international competitive environment and cross–strait relations, the overall operating environment of Taiwan's international shipping industry tended to develop steadily during 2018–2019 but did not show a significant recessionary trend (with an evaluation score of 0.998). During the 2019–2020 period, due to the spread of globalization, the overall operating environment of the international shipping industry in Taiwan also began to weaken (with an evaluation score of 0.996). The main reason for the index growth during 2020–2021 may be the accumulation of goods during COVID-19. When the pandemic subsided, requirements to ship large material objects for home offices increased, accelerating market demand for international container transport. In contrast, the change of technical efficiency of Taiwan's international container ports was also found to vary exactly in opposition to the frontier change indicator; yet the overall changes have leveled off in recent years (values of EFFCH have always approximated 1).

5. Conclusions

Since the outbreak of COVID-19 at the end of 2019, the demand for international seaborne trade has been significantly impacted, with weak demand in the international shipping market leading to a gradual decline in container business orders from international shipping enterprises. The impact of COVID-19 on the global shipping market cannot be underestimated. According to the statistics of the Department of Transportation Affairs of Taiwan, due to the pandemic's impact on global shipping, global shipping derived from the shortage of containers and the phenomenon of port congestion have both affected Taiwan's major commercial ports. As a result, the cargo handling capacity of Taiwan's international commercial ports in the first four months of 2022 amounted to only 240 million billable tons, a year-on-year decrease of 2.4%, of which the cargo loading and unloading capacity declined by 1.4% and 3.1% year-on-year, respectively. Among them, Kaohsiung Port ranked first among Taiwan's commercial port throughputs with 140 million charged tons (accounting for 59.9% of the total handling volume) but decreased by 1.7% compared with the same period the previous year. It was followed by the Taichung Port, which contributed 43.34 million charging tons (18.2%) with an annual increase of 0.2%. Next was Taipei Port and Keelung Port, which produced 26.38 (11%) and 21.23 (8.9%) million charging tons, with a reduction of 10.4% and an annual increase of 2% year on year, respectively [29]. In general, the operating performance of Taiwan's major international commercial ports declined due to the impact of the pandemic. Therefore, this study collects real operating data of Taiwan's major international container ports during the COVID-19 pandemic and combines the MPI and DEA theoretical methods to investigate the frontier changes of Taiwan's container ports under its impact.

Through this research and analysis, this study identifies that during the years affected by COVID-19, the total factor production capacity of Taiwan's international container ports fluctuated. When the pandemic broke out in 2019, the overall operating environment began to decline until the pandemic slowed, and the operating atmosphere only improved during 2020–2021 (MPI evaluation score of 1.097). However, during 2021–2022, the entire international container shipping market in Taiwan began to go downhill again compared to the previous year. This change is consistent with the operation law of the global container shipping market. Previous studies [30] have indicated that in 2021, under the active guidance of the Ministry of Transport of China, 13 major global liner companies, including Cosco Shipping Group, invested up to 27 million TEU in China's main export routes (with an increase of 19.6% compared to 2020). This is much higher than the average growth level of global container placement (4.6%). Yet, in the last year, many international container ports have again had large numbers of empty containers. Schenker (China) Ltd. Vice President of Greater indicated that a major reason for the accumulation of empty containers in major ports around the world was the excessive container production during COVID-19. According to the shipping consulting firm Drewry, in 2021, the global production of more than 7 million containers was three times the production of conventional years. Thus, the pullback in the container market of Taiwan during 2021–2022 was consistent with this phenomenon.

This study found that Taiwan's international container shipping industry has been severely affected by the COVID-19 pandemic. Not only during the pandemic period but also in the post-pandemic era, in which some new problems have emerged. These include excess empty containers, which is a new factor restricting the development of the international container shipping industry. In contrast, China's international container transportation industry plays a pivotal role in the global competitive market, accounting for nearly 70% of the world's Top 10 international container ports. Due to the impact of the pandemic, the relationship between the two countries has distanced, which may also increase the resistance to the development of the international container shipping industry in Taiwan. To this end, relevant managers can at least start from the following levels to enhance the operational performance of the port: on the one hand, optimize ports' modes of import and export, and shorten waiting times for ship operations in port areas. Usually, due to the lack of port operators, if ships stay in the port area too long, they will face high demurrage costs, which may greatly increase the chances of a shipping company leaving the port after unloading goods, resulting in a reluctance to remain in the port to wait for other loading tasks. On the other hand, expand the overall vision, from a “competition mode” to a “co-creation mode” of development. The occurrence of the pandemic forces more attention on the value of resources. In the process of the gradual recovery and development of Taiwan's international container industry, if managers can develop a strategy of establishing an international sustainable container transport development alliance, it will be possible to create more mutual benefits for the major international container ports in Taiwan.

Conflicts of interest

The authors declare no conflict of interest.

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