2024-03-25

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Danladi, C

https://pearl.plymouth.ac.uk/handle/10026.1/22251

10.1186/s41072-024-00163-2
Journal of Shipping and Trade
Springer Science and Business Media LLC

Danladi *et al. Journal of Shipping and Trade* (2024) 9:7
https://doi.org/10.1186/s41072-024-00163-2

Journal of Shipping and Trade

ORIGINAL ARTICLE Open Access

Efficiency analysis and benchmarking of container ports operating in lower-middle-income countries: a DEA approach

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Abstract

Container ports play a pivotal role in international trade, facilitating the movement of goods and fostering economic development. While much attention has been given to the efficiency of ports in high-income countries, container ports in lower-middle-income (LMI) countries have received less attention. This paper addresses this research gap by assessing container ports' operational efficiency across diverse LMI countries and determining ways for their efficiency enhancement and management optimization. The cross-sectional data for the year 2012 was collected for 53 container ports in LMI countries. This research utilizes data envelopment analysis, which offers the advantage of considering multiple inputs and outputs. The results show that the overall technical inefficiencies of LMI countries' container ports are mainly due to pure technical inefficiency rather than scale inefficiencies, and the most efficient ports have a combination of large and hub ports. They also reveal that larger ports (as measured by throughput) are not necessarily more efficient than ports with a small production scale. The results of this research can provide government authorities, port authorities, terminal operators, and investors with valuable insights into resource allocation, competitive advantage, and optimization of operating performance.

Keywords: Container ports, Benchmarking, Port efficiency, Data envelopment analysis, Lower-middle-income countries, Port performance, Port productivity

Introduction

The rate of growth in the lower-middle-income countries' container port markets has been dramatic in recent years. This has been driven by globalization, deregulation, changes in consumption patterns, technological progress, and the rise of LMI countries such as Vietnam, India, Bangladesh, and Indonesia as the world's manufacturing centers. According to UNCTAD (2022), growth in containerized seaborne trade has risen in all lower-middle-income countries, with an estimated 5.6% in the African region, 3% in Latin America and the Caribbean, and 3% in Asia region, which remained the world leading maritime cargo handling center, accounting for 42% of goods loaded and 64% of those unloaded in 2021.

Ports form a vital link to international maritime trade, connecting global, regional, and local transportation networks and supply chains (Cheon et al. 2010). According to UNCTAD (2018), about 80% of world trade is carried via maritime transportation. Port efficiency is an essential contributor to international trade and countries' competitiveness (Cheon et al. 2010). To improve port efficiency, port managers must continually assess and benchmark their operations against the best practices (Hung et al. 2010).

Port efficiency is a significant determinant of transport and logistics costs, and improving port efficiency from the 25th to 75th percentiles reduces shipping costs by more than 12% (Clark et al. 2004). However, LMIC container ports faced several challenges which affected their efficiency. According to the World Bank's logistics performance index, LMI countries scored 2.62 in 2017 on a scale of 1 to 5, compared to 3.60 for OECD countries (World Bank 2018). In terms of infrastructure, the Quality of Port Infrastructure Index published by the World Economic Forum (2017) revealed that LMI countries scored 3.34 on a scale of 1 to 7, compared to 5.017 for OECD countries. These figures are evidence of problems in lower-middle-income countries' container port sector.

In light of the above discussion, the little knowledge available on port performance in lower-middle-income countries is surprising. The few studies available have focused mostly on single countries or small geographical regions (Suárez-Alemán et al. 2016; Nguyen et al. 2016; Trujillo et al. 2013; Wu and Goh 2010; Iyer and Nanyam 2021). This may be due to limitations in data availability and difficulties in collecting data from such a large and diverse group of ports, which belong to various countries in different geographical regions. Yet studying port efficiency in lower-middle-income countries is considerably important for several reasons. Firstly, LMI Countries represent a substantial portion of international trade and play a critical role in global trade, with 59% of global exports and 64% of global imports passing through them (UNCTAD 2018). This has induced a huge demand for seaport services in the region. Secondly, as global trade continues to expand, there is a growing need for efficient and competitive ports in LMI countries to support the flow of goods. More importantly, recent works by Nguyen et al. (2020), Baert and Reynaerts (2020), Kavirathna et al. (2019), Adler et al. (2022), and Cheng et al. (2022) indicate that efficiency plays a crucial role in the port competition. Thirdly, many manufacturing companies have relocated their manufacturing sites to LMI countries such as Vietnam, India, Bangladesh, and Indonesia. The changing landscape of manufacturing is boosting demand for raw materials and finished products between LMI countries and other markets. In this context, a better understanding of the under- and best-performing ports in LMIC would inform how best policymakers and regulatory authorities will channel the available resources to invest in projects in an efficient way and implement the best policies.

The current study employs data envelopment analysis for efficiency analysis, which provides a benchmarking of the container port terminals based on the estimated efficiencies. This approach enables the identification of under- and best-performing container terminals (Nikolau and Dimitriou 2021) for the following reasons: first, DEA can handle multiple inputs and outputs (Cook et al. 2014; Coelli et al. 2005; Tongzon 2001). Secondly, DEA does not require a priori information about the relationship between output and inputs. Lastly, DEA has been used successfully in several studies to benchmark container ports' efficiency in transportation economics (Hung et al. 2010; Tongzon 2001; Yuen et al. 2013).

Overall, this research aims to (1) assess the efficiency of container ports in LMI countries, (2) benchmark the performance of container ports in LMI countries, (3) identify the factors influencing port efficiency, and (4) propose recommendations to improve port efficiency in LMI countries. It contributes to the existing literature by providing managerial insight to port operators and policymakers for the improvement of the under-performing container port terminals, at least those belonging to or resembling the LMIC container ports, and theoretical contribution to the field of port economics, port management, and efficiency assessment methodologies, providing valuable knowledge for improving the performance of ports in LMI Countries.

The remainder of this paper is structured as follows: literature related to port efficiency is discussed in "Literature review" section. Methodological issues, including the empirical evaluation of port management and efficiency using DEA, are introduced in "Research methodology" section. Data descriptions are given in data section. Results are shown in Empirical results and discussions. Summary of findings are shown in summary and finding section. Policy implications are shown in policy implications and theoretical contribution section. Finally, Limitation and Future research are shown in Limitation and future research section.

Literature review

Benchmarking port performance techniques

Performance benchmarking is the evaluation of performance in relation to a comparable group (Tsakiridis et al. 2021). Over the last decades, various port performance indicators have been employed in order to enhance port operations and offer valuable insights for port development planning and strategy. The assessment of port operations can be conducted using many indicators, as suggested by UNCTAD in 1976. These studies have demonstrated that the idea of port performance may be analyzed from multiple perspectives and appraised using diverse approaches, depending on study aims and specific assumptions about various aspects. For example, port performance has been variously evaluated by calculating cargo-handling productivity at berth (UNCTAD 1976), by measuring the productivity of a single factor (De Monie 1987), or by comparing actual with optimum throughput a specific period (Talley 1988). These traditional techniques measure partial productivity and are insufficient to provide profound insights into the management or policy implications of container port efficiency. However, a port production function necessitates the utilization of a number of different inputs and outputs. Because of this, the economic literature has developed and is now concentrating more and more on overall measures of port performance. These measures take into consideration a variety of inputs that are utilized, the technology that is employed to transform inputs into outputs, and the productive size of the organization. Within this particular domain, there are two distinct ideas that stand out: productivity and efficiency and the best practice located on the production frontier (Suarez-Aleman et al. 2016). According to Suarez-Alema et al. (2016), constructing an efficient frontier has been addressed from two different approaches: Parametric, with stochastic frontier analysis (SFA), and non-parametric, with data envelopment analysis (DEA).

Port efficiency and port reform

A study of the efficiency of the port sector first appeared in academic Journals in 1983, reported by Roll and Hayuth 1993, who used DEA to assess the efficiency of 20 ports. Since then, there have been many empirical studies of the productive efficiency of seaports using DEA (Tongzon 2001; Chang and Tovar 2014; Cullinane and Wang 2006a, b; Pérez et al. 2016; González and Trujillo 2009; Barros 2006). Wanke (2013) adopted a two-stage DEA process to measure the efficiency of 27 Brazilian ports for 2011. In the first stage, DEA was used to calculate the efficiency score. Shipment consolidation frequency was employed in the second stage to allow solid and containerized cargoes to be handled, and then their productivity was regressed on contextual variables. They found that the hinterland size and operations of both types of cargo positively affect consolidated efficiency. In addition, they found that private sector participation in port operations has resulted in massive infrastructure and superstructure investments, increasing efficiency and productivity. However, their study was limited in its application as it chose to focus on a small sample of ports solely drawn from one country for the year 2011.

Regarding the effects of ownership structure on port efficiency, Estache et al. (2002) examine the impact of Mexico's 1993 port reforms by using panel data from 44 observations from 11 independent port administrations. They observed higher efficiency in decentralized ports when compared to state-owned ports. Cullinane et al. (2002) also found that state-owned ports are less efficient than decentralized ports. Tongzon and Heng (2005) investigated the relationship between port ownership structure and major container ports' worldwide operational efficiency using stochastic frontier production function for the panel dataset. They found that private sector participation in port ownership, to some extent, can improve operational efficiency. Transforming port ownership from the public sector to the private sector will create higher efficiency through massive investment in port infrastructure and technical skills, and state-owned ports may operate less efficiently than comparable privatized or decentralized ports. This lower efficiency may be due to more significant political intervention, less competition, and high government control. However, some studies generate different results. Liu (1995) examined how different port ownership structures affected the productivity and efficiency of 28 ports in the UK using a Stochastic production function. The authors found no correlation between port ownership structure and port operational efficiency. Likewise, Notteboom et al. (2000) used the Bayesian Stochastic Frontier model to compare the efficiency level of 36 European Container ports and 4 Asian container ports. The authors failed to demonstrate that there is a relationship between the type of ownership structure and port operational efficiency.

Recently, Cano-Leiva et al. (2023) analyzed the effect of privately managed terminals on the technical efficiency of Spanish ports from 2002 to 2018 using a two-stage approach. In the first stage, a parametric (SFA) and non-parametric (DEA) approach is used to calculate the productive efficiency of each port. In the second stage, a linear regression model is run to examine the effect of some exogenous factors on the technical efficiency of Spanish ports. They found that privately operated terminals are more efficient than publicly operated terminals. Further analysis of findings shows that size and location affect the productivity and efficiency of ports. This indicates that larger ports and ports close to the refinery are more efficient.

In contrast, Iyer and Nanyam (2021) analyze the technical efficiency of 26 container terminals in India using a data envelopment approach for the years 2015–2018 and interpret the results with respect to location advantage, administrative control, and private sector control of terminal operations. The authors concluded that private sector participation in port operations has not improved port productivity. The dominant factor influencing efficiency is found to be size, offering advantages of economies of scale.

The impact of port sector reforms has also been the subject of extensive research. López-Bermúdez et al. (2019) analyzed the efficiency and productivity of twenty Brazilian ports between 2008 and 2017 using stochastic frontier analysis. The authors concluded that reforms led to improved efficiency in Brazilian ports. Similarly, Pérez et al. (2016) evaluated how port organizational reforms affected port efficiency in Latin America and the Caribbean. The results illustrated that private sector participation stimulates port efficiency, particularly in enabling private operators to focus on ports' operations and cargo handling services. Cheon et al. (2010) adopted an analysis of the Malmquist Productivity Index to analyze how port institutional reforms influenced the efficiency gain between 1991 and 2004. They found that ownership restructuring contributed to total factor productivity gains through improvement in Container terminal management, production scale adjustment, and technological progress.

Focusing on African port reforms, Trujillo et al. (2013) found that port reforms led to improved efficiency scores during the observed period. Similarly, Barros and Peypoch (2012) compared the productivity change for three African ports (Nigeria, Angola, and Mozambique). The authors concluded that private terminals are more efficient than those left in the public domain, and reforms resulted in massive investment in infrastructure and private operators' adoption of new technology in cargo and port operations. Examining Nigerian port sector reforms, Nwanosike et al. (2016) used a Malmquist Index to measure how port institutional reforms influenced the efficiency gained between 2000 and 2011. They found that Nigerian port reforms in the early 2000s generated significant productivity improvement but mainly through scale efficiency rather than technological progress. The outcomes provide explanatory evidence that private sector participation in ports has improved the quality of cargo handling equipment, which in turn improved the turnaround time of vessels and terminal efficiency.

Port efficiency and other factors

The relationship between connectivity and cost was highlighted in UNCTAD (2019), showing the critical role of well-connected ports in minimizing logistics and transport costs. Tovar and Wall (2022) investigated the relationship between maritime connectivity and port efficiency for 16 Spanish ports from 2006 to 2016 using SFA. The authors concluded a positive relationship between connectivity and port efficiency. This shows how well a country is connected to the global shipping network, plays a crucial role in international trade, and reduces handling costs. Similarly, Suárez-Alemán et al. (2016) found that ports with higher connectivity have higher efficiency. However, this study was limited in its application as it focused on country-level data rather than port-level data.

Research in port efficiency has extended to the benchmarking and ranking of efficient ports. Nikolaou and Dimitriou (2021) collected 5 years of data on the top 50 international container terminals in the world, used DEA to compute the relative productivity measures for the sample ports, and then regressed their productivities on a number of explanatory factors. The authors concluded that port quay cranes positively impact terminal container performance.

Kammoun and Abdennadher (2022) apply DEA window analysis and principal component analysis (PCA) to benchmark and measure the efficiency of container ports and to understand factors that affect the competitiveness of the 30 largest container ports in Europe from 2005 to 2018. They consider eight explanatory variables: port turnaround time, operating hours, port safety and quality, labor and capital productivity, Liner Shipping Connectivity index, cost of exports and imports, the number of documents to import, and the number of documents to export containers, quality of port infrastructure, and the port logistics performance index. The authors found that Northern European ports are more competitive but less efficient. This is due to the impact of handling costs on port competitiveness. The negative correlation may also have been caused by over-investment and excess use of inputs by ports to provide quality customer services. These findings align with Figueiredo De Oliveira and Cariou (2015), who claimed that a port subjected to port competition might record lower efficiency scores due to over-investment.

The evolution of the impact of smart port design on port performance has also been the subject of extensive research. Yen et al. (2023) investigated how smart port design can influence the efficiency of maritime ports using a three-step DEA-Tobit regression approach model for the top 20 container ports. The study examined three aspects of smart ports: automation, environment, and intelligence. They found that Pollution controls has the highest positive impact on port efficiency. On the contrary, information sharing from the intelligence aspect has a negative impact on efficiency due to technological requirements and information overload.

Some researchers focused on assessing the impacts of the COVID-19 pandemic on the efficiency of ports. Gu et al. (2023) analyses the impact of COVID-19 on port operations in Asian ports. They found that the outbreak of the COVID-19 pandemic has had a significant adverse effect on port operations and led to varying levels of loss on maritime transportation as the situation is different among regions. It is worth noting that the outbreak of COVID-19 has impacted the port industry following the implementation of strict prevention measures to curb the transmission of the disease. These measures include social distancing, quarantine controls, workplace closures, and lockdown restrictions, which significantly affect the global supply chain.

Conceptual framework

Based on prior literature review, many port-specific variables that impact port efficiency have been found.

The conceptual framework model is illustrated in Fig. 1. The main objective of the study is to assess the container ports' operational efficiency across diverse LMI countries and determining ways for their efficiency enhancement and management optimization. Benchmarking of container ports would enable the comparison between ports of

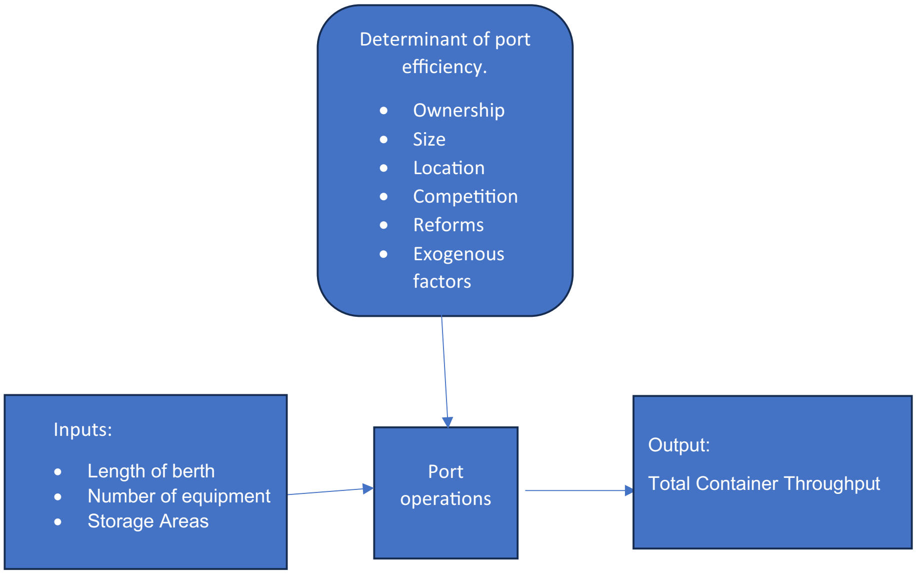

Fig. 1 Conceptual framework

similar income groups to identify the best practice. By focusing on operational factors and determinants of port efficiency, benchmarking ports can identify areas for improvement, implementing best practices.

Research gap

The efficiency of container ports in lower-middle-income countries has become an increasingly important topic due to their pivotal role in global trade and economic development. However, several research gaps still exist in understanding and benchmarking the efficiency of these ports. For instance, a review of studies in transport policy journals conducted by Merkel and Holmgren (2017) discovered a total of 53 published Journals between 2000 and 2016. The review indicates that the studies favor the developed world despite the importance of container ports in LMI Countries and global trade. The few studies available have focused mostly on single countries or small geographical regions. For example, Nong (2023) measured the efficiency of 22 ports listed in the stock market in Vietnam (a developing country) from 2019 to 2021, highlighting the influence of scale and management structure on port performance. Comprehensive analyses of ports across LMI countries are hardly comparable. This may be due to difficulties in collecting.

This paper addresses these issues by analyzing a sample of 53 Major and minor container ports in LMI countries using data envelopment analysis. The focus on the efficiency and productivity of the 53 container ports shall contribute to container port economics in efficiency improvement and the benchmarking of container terminals. This study intends to help decision-makers identify high-performing terminals so that the best practices may be implemented in low-performing ones.

Research methodology

This research utilizes quantitative methods for data collection and analysis. The choice of a quantitative method for data collection can be justified for the following reasons. Firstly, quantitative data on port operations, such as container throughput, length of berth, storage area, and number of equipment, are often readily available from port authorities, shipping companies, and relevant government agencies. Secondly, quantitative methods, such as DEA, enable the researchers to compare the efficiency of multiple ports, benchmark performance, and identify best practices. This is essential for making informed decisions and improving efficiency. Thirdly, port efficiency analysis involves numerous inputs and output variables. Quantitative methods such as DEA can handle such complexity and offer a structured approach to analyzing the nature of port operations. Lastly, quantitative analysis generates data-driven insights, allowing researchers to draw conclusions based on empirical evidence rather than relying solely on qualitative assessment.

Data envelopment analysis

This study employs the traditional DEA to measure technical efficiency, pure technical efficiency, and scale efficiency and further determines the current return to scale for container ports.

Data envelopment analysis can be defined as a non-parametric method for measuring the efficiency of a decision-making unit (DMU) with multiple inputs and outputs (Charnes et al. 1985). This is achieved by calculating the relative performance of the under-investigation DMUs to the group observed best practice (Panayides et al. 2009; Cook et al. 2014). In recent years, there has been an increase in the application of Data Envelopment Analysis since the original work of Charnes et al. 1978. Since then, a large number of papers have appeared using DEA. For example, a recent survey and analysis of the first 40 years of scholarly literature on DEA (1978–2016) by Emrouznejad and Yang (2018) found approximately 11,961 distinct DEA Authors and 25,137 distinct keywords in all DEA-related articles.

The origins of the data envelopment analysis (DEA) can be attributed to Farrell (1957), who introduced a methodology for evaluating deviations from an idealized production frontier isoquant. This approach involved the development of a piecewise linear envelopment of the data to determine the frontier. The research conducted by Charnes et al. (Citation1978) contributed to the advancement of this field. They provided a linear programming (LP) methodology as a solution to the challenges presented by the previous fractional programming (FP) approach. This development led to the establishment of the DEA-CCR model. The DEA-CCR model was subsequently succeeded by the DEA-BCC model, as proposed by Banker et al. (1984). The primary distinction between these two models is their respective applications to scenarios characterized by constant returns to scale (CCR model) and variable returns to scale (BCC model). Since its introduction by Charnes et al. (1978), there have been many applications of DEA in the port sector to calculate productive efficiency.

DEA is suitable for this analysis for the following reasons: First, DEA has been proven in performance analysis when multiple inputs and multiple outputs are involved (Cook et al. 2014; Charnes et al. 1985; Panayides et al. 2009). Secondly, DEA calculations are non-parametric and do not require a priori information about the relationship between inputs and output variables. Thirdly, the port industry has used benchmarking as a performance evaluation method. DEA makes benchmarking easier and more realistic because it allows for the derivation of efficiency to envelop, which contain the most efficient ports in the group analyzed, against which other ports are compared, instead of just choosing the most efficient port (Panayides et al. 2009; Cook et al. 2014; Tongzon 2001). Lastly, DEA has been used successfully in several studies about the efficiency of container ports in the field of transportation economics (Bichou 2013; Yuen et al. 2013; Hung et al. 2010; Cullinane and Wang 2006a, b; Cullinane and Wang 2010; Figueiredo De Oliveira and Cariou 2015; Almawsheki and Shah 2015; Kutin et al. 2017; Périco and Ribeiro da Silva 2020; Pehlivan 2020; Nguyen et al. 2020; Djordjević et al. 2023; Kuo et al. 2020).

Firm efficiency is reflected by the relationship between the firm's outputs and the inputs it uses at a given period (Coelli et al. 2005). With DEA, there is a choice of using an input-orientation model (focus on minimizing the inputs for a given output) or an output-oriented model (focus on maximizing outputs for a given input) (Coelli et al. 2005). The former is closely related to operational and management issues, while the latter relates to port planning and strategy (Cullinane and Wang 2006a, b).

This study adopts the output-oriented model because most of the inputs selected (Length of berth, storage area) were quasi-fixed. This led to the conclusion that the output-oriented model would provide the most accurate results. All the DEA models are now described as follows: The objective of the CCR model is to maximize outputs given a set of inputs, where the highest possible score of a DMU is 1.0 (Charnes et al. 1978). The CCR model can be mathematically expressed as

$$\frac{\sum_{r=1}^{n}(u_{rb})(y_{rb})}{\sum_{k=1}^{m}(v_{kb})(x_{kb})} \tag{1}$$

Subject to:

$$\frac{\sum_{r=1}^{n}(u_{rb})(y_{rb})}{\sum_{k=1}^{m}(v_{kb})(x_{kb})} \leq 1 \quad \text{for all } j$$

$u_{rb}, v_{kb} \geq \varepsilon$ for all r, k

y_{rj} = the vector of output r produced by the unit j.

x_{kj} = the vector of input k used by the unit j.

u_{rb} = the weight given to output r by the base unit b.

k_{kb} = the weight given to input k by the base unit b.

$j = 1, 2, 3, \ldots, p$

$r = 1, 2, 3, \ldots, n$

$k = 1, 2, 3, \ldots, m$

ε = a very small positive number.

The BCC model assumes the variable return to scale (VRS) and represents pure technical efficiency (PTE) without including the scale efficiency (SE). The BCC model can be formulated as:

$$\underset{u,v,\omega}{Max}\ \theta_b = \sum_{r=1}^{s} u_r\left(y_{rjb}\right) + \omega \tag{2}$$

Subject to:

$$\sum_{i=1}^{m} v_i\left(x_{ijb}\right) = 1$$

$$\sum_{i=1}^{s} u_r\left(y_{rj}\right) - \sum_{i=1}^{m} v_i\left(x_{ij}\right) + \omega \le 0$$

$$u_r \ge \varepsilon$$

$$v_i \ge \varepsilon$$

r = 1,2,3 …, s,
i = 1,2,3 …, m,
j = 1,2,3 …, N,
ω = free.

In the above equation, if $\omega^{>}$ 0, then the model becomes DEA with an Increasing Returns to Scale (IRS), and if $\omega < 0$, it becomes DEA with a Decreasing Returns to Scale (DRS). Also, it is noted that DMU j_b is Pareto-efficient if and only if θ_b (pure technical efficiency) = 1.

The CCR score, θ^*_{CCR} Which represents Technical Efficiency (TE), is a combination of pure Technical Efficiency (PTE) and Scale Efficiency (SE). That is, TE = PTE × SE. Hence Scale efficiency is defined as

$$SE = \frac{\theta^*_{CCR}}{\theta^*_{BCC}} \tag{3}$$

Data selection

The sample consists of a cross-sectional data set for 53 container ports in LMI countries in 2012. Of these 53 container ports, Mumbai, Banjul, Warri, and Calabar ports are excluded because the required data are unavailable.

Method of data collection

It is important to select the data from a reliable source to provide accurate results. The data required for the analysis is collected through quantitative methods. Data sources for efficiency analysis are collected from secondary sources, such as 'Containerization International Yearbook,' a publication that provides a detailed description of Container handling equipment and characteristics worldwide, annual reports, websites, and statistical handbooks for various countries. The data collected from different sources was examined, scrutinized, and compared for accuracy and conformity with one another. As the study focused on benchmarking the operational efficiency of container ports in LMI countries, secondary data is used as a method of data collection because the necessary inputs and outputs for benchmarking analysis ports to assess their efficiency relative to their peers. Using secondary data was decided upon after carefully evaluating the suitability of other forms of data collection. Thus, the choice of secondary data is predicated on its advantages, such as comparative and contextual data, speed of data gathering, permanence, and convenience (Saunders et al. 2016).

To ensure data quality and credibility of findings, some measures were taken to validate the data collected. This included selecting appropriate inputs and output variables from relevant empirical literature that influenced port performance. All inputs and output variables should be positive and non-zero, satisfying the positivity requirement, and the data from different sources were examined and compared for accuracy and conformity with one another.

This research uses aggregate data at a port level for efficiency analysis because of the following reasons: Firstly, some container ports in LMI countries handle containers in multipurpose berths, part of which are also utilized for non-container container activities in contrast to some container ports that are designed solely for container ships. Secondly, based on the argument that container terminals are more suitable for one-to-one comparison than the whole port (Wang et al. 2005; Cullinane and Wang 2006a, b). However, data sources often reported the required data, particularly container throughput at the port's aggregate level, rather than based on the individual terminals that make up each of the ports within the sample. In such a case, the input and output of individual terminals are reported as aggregate at the port level.

According to economic theory, a Container port depends on efficient port land, labor, and capital utilization (Dowd and Leschine 1990). Given these characteristics, the analysis identified three inputs: the length of berths, the storage area, and the number of cargo handling equipment (ship shore gantry crane, yard gantry, mobile crane, straddle carriers, and reach stackers). However, information on labor is excluded from the efficiency estimation as there is no reliable database to collect data on labor at the port level. In addition, the workforce structure of the port organization is complicated, consisting of different types of full-time and part-time jobs and other contract jobs that are not directly administered by the port management (Cheon et al. 2010). Therefore, several researchers, such as Cheon et al. (2010), Tongzon (2001), Tongzon and Heng (2005), and Bichou (2013), all claimed that due to the difficulties of obtaining reliable data on labor, this variable should be excluded for efficiency estimation. In port performance analysis, the choice of input variables, such as berth length, is critical. The berth length is a linear distance for ships to berth for loading and unloading operations. The berth length is chosen as the input variable because it affects a port's capacity to handle vessels of different sizes and quantities. Longer berths can simultaneously accommodate more or larger ships, contributing to higher throughput and efficiency. As with most previous studies, this has been incorporated as input variables representing the facilities involved in the container production process. For instance, Cullinane et al. (2002) and Notteboom et al. (2000) define total berth length as input variables.

Furthermore, with the ongoing shift towards larger vessels in global trade, it has become imperative for ports to undertake necessary adaptations. The provision of extended berths is crucial for efficiently handling these larger vessels. Ports with insufficient berth length may encounter difficulties attracting contemporary, larger ships, adversely affecting their competitiveness. The length of the berth directly influences a port's throughput capacity. A longer berth allows for the simultaneous handling of more vessels and larger ships, increasing the potential for container handling. The relationship is emphasized by Coto-Millan et al. (2000), who noted that berth length is a critical factor in determining a port's efficiency and capacity utilization.

This study also chooses storage area as the input variable for port performance analysis; storage capacity, or the amount of space available for the storage of cargo and containers, is a significant variable for port performance analysis because ports that possess sufficient storage capacity are capable of effectively managing substantial quantities of cargo, facilitating the smooth transportation of commodities across various modes of transport such as ships, trucks, and trains. The storage capacity of a port determines the capacity of ports to receive vessels (Perez et al. 2016). This factor significantly enhances port efficiency by decreasing dwell periods and transportation expenses. The storage area has been used in various research that applied DEA to benchmark the efficiency of ports. For instance, Nwanosike et al. (2016) and Perez et al. (2016) used storage area as an input variable.

The last input variable for efficiency analysis is the number of equipment. The quantity of equipment units, such as cranes, forklifts, ship-shore gantry, RTG, and straddle carriers, directly influences the operational productivity of a port. The presence of additional equipment generally facilitates expedited and enhanced freight handling processes. Ports with sufficient equipment can manage a larger capacity of containers and commodities, hence becoming a crucial factor in determining port efficiency. A study by Ng and Liu (2010) demonstrates the significance of equipment availability in port operations. The number of equipment has been used in various research that applied DEA to measure port efficiency; for instance, Cullinane and Song (2002), Nwanosike et al. (2016), Chang and Tovar (2014), Wu and Goh (2010) used the number of equipment as input variable.

The total volume of containers loaded and unloaded at the port level (total container throughput) is considered the output variable. Previous port efficiency literature shows container throughput is the most dominant and widely acceptable indicator for port output variables in efficiency analysis. This is because it is closely related to the need (Table 1).

For cargo handling facilities, and is the primary basis upon which container ports are compared, especially in determining their size of operations, level of investment, and level of economic activities (Cullinane and Wang 2006a, b).

Table 1 Descriptive statistics for lower-middle-income countries for 2012

	Output container throughput	**Inputs**		
		Berth length	**Total storage area**	**Number of equipment**
Mean	977,334	1092	28,591	36
Standard deviation	1,370,773	888	82,456	33
Minimum	36,000	150	800	3
Maximum	7,245,121	4,382	600,000	144
Total Number	53	53	53	53

Table 2 Efficiency scores of the 39 container ports in lower-middle-income-countries

Port	Country	Region	DEA-CCR	DEA-BCC	SE	Return to scale
Luanda	Angola	Sub-Saharan Africa	0.599	0.615	0.974	Increasing
Douala	Cameroon	Sub-Saharan Africa	0.200	0.204	0.977	Increasing
Abidjan	Cote d'Ivoire	Sub-Saharan Africa	0.270	0.275	0.980	Decreasing
Djibouti	Djibouti	The Middle East and North Africa	0.297	0.310	0.960	Decreasing
Alexandria	Egypt	The Middle East and North Africa	0.237	0.283	0.836	Decreasing
Damietta	Egypt	The Middle East and North Africa	0.734	0.781	0.9940	Increasing
El Dekheila	Egypt	The Middle East and North Africa	0.182	0.216	0.846	Decreasing
Port Said	Egypt	The Middle East and North Africa	0.584	0.867	0.673	Decreasing
Tema	Ghana	Sub-Saharan Africa	0.447	0.458	0.976	Decreasing
Puerto Castilla	Honduras	Latin America and the Caribbean	0.488	1.000	0.488	Increasing
Purto Cortes	Honduras	Latin America and the Caribbean	0.855	0.918	0.932	increasing
Chennai	India	South Asia	0.620	0.625	0.9992	Decreasing
Jawaharlal Nehru	India	South Asia	0.832	1.000	0.832	Decreasing
Kandla	India	South Asia	0.209	0.214	0.977	Increasing
Kochin	India	South Asia	0.315	0.322	0.979	Increasing
Kolkata	India	South Asia	0.298	0.316	0.940	Decreasing
Mundra	India	South Asia	0.552	0.573	0.964	Decreasing
Tuticorin	India	South Asia	0.405	0.419	0.968	Increasing
Visakhapatnam	India	South Asia	0.203	0.217	0.937	Increasing
Tanjung Perak	Indonesia	East Asia and Pacific	0.922	1.000	0.922	Decreasing
Belawan	Indonesia	East Asia and Pacific	0.426	0.471	0.905	Increasing
Makassar	Indonesia	East Asia and Pacific	0.393	0.474	0.830	Increasing
Tanjung Priok	Indonesia	East Asia and Pacific	0.700	1.000	0.700	Decreasing
Casablanca	Morocco	The Middle East and North Africa	0.233	0.237	0.981	Decreasing
Corinto	Nicaragua	Latin America and the Caribbean	0.126	0.151	0.830	Increasing
Apapa	Nigeria	Sub-Saharan Africa	0.124	0.131	0.950	Decreasing
Tin Can Island	Nigeria	Sub-Saharan Africa	0.643	0.659	0.967	Increasing
Onne	Nigeria	Sub-Saharan Africa	0.107	0.174	0.613	Increasing
Karachi	Pakistan	South Asia	0.311	0.421	0.739	Decreasing
Port Mohammed Bin Qassim	Pakistan	South Asia	0.420	0.436	0.963	Increasing
Manilla	Philippines	East Asia and the Pacific	0.464	0.616	0.754	Decreasing
Iloilo	Philippines	East Asia and the Pacific	0.313	0.519	0.603	Increasing
Port Sudan	Sudan	Sub-Saharan Africa	0.345	0.400	0.862	Increasing
Colombo	Sri Lanka	South Asia	0.575	0.770	0.747	Decreasing
Illichivsk	Ukraine	Europe and Central Asia	0.135	0.137	0.987	Increasing
Odessa	Ukraine	Europe and Central Asia	0.350	0.351	0.999	decreasing
Mombasa	Kenya	Sub-Saharan Africa	0.582	0.596	0.976	Increasing
Dakar	Senegal	Sub-Saharan Africa	1.000	1.000	1.000	Constant
Dar es Salaam	Tanzania	Sub-Saharan Africa	0.303	0.303	0.998	Decreasing

Table 2 (continued)

Port	Country	Region	DEA-CCR	DEA-BCC	SE	Return to scale
Chittagong	Bangladesh	South Asia	1.00	1.000	1.000	Constant
Tangier Med	Morocco	The Middle East and North Africa	0.542	0.628	0.863	Decreasing
Bejaia	Algeria	The Middle East and North Africa	0.122	0.130	0.940	Increasing
Cotonou	Benin	Sub-Saharan Africa	0.195	0.221	0.879	Increasing
Thilawa	Myanmar	South Asia	1.000	1.000	1.000	Constant
Sihanoukville	Cambodia	South Asia	0.322	0.349	0.925	Increasing
New Mangalore	India	South Asia	0.303	1.000	0.303	Increasing
Batangas	Philippines	South Asia	0.243	1.000	0.243	Increasing
CAI MEP	Vietnam	South Asia	0.744	0.789	0.943	Increasing
Danang	Vietnam	South Asia	0.166	0.168	0.985	Decreasing
Haiphong	Vietnam	South Asia	0.829	0.844	0.982	Decreasing
Ben Nghe	Vietnam	South Asia	0.287	0.292	0.982	Increasing
Saigon	Vietnam	South Asia	0.274	0.291	0.942	Increasing
Tan Cang	Vietnam	South Asia	1.000	1.000	1.000	Constant
Average efficiency score			0.450	0.532	0.877	

Empirical results and discussion

Performance of the lower-middle-income country's container ports

The performance model in this study is run under the assumption of output maximization (also known as output orientation). Table 2 shows the technical efficiency (CCR), pure technical efficiency (BCC), scale efficiency (SE), and the nature of a return to scale (RTS). The technical efficiency (TE/DEA-CCR mean = 0.450) is broken down into pure technical efficiency (PTE/DEA-BCC, mean = 0.532) and scale efficiency (SE, mean = 0.877), and the nature of a return to scale (RTS) is produced in Table 2.

The results reveal that DEA-BCC yields a higher average efficiency estimate (0.532) than the DEA-CCR Model (0.450) and where an index of 1.00 equates to perfect (Maximum) efficiency. 4 and 10 out of 51 container ports included in the analysis were identified as efficient when the DEA-CCR and DEA-BCC were applied. Furthermore, the results show that the DEA-BCC model yields more efficient ports than the DEA-CCR model. This is because a DEA Model with an assumption of constant return to scale provides information purely on technical and scale efficiency together (CCR), while a DEA model with the assumption of a variable return to scale identifies technical efficiency alone.

The efficiency rankings from DEA-CCR and DEA-BCC analysis had a 0.925 Spearman's rank-order correlation coefficient. The high and positive Spearman's rank-order correlation coefficient showed that the efficiency estimates yielded by the two approaches follow a similar pattern. The results reveal that the overall technical inefficiency of LMI container ports is primarily due to pure technical inefficiency rather than scale inefficiencies. This is evident in the low pure technical efficiency value compared to the scale efficiency value.

Furthermore, six ports considered inefficient under the DEA-CCR have become efficient under the DEA-BCC when the scale of operations is not considered (Banker et al. 1984). This is because smaller ports may have some issues that could bar them from performing as efficiently as the large ports. Therefore, assuming VRS suppresses this limitation and brings the smaller ports closer to the efficient frontier.

In terms of Individual container port performance, Dakar, Thilawa, Chittagong, and Tan Cang had achieved the best record in their productive efficiency with an efficiency score of 1.0 in DEA-CCR and DEA-BCC and hence considered the most efficient terminals.

Chittagong depicts a high-efficiency score. One possible explanation could be attributed to the strategic location of Chittagong as a significant transportation hub in Bangladesh. Chittagong is the largest port in Bangladesh, facilitating 90% of the country's international trade. The strategic location of Chittagong in the Bay of Bengal in the Indian Ocean along the major shipping lane and the surrounding advantageous hinterland paved the way for the port of Chittagong to be highly efficient (Munim et al. 2022). Bangladesh is directly connected to four major regional hubs: Singapore, Colombo, Port Klang, and Tanjung Pelapas. The port of Chittagong is considered the gateway port for Bangladesh.

Tan Cang recorded an efficiency score of 1. The high efficiency score could be attributed to the strategic location of Tan Cang container port. Tan Cang Container Port is located in southern Vietnam. Ports located in the Southern part of Vietnam serve as the gateway for importing and exporting Cargo in Vietnam, accounting for more than 74% of the total container volume in Vietnam and 55% of the total ships in Vietnam (Nguyen et al. 2021).

The ports of Tanjung Perak, Tanjung Priok, Puerto Cortes, and Damietta recorded efficiency scores between 0.7 and 0.92.

Jawaharlal Nehru Port recorded an average efficiency score of 0.83 for the sample period. This could be attributed to the fact that Jawaharlal Nehru container port is the largest container port in India, handling more than 40% of India's container traffic. JNP is equipped with one of India's most modern cargo-handling facilities and is ranked among the top 100 container ports in the world (Iyer and Nanyam 2021). In addition, JNP enjoyed better connectivity with the hinterland by being close to National Routes 4B and 17 and other state highways that immediately connect JNPT to Thane, Nasik, and Ahmedabad, allowing for faster cargo clearance from the port. In addition to having access to the Konkan, Central, and Western rail networks, the port also had road connections to 23 inland container depots (ICDs) (Raghuram et al. 2017).

Tanjung Perak recorded an efficiency score of 0.922. One possible explanation could be attributed to the strategic location of Tanjung Perak as a significant transportation hub in East Java. This is due to the strategic location of Tanjung Perak along the major shipping lane and the surrounding advantageous hinterland that paved the way for the port of Tanjung Perak to be highly efficient (Dewa et al. 2018).

Apart from Dakar, all the best-performing ports are in South Asia, East Asia, and the Pacific region, the most developed and Industrious region of LMI countries. This implies that the best performers are taking advantage of their location to improve and maintain their efficiency and the rise of South Asia in the manufacturing sector (Suárez-Alemán et al. 2016). This is consistent with the findings of Iyer and Nanyam (2021) and Sun et al. (2017), who asserted that geographical location positively impacts port efficiency.

Despite the relative trend of high operational efficiency, some ports depict extremely low efficiency scores. For example, Apapa port has the lowest total average efficiency score in the sample, with a value of 0.135 in DEA-CCR. In addition to the port of Apapa, 28 DMUs scored lower than 40% of the total average efficiency rating when DEA CCR was applied.

A degree of caution must be exercised to interpret or explain these results. For example, Apapa Port accounts for 80% of imports and exports in Nigeria. APM has invested heavily in Apapa Port, but its efficiency score is 0.153. Furthermore, Apapa Port was previously owned and operated by the Nigerian Port Authority. The operation was shifted to the private terminal operator in 2007, resulting in massive infrastructure investment, causing overcapacity and congestion. Therefore, the lower efficiency score does not indicate that the port was inefficient during the period. Instead, it may have resulted from a significant input increase after the expansion.

The nature of investment in port infrastructure impacts the efficiency score. These findings are in line with Figueiredo De Oliveira and Cariou (2015), who asserted that a port might record a lower efficiency score due to over-investment. This is worth noting because the time lag between the investment and the actual utilization of the facility could explain inefficiency.

Douala recorded an efficiency score of 0.246; the poor efficiency score could be attributed to the long waiting of ships and the long dwell time of cargo in the port of Douala. The dwell time for the port of Douala is estimated at 22 days, five times higher than Durban and twice higher than Mombasa (Raballand et al. 2018).

Onne Port recorded a poor efficiency score of 0.145; the low efficiency score could be attributed to bureaucratic bottlenecks, constant delays, and a high cost of clearing illegal charges due to the multiplicity of government agencies and duplication of roles by government officials. This situation has created an avenue for poor efficiency scores and imposes a high logistics cost on port users. In addition, reliance on the physical examination of cargo by customs due to the lack of scanners is a significant challenge for Onne Port. According to ease of trading across borders, an indicator for measuring ports' effectiveness ranked Nigeria at 182/183 out of 185 countries (Okazaki 2018).

The benchmarking results show how many efficient ports have been utilized as a reference. Benchmarking can be explained from two perspectives. First, from the perspective of port efficiency, it indicates how many inefficient ports have used them as a standard for efficiency. When considering inefficient ports, show which efficient ports they refer to or use as a scale to measure and evaluate their efficiency (Mustafa et al. 2020). From the results in Table 2, it is apparent that Tan Cang port has been used thirty-one times as a benchmark. Tan Cang Container Port, located in the Southern part of Vietnam, serves as the gateway for the import and export of Cargo in Vietnam, accounting for more than 74% of the total container volume in Vietnam and 55% of the total ships call in Vietnam (Nguyen et al. 2021).

Further analysis shows that the port of Thilawa has been used ten times as a benchmark. Interestingly, the port of Puerto Cortes is not a key hub port of South Asia, yet it is efficient. This is because Puerto Cortes is the biggest port in Myanmar (in terms of operational resources, production TEU, and the number of shipping lines). Its efficiency could be attributed to well-coordinated hinterland connection, highly effective resource management, and optimization of container terminals. These findings are similar to results from studies in other developing countries. For example, Mustafa et al. (2020), who examine the technical efficiency comparison of container ports in Asian and Middle Eastern regions using DEA, show that Ports that are not key hub ports are highly efficient due to well-organized and highly effective resource management.

The study investigates the status of return to scale for the container ports in LMI countries. Table 2 also reports the scale properties of the port production function yielded by DEA.

From Table 2, approximately 7.5% of container ports in LMI countries container ports achieved a constant return to scale. Nearly 41.5% of LMI countries' container ports operate at decreasing return to scale, which implies that the percentage for the increment in outputs falls behind that in inputs. Approximately 50.9% of LMI country container ports operate at an increasing return to scale (IRS), which indicates that these container ports should consider further expansion as they are operating at an Increase in return to scale that is greater than their constant return to scale (CRS).

Within the port literature, size has often been found to be an essential factor that drives variation in port efficiency. It is often suggested in port literature that the largest ports must have the highest efficiency level due to more expert management teams and a greater scale of operations, which offer a greater level of activity (González and Trujillo 2009).

As shown in Table 2, four out of fifty-three ports were found to be efficient using the DEA-CCR model; the most efficient ports have a combination of large and hub ports such as Tan Cang, Chittagong, and small and medium ports such as Dakar and Thilawa. These findings show that larger ports (as measured by throughput) are not necessarily more efficient than ports with a small production scale. These results conflict with the findings of Cullinane and Wang (2006a, b), Tongzon and Heng (2005), Martinez-Budria et al. (1999), Sohn and Jung (2009), who asserted that most container terminals that are large in production scale are more likely to be associated with higher efficiency scores.

To determine whether operating efficiency differences exist among regions (Sub-Saharan Africa, South Asia, Europe, Central Asia, Latin America, the Caribbean, the Middle East and North Africa, and East Asia and the Pacific). Table 3 shows South

Table 3 Average efficiency score by region. *Source*: Author

Region	DEA-CCR	DEA-BCC
Sub-Saharan Africa	0.401	0.420
South Asia	0.493	0.593
Europe and Central Asia	0.242	0.244
Latin America and the Caribbean	0.489	0.689
The Middle East and North Africa	0.366	0.431
East Asia and Pacific	0.536	0.680

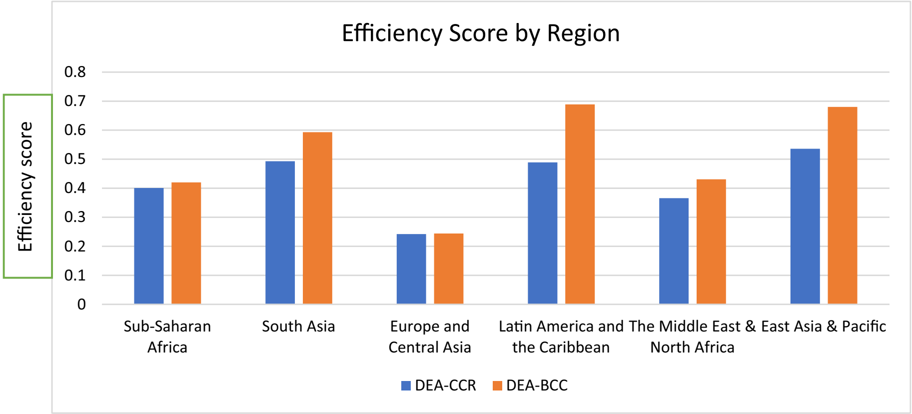

Fig. 2 Efficiency of container ports in different regions

Asia container ports are more efficient on average than container ports in other regions. This implies that South Asia container ports are more competitive than other regions. These findings can be explained by Fig. 2, showing the average efficiency scores in the different regions and reveals that the average efficiency of South Asian ports is higher than in other regions. At the same time, container terminals in Europe and Central Asia have the lowest average efficiency score. Therefore, the high efficiency score in South Asia could be attributed to the rise of South Asia in the manufacturing sector. Latin American and Caribbean container ports in the sample also exhibited a high efficiency score.

However, these results should be reviewed with caution, bearing in mind that some important regional ports are excluded from the sample due to data unavailability. These missing ports are likely to influence the efficiency score negatively or positively. Nevertheless, these findings are interesting because such differences might indicate that more complicated factors exerted the region's efficiency. For example, the management style, the extent of competition, globalization, technical progress, policy changes, and ease of access to the hinterland could have a significant regional impact.

Summary of findings

The study aimed to assess and benchmark the efficiency of container ports in lower-middle-income countries using a data envelopment analysis (DEA) approach.

The findings can briefly be concluded as follows: Firstly, the overall technical efficiency of LMI container ports is primarily due to pure technical inefficiency rather than to scale inefficiencies, emphasizing the need for improved management practices before addressing port scale economies. This finding is consistent with the results of Hung et al. (2010) who benchmark the operating efficiency of East Asian container ports. Secondly, significant variation in port efficiency levels across the sampled LMI countries was observed, influenced by factors like infrastructure investment, governance quality, and trade policies. Thirdly, approximately 50.9% of LMI country's container ports operate at an increasing return to scale (IRS), signaling the potential for further expansion due to recent business growth. Fourthly, six ports (Jawaharlal Nehru, Puerto Cortes, Dakar, Tanjung Priok, Kochin, and Dakar) achieved the best efficiency (1.0 in DEA-CCR and DEA-BCC), attributed to substantial infrastructure investment, modernization, and operational efficiency enhancements. This aligns with recent research by Cano-Leiva et al. (2023) emphasizing the critical role of infrastructure development in improving port efficiency. Fourthly, it's been found that the average efficiency of container ports in different regions differs. Regional variations indicate that South Asia container ports, on average, demonstrate higher efficiency, suggesting a better competitive landscape compared to other regions.

Policy implications and theoretical contributions

The above analysis suggests several essential policy lessons for LMI and other countries. First, this paper can provide practical insights into the operational efficiency of container ports in LMI countries. Port managers and terminal operators can use the benchmarking results to identify areas where performance is needed. This information is invaluable for deciding on resource allocation, infrastructure development, and optimization. Port managers can allocate resources more effectively by pinpointing inefficiencies and performance gaps, whether investing in infrastructure upgrades, enhancing workforce skills, or implementing technology solutions to boost efficiency.

In addition, this paper contributes to the theoretical understanding of performance comparisons across ports with diverse characteristics. It highlights the importance of considering factors beyond economic development when benchmarking ports and provides a framework for conducting comparative analyses in similar contexts.

In summary, this paper can offer practical managerial insights for port operators and policymakers and theoretical contributions to port economics, port management, and efficiency assessment methodologies. It bridges the gap between theory and practice, providing valuable knowledge for improving the performance and efficiency of container ports in LMI Countries.

Limitation and future research direction

The findings of this study have significant implications for further research in the field of port economics. The DEA modeling considered three input and one output variable due to data limitations. It is recommended future research includes more variables in the performance analysis. This research used a traditional DEA approach to measure port efficiency. Some other model forms, such as meta-frontier DEA, are also worthy. The study is based on a single period (cross-sectional data for the year 2012); Ports usually have multi-year investment plans for infrastructure and investment. It is recommended to use panel data for future analysis to capture the efficiency changes over the years, expansion as a result of investment, and possible innovation. Some external factors can affect port efficiency. Some factors could be explored, including unstable conditions, government reforms, Hinterland connectivity, and management expertise. Gathering pertinent information about these aspects may present challenges and require a significant investment of time, surpassing the boundaries of this paper. Nevertheless, it is imperative to explore this analysis in greater depth.

Researchers can further develop benchmarking models to include a broader range of performance indicators, including sustainability metrics, resilience measures, and digitalization progress. This would provide a more comprehensive view of port efficiency in the modern context. Lastly, given the increasing frequency of disruptions (e.g., pandemics and natural disasters), research should explore how ports in LMICs can enhance their resilience. Studies on business continuity planning, disaster preparedness, and supply chain resilience within the port context are critical.

Appendix 1: List of container ports in lower-middle-income countries

S/N	Port name	Country	Region
1	Luanda	Angola	Sub-Saharan Africa
2	Douala	Cameroon	Sub-Saharan Africa
3	Abidjan	Cote d'Ivoire	Sub-Saharan Africa
4	Djibouti	Djibouti	The Middle East and North Africa
5	Alexandria	Egypt	The Middle East and North Africa
6	Damietta	Egypt	The Middle East and North Africa
7	El Dekheila	Egypt	The Middle East and North Africa
8	Port Said	Egypt	The Middle East and North Africa
9	Tema	Ghana	Sub-Saharan Africa
10	Puerto Castilla	Honduras	Latin America and the Caribbean
11	Purto Cortes	Honduras	Latin America and the Caribbean
12	Chennai	India	South Asia
13	Jawaharlal Nehru	India	South Asia
14	Kandla	India	South Asia
15	Kochin	India	South Asia
16	Kolkata	India	South Asia
17	Mundra	India	South Asia
18	Tuticorin	India	South Asia
19	Visakhapatnam	India	South Asia
20	Tanjung Perak	Indonesia	East Asia and Pacific
21	Belawan	Indonesia	East Asia and Pacific
22	Makassar	Indonesia	East Asia and Pacific
23	Tanjung Priok	Indonesia	East Asia and Pacific
24	Casablanca	Morocco	The Middle East and North Africa
25	Corinto	Nicaragua	Latin America and the Caribbean
26	Apapa	Nigeria	Sub-Saharan Africa
27	Tin Can Island	Nigeria	Sub-Saharan Africa
28	Onne	Nigeria	Sub-Saharan Africa
29	Karachi	Pakistan	South Asia
30	Port Mohammed Bin Qassim	Pakistan	South Asia
31	Manilla	Philippines	East Asia and the Pacific
32	Iloilo	Philippines	East Asia and the Pacific
33	Port Sudan	Sudan	Sub-Saharan Africa
34	Colombo	Sri Lanka	South Asia
35	Illichivsk	Ukraine	Europe and Central Asia
36	Odessa	Ukraine	Europe and Central Asia
37	Mombasa	Kenya	Sub-Saharan Africa
38	Dakar	Senegal	Sub-Saharan Africa
39	Dar es Salaam	Tanzania	Sub-Saharan Africa
40	Chittagong	Bangladesh	South Asia
41	Tangier Med	Morocco	The Middle East and North Africa

S/N	Port name	Country	Region
42	Bejaia	Algeria	The Middle East and North Africa
43	Cotonou	Benin	Sub-Saharan Africa
44	Thilawa	Myanmar	South Asia
45	Sihanoukville	Cambodia	South Asia
46	New Mangalore	India	South Asia
47	Batangas	Philippines	South Asia
48	CAI MEP	Vietnam	South Asia
49	Danang	Vietnam	South Asia
50	Haiphong	Vietnam	South Asia
51	Ben Nghe	Vietnam	South Asia
52	Saigon	Vietnam	South Asia
53	Tan Cang	Vietnam	South Asia
Source	Authors		

Abbreviations

BCC	Banker, Charnes and Cooper
CCR	Charnes, Cooper and Rhodes
CRS	Constant return to scale
DEA	Data envelopment analysis
DRS	Decrease return to scale
DMU	Decision making units
IRS	Increase return to scale
LMI	Lower-middle-income
OECD	Organization for Economic Cooperation and Development
PCA	Principal component analysis
PTE	Pure technical efficiency
SE	Scale efficiency
TE	Technical efficiency
UK	United Kingdom
UNCTAD	United Nations Conference on Trade and Development

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s41072-024-00163-2.

Additional file 1. Cross-sectional data for the year 2012.

Acknowledgements

Authors would like to send special thanks to ports that all participate in this work. Special thanks go to all the reviewers that have contributed to advise this work. China Merchants Energy Shipping supports the article processing fee of this work.

Author contributions

CD was responsible for collection of data, analyzing data and prepared draft of manuscript. ST, LT, PT, and CO reviewed the manuscript. All Authors read and approved the final manuscript.

Funding

Open access funding provided by The Hong Kong Polytechnic University

Availability of data and materials

The data used in this manuscript were obtained from containerization international yearbook 2012 and from multiple port statistics (Individual port website). All data generated or analyzed during this study are included in this published article (Excel File name: Data for efficiency analysis). The data file is added as Additional file 1 with excel file name Data for efficiency analysis. The data that support the findings of the study is available from corresponding author upon request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no known competing financial interest or personal relationships that could influence the work reported in this paper.

Received: 23 June 2023 Revised: 6 February 2024 Accepted: 17 February 2024

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