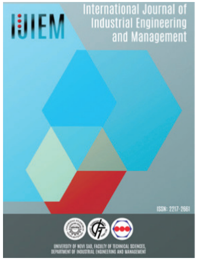
ISSN 2683-345X

journal homepage: http://ijiemjournal.uns.ac.rs/

International Journal of Industrial
Engineering and Management

2026 / ARTICLE-IN-PRESS / 410



Original research article

The Effect of Liner Shipping Connectivity on Container Ports' Efficiency in The Middle East: Data Envelopment Analysis Approach

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ABSTRACT

Existing efficiency models frequently rely on aggregated country-level data, obscuring the specific impact of individual port-level liner shipping connectivity on technical efficiency. This study addresses this limitation by investigating how granular connectivity metrics influence port productivity using Data Envelopment Analysis combined with the Malmquist Productivity Index. Analyzing a panel dataset of 24 Middle Eastern container ports from 2009 to 2016, the research uniquely incorporates the Port Liner Shipping Connectivity Index as a distinct input variable to model global network integration. This framework enables the decomposition of Total Factor Productivity into technological and efficiency changes, isolating the specific drivers of performance variations. The results reveal significant heterogeneity: median productivity gains reached 38.1% in Abu Dhabi and 19.3% in Jubail, driven primarily by efficiency improvements. Conversely, established hubs like Jebel Ali relied on technological change to achieve 3.7% growth, while other ports faced declines of up to 6.6%, indicating a critical need for targeted operational reforms. Consequently, this study provides a quantitative basis for strategic investments in maritime network integration and infrastructure to enhance long-term regional competitiveness.

ARTICLE INFO

Article history:

Received October 4, 2025
Revised December 18, 2025
Accepted February 11, 2026
Published online April 20, 2026

Keywords:
Container port efficiency;
Data Envelopment Analysis;
Liner shipping connectivity;
Malmquist Productivity Index;
Port Liner Shipping Connectivity Index

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1. Introduction

Global maritime shipping plays a critical role in the world economy, with over 80% of international trade volume and 70% of its value transported through the maritime transport network [1]. Ports, as crucial parts of this network, serve as vital gateways, facilitating the movement of goods between continents and supporting international supply chains. With the escalating demands of global supply chains and the technology advancement in the shipping industry, seaports are obliged to provide advanced performance to facilitate the cargo movement through the maritime transport network. Additionally, the emergence of container mega-ships calls for higher efficiency from all actors, especially container ports, which rely heavily on infrastructure support [2]. The consequent need for deeper berths and larger cranes has led progressive investments and development in port infrastructure worldwide. Port decision makers have increasingly been under pressure to improve efficiency by ensuring that services are provided on an internationally competitive basis [2]. To stimu-

Published by the University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia.

https://doi.org/10.24867/IJIEM-410

late competitiveness, container port efficiency is an important factor. To remain competitive, ports must demonstrate operational efficiency, which is influenced by numerous factors, including connectivity, infrastructure, and management practices [3]. The efficient handling of containers is essential for attracting liner shipping companies and gaining a broader market share. Conversely, port inefficiency can lead to congestion, delays, and a loss of business, ultimately impacting regional and global trade [4]. Therefore, container ports worldwide are planning long-term investments in infrastructure to adequately respond to liner shipping strategies. Improving operational efficiency has thus become increasingly critical, and this issue has become a focal point for port decision makers striving to attract more liner shipping companies [5]. Accordingly, this global trend has significantly impacted container ports in the Middle East, where ports hold strategic importance due to their geographic location, bridging East and West. The Suez Canal, a key element of the main East Asia-Europe routes, further underscores the importance of maritime shipping in the Middle East, intensifying the competition between ports in the region to attract liner strategies [6]. Because of the expected traffic increase in associated maritime routes, anticipating increased traffic and larger vessels, ports throughout the region have been under pressure to prepare for higher demand. This preparation involves substantial investments in infrastructure and operational enhancements to accommodate the expected growth in the container shipping sector.

As these ports undergo modernization to accommodate rising container traffic and shipping industry dynamics, they face challenges such as capacity constraints, regional competition, and the need for continuous infrastructure upgrades to attract and handle modern mega-ships [7]. These dynamics necessitate innovative management and development strategies to ensure that ports not only keep pace with global trends but also leverage their strategic advantages to enhance their operational efficiency and increase their regional competitiveness. The evolving dynamics of the global container shipping industry, coupled with the increase of regional port competition [4], have prompted extensive literature on measuring container port efficiency using frontier method [5]-[11]. In this vein, Data Envelopment Analysis (DEA) has emerged as a robust frontier method, often preferred over parametric approaches such as Stochastic Frontier Analysis (SFA) [12], [13] for performance evaluation. Previous applications of DEA have investigated various determinants of efficiency, including port competition [14], ownership structures [15], and logistics performance [16]. However, the majority of these studies focus predominantly on physical port capabilities—such as terminal area and equipment—with limited attention to the strategic influence of shipping connectivity. A major difficulty in previous assessments of shipping connectivity [17]-[19] is the primary reliance on the country-level Liner Shipping Connectivity Index (LSCI). This aggregate measure attributes the same connectivity value to all ports within a country, thereby obscuring port-specific competitive advantages. Although the Port Liner Shipping Connectivity Index (PLSCI) offers a granular alternative by evaluating integration into global networks at the individual port level, its application in efficiency analysis remains scarce, with research limited to specific contexts such as Spanish ports [20]. Furthermore, literature on port efficiency in the Middle East is relatively sparse [21]-[23] and no existing study in this region has quantitatively assessed the impact of port-level liner shipping connectivity on technical efficiency.

To address this critical research gap, this study assesses the effect of liner shipping connectivity on container port efficiency in the Middle East using a DEA-Malmquist Productivity Index (MPI) approach. The primary objective is to evaluate how effectively ports utilize their connectivity profiles—measured via PLSCI—to generate throughput. By integrating PLSCI as a distinct input variable, this work models the port's integration into the global liner network as a fundamental resource for productivity. This study distinguishes itself by overcoming these analytical limitations through three original achievements. First, it analyzes the impact of the port-specific PLSCI on container port efficiency within the Middle East, offering a novel perspective that transcends traditional physical input-output models. Second, by decomposing Total Factor Productivity (TFP) into technological and Efficiency Changes (EFFCH), the analysis isolates the specific drivers of performance, revealing whether gains are attributed to network integration or managerial optimization. Third, the findings provide actionable, empirical evidence for decision-makers in a strategic maritime region, offering a granular benchmark that links connectivity directly to operational success. These achievements offer a precise framework for formulating development strategies that leverage network position alongside infrastructure investments.

2. Literature Review

Efficiency involves using resources effectively to achieve intended outcomes while reducing resource waste. Technical efficiency is a key concept in the field of efficiency measurement, particularly in operations and economics, for identifying best practices, improving resource utilization, and setting operational benchmarks in industries such as manufacturing, maritime, healthcare, and education. The relative technical efficiency is the ratio of the weighted sum of outputs to a weighted sum of inputs [24]. It refers to the ability of a Decision-Making Unit (DMU), such as a firm, organization, or port to maximize its outputs from a given set of inputs or to minimize its inputs for a given level of output. There are two main technical methods used for measuring efficiency: SFA and DEA [25], [26]. SFA determines an efficient frontier production in large-scale benchmarks with time series data by estimating a parametric econometric frontier model [27], [28]. DEA was proposed by Charnes et al. [29], and developed by Banker et al. [30] six years later. It is a nonparametric method used to evaluate the performance of DMUs, as a decision support technique for organizations, by calculating DMUs' technical efficiency through linear programming to transform multiple related inputs into outputs.

DEA is widely regarded in the literature as a robust method better suited for performance evaluation compared to conventional econometric techniques such as regression analysis and simple ratio analysis [24]. DEA method allows for an unbiased performance evaluation of DMUs without the constraints imposed by parametric assumption about the production frontier. Unlike regression analysis that requires a pre-specified functional form (linear, quadratic, etc.), DEA is a non-parametric method. DEA doesn't impose any assumptions about the underlying production function or distribution, making it more flexible [24]. DEA can handle multiple inputs and outputs simultaneously. This contrasts with simple ratio analysis, which can only address one input-output relationship at a time. Additionally, Cook et al. [31] noted that while regression analysis estimates the average performance of a group of DMUs, DEA, is utilized as a benchmarking tool, emphasizes the performance of individual DMUs. Consequently, DEA establishes a clear benchmarking framework, offering valuable insights for performance improvement by assessing the relative efficiency of each DMU through comparison with the best-performing units (efficient frontier) in achieving a certain output level given the inputs it employs. This principle is vital in container port operations, where planning and managing logistics and infrastructure is key, to assess how effectively ports transform inputs (such as labor, capital, and assets) into outputs (services). A port is technically efficient when it maximizes its output in the utilization of given levels of resources. Studies on port efficiency have applied the various technical efficiency methods to assess the relative technical efficiency of an individual ports within a group to determine whether a port is technically efficient compared to the other ports. A port is considered technically efficient when it is on the efficiency frontier, meaning it has a relative efficiency score of one, indicating optimal performance given its inputs and outputs. This implies no other DMU in this case, port- observed has performed better with similar or fewer resources. Depending on the purpose of the analysis, previous studies on ports have implemented DEA models to investigate various aspects such as operational efficiency [5], [21], [32]-[37], resource allocation [38], and market concentration [39], [40]. In addition, others discussed port competition [14], [41], port privatization [40], [42], and environmental performance [41], [43], [44]. Depending on the analytical focus, previous DEA applications in the port sector can be categorized into three primary streams. The first stream examines operational efficiency and resource optimization; for instance, Bichou [32] utilized DEA to assess the impact of operating conditions on terminal performance, while Lozano et al. [38] adopted a centralized DEA approach to target resource allocation strategies in Spanish ports. The second stream investigates the effects of governance and policy, such as Cabral and Ramos [40], who analyzed whether privatization enhanced the technical efficiency of Brazilian ports, and Yuen et al. [41], who explored the influence of ownership structures and foreign participation. The third stream addresses market dynamics, illustrated by Nguyen et al. [39], who evaluated market concentration among Southeastern Asian ports using super-efficiency DEA. These studies collectively establish the utility of DEA for benchmarking, identifying potential developments for inefficient ports [5].

Researchers have applied DEA across different geographic contexts to assess port efficiency. For example, major container ports at global-level in the works of [42], [45]-[47]. Efficiency evaluations through DEA have not only been confined to ports at global level but also across different geographic contexts. Studies have compared port Efficiency at regional level such as, European ports [48], [49], Asian pacific ports [50]. Middle Eastern ports [22], [23], and Mediterranean ports [51]. Also, container ports were analyzed in at country-level, Mexican ports [52], Japanese ports [53], and Brazilian ports [40]. The insights derived from these studies have offered valuable information for policymakers and port managers to make well-informed decisions concerning port operations and investments.

2.1 DEA Model Selection

Depending on the objectives of port efficiency evaluation, DEA models can be differentiated based on their orientation towards either inputs or outputs. Both orientations hold significant utility within the framework of applying these models to the container port industry. Input-oriented model is related to operational and managerial perspective, while output-Suárez-Alemán model is related to planning and strategies perspective [42]. Before using DEA, researchers have to determine whether to reduce input or increase output. Charles & Kumar [54] addressed two questions explaining the two orientations. The input orientation handles the question, how much input can be decreased for a given output? The output orientation handles the question, how much output can be increased for a given input? Cook et al. [31] suggesting using DEA input-oriented model to monitor inputs if the goal is to recognize over-utilizing resources, and they suggest using output-oriented model if the goal is to enhance or increase output.

Lee and Chou [50] evaluated the efficiency of 16 container ports in Asia Pacific region for the year 1996. Gökçek and Şenol [51] also examined the efficiency of 28 Mediterranean container terminals for the year of 2016. On the other side, panel data known as longitudinal data or time-series cross-sectional data, combines features of both time-series data and cross-sectional data. It is the type of data obtained for multiple ports at multiple points in time. Panel data provide more reliable insights into firm performance by allowing to track each firm performance across sequential time periods [55]. Therefore, the use of panel data allows to tackle the issue of evolving port efficiency over time. Itoh [53] deployed panel data for the period from 1990 to 1999 to analyze changes in the efficiency of eight international container ports in Japan. Cullinane and Wang [33] analyzed the efficiency of the top 25 container ports globally by deploying Panel data. Wang and Cullinane [56] concluded that using panel data instead of cross-sectional data would significantly improve the validity of efficiency estimates. Cullinane and Wang [33] assess DEA panel data methods by applying them to 25 major container ports. Their empirical findings confirm the importance of using panel data, revealing significant inefficiencies in container port operations, with port efficiency varying over time, sometimes drastically. After determining the necessity and purpose of using DEA and specifying the goal of port efficiency, choosing suitable inputs and outputs is essential. In order to provide reliable efficiency evaluation, the total number of input and output has to be half the number of DMUs [31]. Container port inputs can be categorized into land, labor, and capital (equipment). Terminal area and quay length used as input variables that represent land category. The number of berths, quay cranes, and yard equipment are used to delegate capital category. Lastly, due to information unavailability, labor data is not included as an input variable in most studies. Previous literature shows that most inputs used to evaluate efficiency are physical variables, such as terminal area, berth length, number of berths, number of cranes in berth, and number of yard equipment [50].

Itoh [53] used number of container berths, number of cranes, and terminal area as input variables, and included labor in an additional efficiency application. Lee et al. [50] used terminal area, labor units, number of berth, number of cranes, and number of tugs as input variables to evaluate port efficiency. Bichou [32] used terminal area, draft, quay length, yard stacking index, and number of gates to study the impact of operating and market condition on container port efficiency and benchmarking. Hlali [45] used quay length, depth, terminal area, and storage capacity to evaluate the 26 global container ports. Cook et al. [31] indicated that a mixed use of ratio, percentage, and raw data can be utilized as inputs and outputs. In regard to output measures, it is widely common to use number of containers handled in ports to measure efficiency [34], [45], [48], [57], [58]. Other output measures have also been used. For instance, average terminal productivity [40], turnaround time per Twenty-Foot Equivalent Units (TEUs) [35], ship calls [59] and berth productivity [60], consignment rate [40], and ship-working rate [50]. While other variables like port handling capacity, number of ship calls, and average ship size are considered to impact port operational efficiency. Prior studies primarily relied on specific physical input variables. Additionally, most existing studies have narrowly focused on one side of the port operation without multi-dimensional assessment. The multi-dimensional approach towards port performance is essential to achieve a holistic assessment of port performance [60].

2.2 Impact of port connectivity on port efficiency

The connectivity of container ports within the network of container shipping plays a crucial role in port efficiency. Tovar & Wall [20] examined the relationship between port connectivity and efficiency, finding a significant positive correlation between them. Given the crucial impact of port connectivity on container port efficiency, identifying strategies to manage and leverage connectivity metrics becomes imperative. The PLSCI, published by the United Nations Conference on Trade and Development (UNCTAD) since 2019, is designed to assess how well ports are integrated into the global liner shipping network by evaluating their shipping connectivity. The indicator reflects the strategic decisions of shipping liners seeking to maximize profit through market coverage and cost reduction. The index is calculated based on six key components: number of ship calls and their deployed capacity, number of shipping companies and liner services, average ship size, and directly connected ports. Therefore, PLSCI can be used as a proxy for port accessibility to international trade via the shipping network. In related work, Sulaimani [61] demonstrated that port liner shipping connectivity significantly influences container trade flows in the Middle East. While that study focused on the impact of port accessibility on trade flow, the present work extends the discussion by examining how connectivity translates into port-level efficiency. Beside PLSCI, a range of port performance indicators have been developed by Talley et al. [62]. Nevertheless, these indicators often emphasize the capabilities of individual ports while largely overlooking the liner maritime network, which is important to the container shipping network [63]. Therefore, many researchers have started to use the PLSCI to investigate port efficiency.

Research utilizing DEA to assess the influence of maritime connectivity on port efficiency has emerged only recently, with only a limited number of papers published to date. Moreover, most of these studies have used country-level indices of connectivity, primarily the LSCI, which is the precursor to the PLSCI. The LSCI measures the extent to which countries are integrated into the global maritime shipping network. The LSCI was employed in the study of Suárez-Alemán et al. [64] to investigate the evolution and causes of productivity and EFFCH in over 200 ports from developing regions. By using DEA methods, the study found that improvement in liner connectivity enhances port efficiency. Pham et al. [60] employed LSCI as an output variable into two-stage uncertainty DEA model to capture the country's level of integration into the existing liner shipping network to investigate the efficiency of global top 40 container ports. Nadarajan et al. [65] used the LSCI as an output variable in analyzing seaport network efficiency with triangular and trapezoidal fuzzy DEA models. This study, covering data from 133 global seaports over three years (2018–2020), found that incorporating LSCI into DEA models provided new insights into efficiency scores, enhancing the understanding of seaport network efficiency amidst uncertain data.

An alternative measure of connectivity, the Logistic Performance Index (LPI), is developed by the World Bank Group and represents the outcomes of logistics service delivery at the country level. Schøyen and Odeck [48] deployed LPI into DEA to investigate the impact of logistics service delivery performance on container port efficiency of 26 European container ports located in six North European ports. While the LSCI and LPI have been valuable, they primarily reflect country-level connectivity, thus, attributing the same value to ports in the same country. The PLSCI, however, offers a more detailed assessment of port-level connectivity. Using PLSCI can provide a more accurate and granular understanding of port efficiency, capturing the specific connectivity characteristics of individual ports.

Notwithstanding the importance of capturing connectivity at the level of individual ports, the existing literature exhibits analytical gaps that this study addresses by synthesizing three conceptual strands: efficiency measurement, network connectivity, and regional competitiveness. Figure 1 presents the conceptual framework developed for this research. First, it grounds the analysis in Port Efficiency Measurement (Strand 1), utilizing DEA to benchmark input-output transformation beyond simple physical metrics. Second, it integrates Connectivity and Network Integration (Strand 2) by employing the port-specific PLSCI as a distinct input, positing that global network access is a production resource. Third, it contextualizes these dynamics within Regional Competitiveness (Strand 3), examining how Middle Eastern ports leverage their strategic location on the East-West trade route. By linking these strands, this work distinguishes itself from prior studies that rely on aggregate country-level data [64], [65] or physical inputs alone, offering a longitudinal DEA-Malmquist framework to quantitatively assess how shipping connectivity drives technical efficiency and productivity changes across the region.

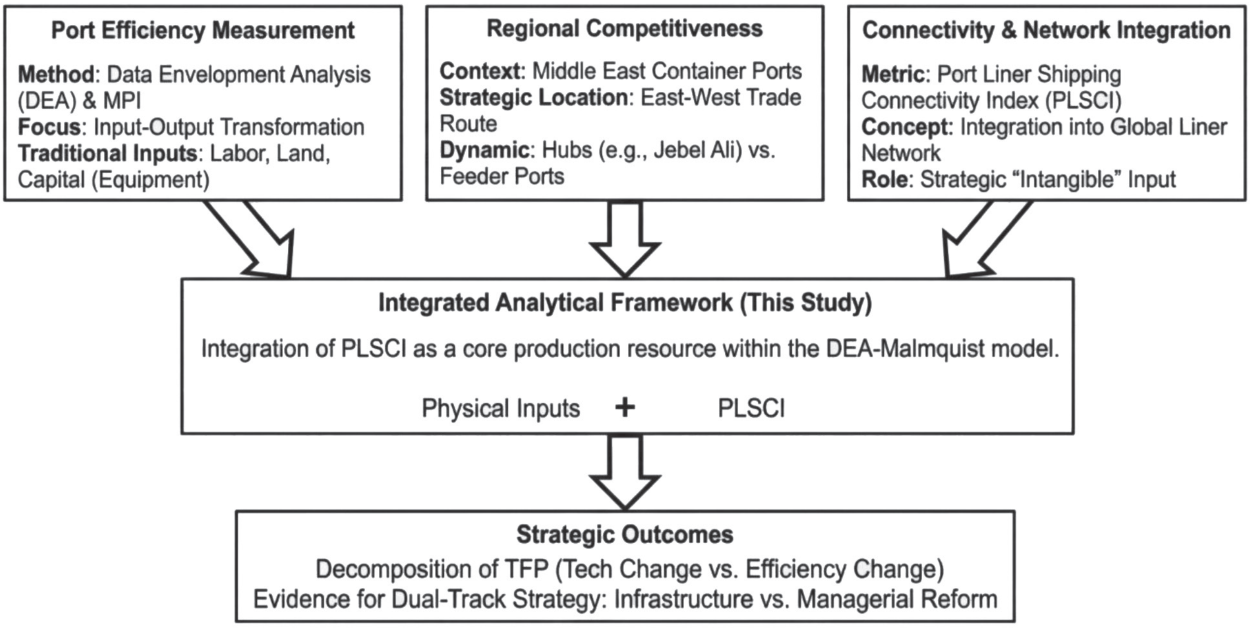

Figure 1. Conceptual framework integrating Port Efficiency (DEA), Connectivity (PLSCI), and Regional Competitiveness

3. Methodology

The methodology allows for an in-depth examination of port technical efficiency, productivity change, and the role of connectivity in influencing these metrics. DEA is a non-parametric linear programming method widely used for assessing the efficiency of decision-making units (DMUs) in scenarios involving multiple inputs and outputs [29], [30].

DEA models can be differentiated based on their orientation towards either inputs or outputs. Both orientations hold significant utility within the framework of applying these models to the container port industry. Input-oriented model is related to operational and managerial perspective, while output-oriented model is related to planning and strategies perspective [42]. The study employs an input-oriented DEA model, focusing on minimizing resource utilization while maintaining output levels. This approach aligns with the operational objectives of ports aiming to optimize resource use while maximizing throughput. Färe et al. [66] demonstrated all needed equations to calculate the MPI by defining x_{ij}^{t}, y_{rj}^{t} that points inputs and outputs for all DMU_i at any certain time t as shown in Equation (1). Cook & Seiford [67] provided an explanation of the equation used to compute the input-oriented MPI, which evaluates productivity changes over two consecutive years (t and t+1), as represented in Equation (2).

$$MPI = \left(\frac{\theta_o^t\,(x_o^t\,,\ y_o^t)}{\theta_o^t\,(x_o^{t+1}\,,\ y_o^{t+1})}\ \frac{\theta_o^{t+1}\,(x_o^t\,,\ y_o^t)}{\theta_o^{t+1}\,(x_o^{t+1}\,,\ y_o^{t+1})} \right)^{\frac{1}{2}} \tag{1}$$

$$MPI = \left(\frac{\theta_o^t\,(x_o^t\,,\ y_o^t)}{\theta_o^{t+1}\,(x_o^{t+1}\,,\ y_o^{t+1})} \right) \left(\frac{\theta_o^{t+1}\,(x_o^{t+1}\,,\ y_o^{t+1})}{\theta_o^t\,(x_o^{t+1}\,,\ y_o^{t+1})}\ \frac{\theta_o^{t+1}\,(x_o^t\,,\ y_o^t)}{\theta_o^t\,(x_o^t\,,\ y_o^t)} \right)^{\frac{1}{2}} \tag{2}$$

The initial component of Equation (2) corresponds to EFFCH, which captures variations in operational and managerial practices, while the second component represents Technological Change (*TECHCH*), reflecting advancements in technology or infrastructure. Accordingly, an MPI value below 1 indicates a decline in productivity, a value equal to 1 suggests no change in productivity, and a value exceeding 1 signifies an increase in productivity between periods t and t+1 [68].

$$TFPCH_{it} = EFFCH_{it} \cdot TECHCH_{it} \tag{3}$$

Further, the EFFCH is divided into Pure Efficiency Change (PECH) and Scale Efficiency Change (SECH), capturing improvements influenced by managerial practices and gains achieved from optimizing the scale of operations, respectively, as shown in Equation (4). To ensure precise model specification, this study calculates the baseline efficiency scores and the aggregate EFFCH assuming Constant Returns to Scale (CRS), while the PECH component is determined relative to a Variable Returns to Scale (VRS) frontier. Consequently, SECH is derived as the ratio of the CRS efficiency score to the VRS efficiency score, distinguishing scale-related productivity shifts from pure operational adjustments [31].

$$EFFCH_{it} = PECH_{it} \cdot SECH_{it} \tag{4}$$

The study adopts DEA combined with the MPI to evaluate the performance of 24 container ports over the period 2009–2016. The DMUs are container ports, and their efficiency is evaluated relative to the best-performing port, which forms the "efficiency frontier". A port is considered technically efficient when it is on the efficiency frontier, meaning it achieves a relative efficiency score of one. This score indicates optimal performance, where no other DMU (port) has been observed to perform better with similar or fewer resources. Ports with a score below one are considered inefficient, indicating that they have not fully optimized their inputs and outputs relative to the best-performing ports on the efficiency frontier.

3.1 Data Description and Variables

This study selects 24 container ports in 15 countries in the Middle East, namely: UAE, Saudi Arabia; Egypt, etc. (see Table 3). Terminals with multipurpose facilities, those handling non-container cargo, and those lacking complete or reliable data were excluded from the sample. The dataset consists of annual observations of the sampled container terminals and spans the period from 2009 to 2016, resulting in a panel dataset of 192 terminal-years or DMUs. Data was primarily sourced from container terminals' websites and annual reports, as well as from secondary sources such as the Containerization International Yearbooks. The LSCI, published annually by UNCTAD since 2004, evaluates the degree of integration for countries connected to the global liner shipping network. It has been further refined by the Port-LSCI (PLSCI), which covers more than 900 container ports around the world and is updated quarterly.

Based on Table 3, we can compare container throughput and PLSCI growth by port in the Middle East from 2009 to 2016. The analysis is conducted in terms of TEUs and growth rates to understand the performance and development of individual ports. The heterogeneity is evident in ports such as Jubail (Saudi Arabia), where the TEU Compound Annual Growth Rate (CAGR) is substantially higher than the average, while other ports like Latakia (Syria) show significant declines in both throughput and connectivity. Analyzing these differences can provide insights into the regional dynamics of port performance.

When considering total container traffic by port, Jebel Ali (UAE) clearly dominates in terms of volume, handling 14.8 million TEUs in 2016 (Table 3), representing the highest volume among the ports listed. Khore Fakkan (UAE) follows with 4.3 million TEUs. However, some smaller ports like Jubail (Saudi Arabia) show remarkable growth in TEU, with a CAGR of 24%, despite handling only 674,000 TEUs in 2016. This is one of the highest growth rates among the listed ports.

In terms of container traffic growth over 2009–2016, Abu Dhabi (UAE) stands out with a TEU CAGR of 15%. Despite a smaller TEU volume of 1.55 million in 2016, Abu Dhabi shows strong growth. However, it faces challenges with its PLSCI, which has decreased by -16% over the same period, reflecting difficulties in maintaining or enhancing connectivity.

Comparing ports by their PLSCI growth rates, Jubail (Saudi Arabia) also shows a strong improvement in connectivity, with a 19% CAGR, which is the highest among the ports listed. This suggests that Jubail's rapid increase in both TEU and connectivity is a result of strategic improvements in its port operations and integration within global shipping networks. On the other hand, some ports, such as Port Said (Egypt) and Damietta (Egypt), have experienced negative growth in TEU, with CAGRs of -2% and -5%, respectively. However, both ports maintain positive PLSCI growth rates, suggesting that, while their container traffic has declined, efforts to improve connectivity are ongoing. Conversely, ports like Latakia (Syria) and Aden (Yemen) show significant declines in both TEU throughput (-11% and -2%, respectively) and minimal or no growth in PLSCI (0% and 1%, respectively), reflecting challenging operating environments and possible geopolitical or economic instability affecting these ports.

Taking into consideration the overall performance, there is substantial variation between ports in terms of growth rates. We go from cases with remarkable growth, such as Jubail (24% TEU CAGR, 19% PLSCI CAGR), Elsokhna (21% TEU CAGR, 7% PLSCI CAGR), and Sohar (20% TEU CAGR, 11% PLSCI CAGR), to ports with declining growth in both throughput and connectivity, such as Latakia and Aden. The results for some of these ports improve significantly when considering the mean growth rate (e.g., average TEU CAGR of 3% and average PLSCI CAGR of 4%), indicating a high level of heterogeneity among the ports, with some advancing significantly more than others.

With respect to the ports where TEU throughput growth is driven mainly by technical improvements (e.g., connectivity enhancement), Khore Fakkan (UAE), Alexandria (Egypt), and Ashdod (Israel) show moderate to high PLSCI growth rates (5%, 5%, and 4%, respectively), indicating efforts to integrate more deeply into the global shipping network. Other ports demonstrate that efficiency improvements are the key driver of productivity gains; for example, Jubail and Elsokhna, where both TEU and PLSCI growth rates are strong, suggest that investments in port infrastructure and operational efficiency have been effective. These variations highlight the different factors driving growth, including regional stability, strategic location, investment in port infrastructure, and connectivity improvements. To synthesize these elements, Figure 2 illustrates the methodological framework, depicting how physical inputs and the strategic PLSCI metric feed into the DEA-MPI model to determine efficiency outcomes.

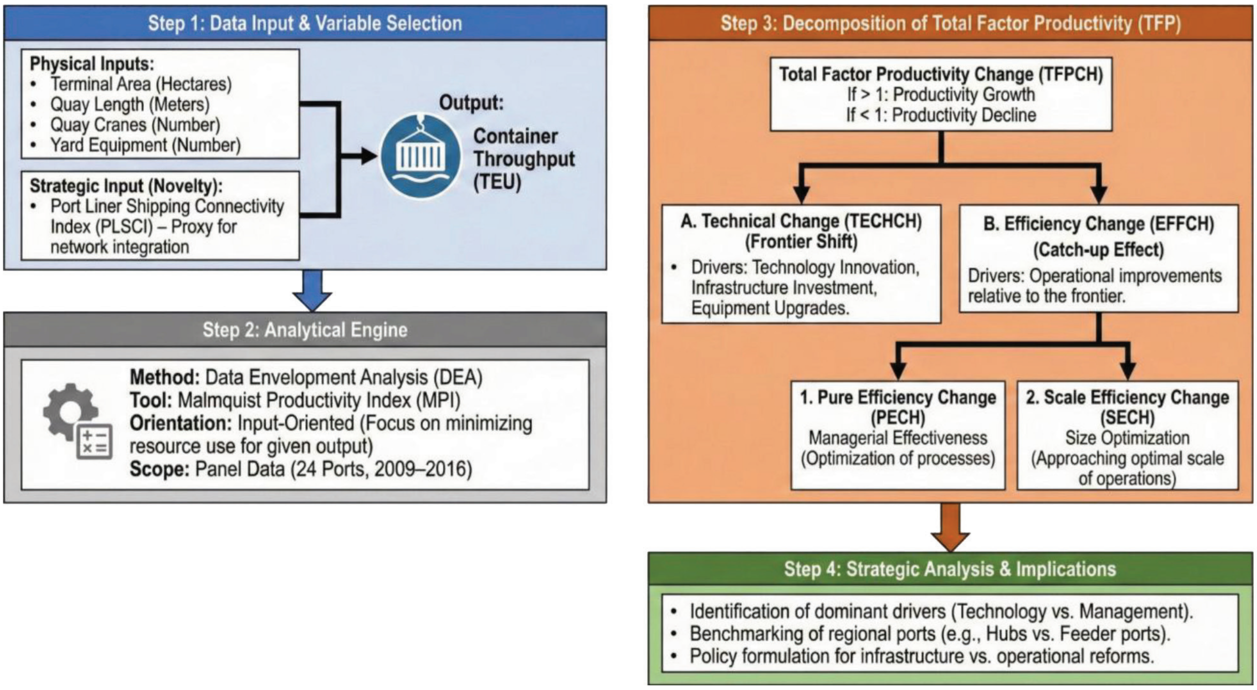

Figure 2. Methodological framework illustrating the integration of PLSCI with physical inputs in the DEA-Malmquist model

Table 1. List of Input/output datasets

Variables	Description	Measurement unit	Source
Inputs			
Terminal area	Total container terminals area	Hectare	Containerization Yearbook, IAPH, Port's website
Quay length	Total length of quays	Meter	Containerization Yearbook, IAPH, Port's website
Quay Cranes	Total quay cranes	number	Containerization Yearbook, IAPH, Port's website
Equipment Yard	Total equipment years	number	Containerization Yearbook, IAPH, Port's website
Draft m	Draft of port	meter	Containerization Yearbook, IAPH, Port's website
PLSCI	Annual PLSCI	index (100)	UNCTAD
Output			
Container	Annual container throughput of port	TEU	Lloyd's list

Table 2. Port descriptive statistics. Source: Prepared by the authors

Variable	Observations	Mean	Minimum	Maximum	Std. Dev.
Inputs					
Terminal area (ha)	192	92	20	579	113
Quay length (m)	192	1997	400	12112	2297
Quay Cranes	192	17	3	117	23
Yard equipment	192	85	8	314	75
Draft (m)	192	16	12	18	2
PLSCI	192	100	12	276	56
Output					
Throughput (TEU)	192	1862	121	15592	2724

Table 3. Container throughput and PLSCI growth by port. Source: Prepared by the authors

no.	port	country	TEU in 2016 ('000)	TEU CAGR 2009-2016 (percent)	PLSCI in 2016	PLSCI CAGR 2009-2016 (percent)
1	Jebel Ali	UAE	14,772	4%	276.0	1%
2	Khore Fakkan	UAE	4,330	6%	177.0	5%
3	Abu Dhabi	UAE	1,550	15%	11.8	-16%
4	Jeddah	Saudi Arabia	3,957	3%	188.2	2%
5	Dammam	Saudi Arabia	1,780	1%	120.7	1%
6	Jubail	Saudi Arabia	674	24%	108.4	19%
7	Port Said	Egypt	3,036	-2%	193.4	4%
8	Alexandria	Egypt	1,634	1%	129.9	5%
9	Damietta	Egypt	810	-5%	131.1	2%
10	Elsokhna	Egypt	1,900	21%	96.6	7%
11	Shahid Rajaei	Iran	2,130	0%	134.7	2%
12	Salalah	Oman	3,325	0%	167.2	3%
13	Sohar	Oman	619	20%	97.6	11%
14	Ashdod	Israel	1,443	6%	121.0	4%
15	Haifa	Israel	1,265	-1%	135.5	7%
16	Beirut	Lebanon	1,147	2%	150.5	4%
17	Aqaba	Jordan	552	-2%	108.0	3%
18	Khalif Bin Salman	Bahrain	380	4%	71.1	10%
19	Latikia	Syria	252	-11%	51.8	0%
20	Aden	Yemen	268	-2%	58.0	1%
21	Shuwaikh & Shuaiba	Kuwait	1,262	5%	34.2	0%
22	Port Sudan	Sudan	616	5%	71.2	7%
23	Doraleh	Djibouti	908	7%	129.2	6%
24	Qatar Ports	Qatar	496	2%	32.2	1%
	Mean		49,106	3%	116.5	4%

4. Results

4.1 Productivity analysis of container terminals

Table 4 presents the DEA-MPI decomposition of TFP changes from 2009 to 2016 at the port level across several Middle Eastern countries. The analysis is conducted in terms of means and medians to account for possible heterogeneity within the TFP changes of different ports. This heterogeneity is apparent in several ports where the mean and median values differ significantly. For instance, in Abu Dhabi, the mean TFPCH is 1.264, while the median is 1.381, indicating a notable difference between average and typical performance.

Table 4. DEA-MPI decomposition of TFP changes from 2009 to 2016. Port level. Source: Prepared by authors

Country	Port	Descriptive	TFPCH	EFFECH	TECHCH	PECH	SECH
UAE	Jebel Ali	Mean	1.036	1	1.036	1	1
		Median	1.037	1	1.037	1	1
	Khor Fakkan	Mean	1.049	1	1.049	1	1
		Median	1.066	1	1.066	1	1
	Abu Dhabi	Mean	1.264	1.151	1.098	1.005	1.146
		Median	1.381	1.108	1.038	1	1.054
Saudi Arabia	Jeddah	Mean	1.026	0.995	1.031	1.002	0.993
		Median	0.988	0.949	1.037	0.984	0.975
	Dammam	Mean	1.004	0.956	1.05	1.002	0.955
		Median	0.934	0.946	1.039	0.999	0.947
	Jubail	Mean	1.265	1.196	1.057	0.98	1.22
		Median	1.193	1.103	1.077	0.993	1.225
Egypt	Port Said	Mean	0.972	0.948	1.025	0.987	0.96
		Median	0.966	0.977	1.02	1	0.977
	Alexandria	Mean	0.985	0.954	1.033	0.99	0.964
		Median	0.988	0.928	1.038	1.001	0.975
	Damietta	Mean	0.941	0.889	1.059	0.99	0.898
		Median	0.904	0.876	1.055	0.979	0.92
	El Sokhna	Mean	1.235	1.121	1.102	1.026	1.093
		Median	1.096	1.082	1.089	1	1.103
Iran	Bandar Abbas	Mean	0.996	0.951	1.047	0.983	0.968
		Median	1.001	0.997	1.048	0.997	0.945
Oman	Salalah	Mean	0.986	0.961	1.026	0.977	0.984
		Median	0.924	0.977	1.046	0.993	0.995
	Sohar	Mean	1.23	1.153	1.067	1	1.153
		Median	1.091	1.091	1.068	1	1.091
Israel	Ashdod	Mean	1.064	1.009	1.055	0.999	1.01
		Median	1.078	1.03	1.062	1	0.995
	Haifa	Mean	0.956	0.926	1.032	0.986	0.94
		Median	0.98	0.929	1.046	0.989	0.92
Lebanon	Beirut	Mean	1.018	0.989	1.029	1	0.989
		Median	1.015	1	1.045	1	1
Djibouti	Djibouti	Mean	0.971	0.915	1.061	1.001	0.914
		Median	0.973	0.923	1.055	1.005	0.916
Sudan	Port Sudan	Mean	1.045	0.945	1.105	1	0.945
		Median	0.981	0.859	1.122	1	0.86
Jordan	Aqaba	Mean	0.88	0.81	1.087	1	0.81
		Median	0.929	0.76	1.097	1	0.784

Country	Port	Descriptive	TFPCH	EFFECH	TECHCH	PECH	SECH
Bahrain	Bahrain	Mean	0.979	0.917	1.068	1	0.917
		Median	1.031	0.981	1.086	1	0.981
Syria	Latakia	Mean	1.057	1.015	1.042	1	1.015
		Median	1.007	0.959	1.048	1	0.959
Yemen	Aden	Mean	1.018	0.981	1.037	1	0.981
		Median	1.023	0.985	1.05	1	0.985
Kuwait	Shuaiba & Shuwaikh	Mean	1.081	1.018	1.063	1	1.018
		Median	1.063	1	1.063	1	1
Qatar	Doha	Mean	1.027	0.95	1.08	0.999	0.951
		Median	1.029	0.915	1.062	1	0.915

Note: Technical Change (TECHCH)

Considering the median container terminal, there is substantial variation among ports. It is evident that ports in the Middle East did not behave uniformly over the observed period. Some ports exhibited remarkable productivity gains—such as Abu Dhabi 38.1%, Jubail 19.3%, and El Sokhna 9.6%—while others showed practically zero growth (Jebel Ali, 3.7%; Khor Fakkan, 6.6%) or even declining growth (Dammam, -6.6%; Port Said, -3.4%). The results for some ports improve significantly when considering the mean instead of the median, pointing again to the high level of heterogeneity among these ports, with some ports advancing far more than others.

Regarding the TFP decomposition of the median terminal, we can distinguish between different patterns in productivity drivers among the ports:

1. Ports with Productivity Driven by Technical Change: Ports like Jebel Ali (TFPCH = 1.037, TECHCH = 1.037) and Khor Fakkan (TFPCH = 1.066, TECHCH = 1.066) in the UAE experienced productivity growth primarily due to technological advancements, with efficiency remaining constant (EFFCH = 1). These ports have optimized their technological aspects without significant changes in management or operational efficiency.
2. Ports with Productivity Driven by EFFCH: Ports such as Abu Dhabi (TFPCH = 1.381, EFFCH = 1.108, PECH = 1.000, SECH = 1.054) and Jubail (TFPCH = 1.193, EFFCH = 1.103, PECH = 0.993, SECH = 1.225) achieved their productivity growth mainly due to improvements in efficiency, particularly scale efficiency. This suggests these ports have optimized their size of operations to enhance overall productivity.
3. Ports with Declining Productivity: Several ports, including Dammam (TFPCH = 0.934) and Port Said (TFPCH = 0.966), show declining productivity levels driven by decreases in efficiency (EFFCH < 1). For instance, Dammam's decline is due to both pure efficiency and SECH reductions (PECH = 0.999, SECH = 0.947), indicating challenges in both management practices and the optimal scale of operations.
4. Mixed Drivers of Productivity Change: Some ports exhibit mixed results. For example, Jeddah (TFPCH = 0.988, EFFCH = 0.949, TECHCH = 1.037) shows a decline in efficiency but some gains from technical change, reflecting a complex environment where technological improvements are not fully translated into overall productivity gains due to inefficiencies.

4.2 The source of differences in productivity

According to the results above, it is evident that the Middle Eastern ports display a significant variation in terms of TFP changes from 2009 to 2016. To better understand the factors driving these changes, it is crucial to analyze the evolution of TFP across various sub-periods. In this subsection, we carry out a disaggregated analysis of the productivity changes. In order to account for timeframes that allows for productivity changes in terms of efficiency or technical changes, we have accounted for four subperiods over the decade. The evolution of TFP for the median terminal by port, as illustrated in the DEA figures, reveals distinct trends over the four sub-periods from 2009 to 2016. In Figure 3, the overall TFP change (TFPCH) demonstrates a varied performance among ports such as Jebel Ali, Abu Dhabi, and Jeddah. While some ports exhibited notable gains, others showed minimal growth or even declines in productivity. This heterogeneity underlines the necessity of decomposing TFP changes into their components to understand the underlying causes of productivity differences.

In Figures 4 and 5, the TFP decomposition into Technical Change (TECHCH) and EFFCH highlights two main trends. Ports like Jebel Ali and Khor Fakkan exhibit productivity growth driven primarily by technological advancements, as indicated by their TECHCH values remaining consistently above 1 throughout the period. This study suggests these ports have optimized their technological infrastructure, achieving efficiency without significant managerial or operational changes. In contrast, Abu Dhabi and Jeddah show substantial improvements in efficiency (EFFCH > 1), suggesting that their productivity growth is driven by improvements in management practices and operational efficiencies.

The evolution of efficiency, as broken down into SECH and PECH, provides further insights (Figures 6 and 7). For ports such as Abu Dhabi and Jubail, productivity improvements are primarily attributed to SECH, reflecting an optimization of port operations' scale. In contrast, for other ports like Jeddah, mixed results are observed, with efficiency improvements

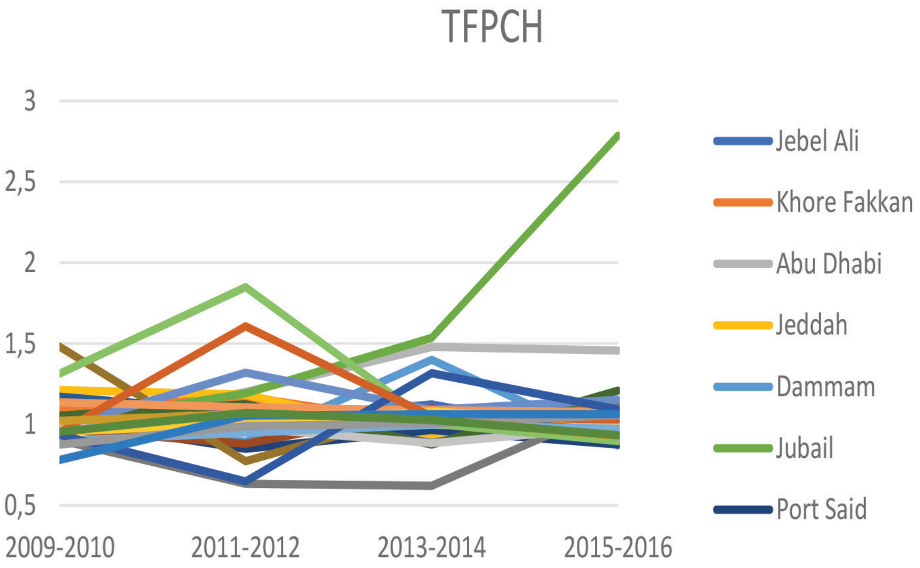

Figure 3. Evolution of TFPCH by port (2009–2016). The trend lines highlight the heterogeneity in productivity performance across the region

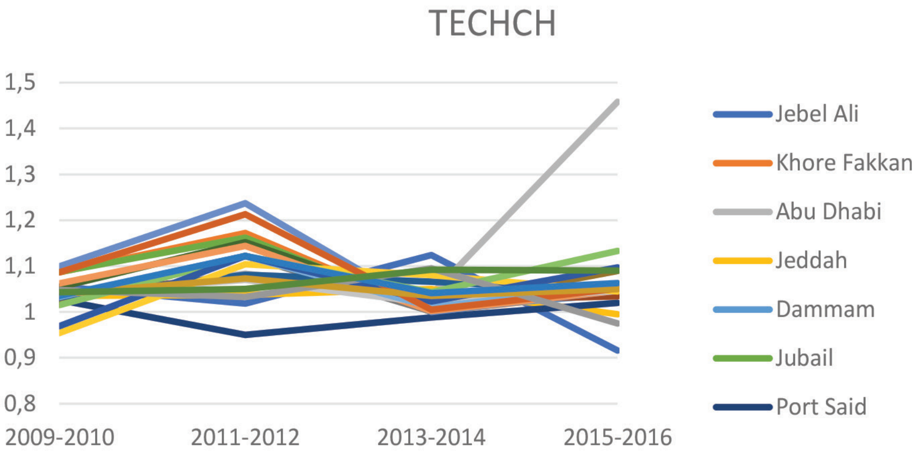

Figure 4. Evolution of TECHCH by port. This component reflects the influence of technological advancements and infrastructure upgrades on port performance

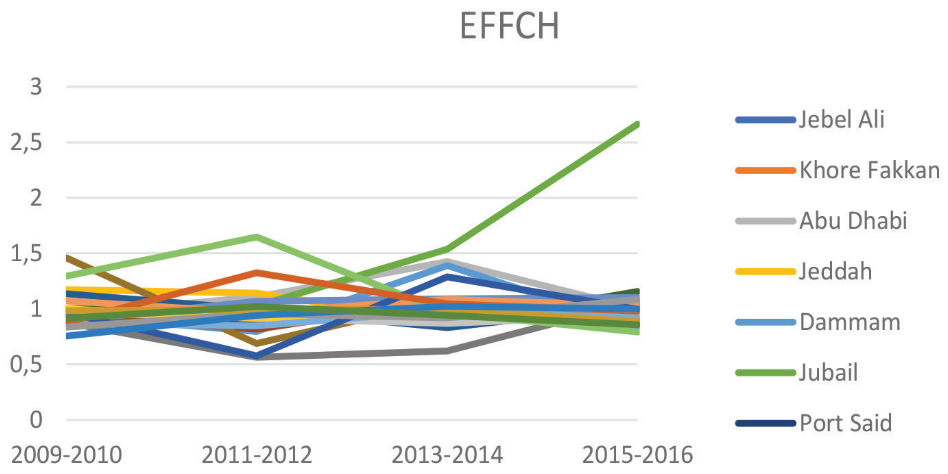

Figure 5. Evolution of EFFCH by port. This index captures improvements attributed to managerial practices and operational optimization

not consistently translating into overall productivity gains, indicating a complex environment where both scale and technical factors play roles.

Lastly, the figures show significant variance in PECH across different ports and timeframes, revealing the critical role of pure managerial practices and port-specific factors, such as port governance, infrastructure utilization, and logistics coordination in driving productivity differences. Ports like Abu Dhabi and Sohar demonstrate substantial gains in pure efficiency over the period, suggesting that these ports have optimized their internal processes, reduced waste, and enhanced operational coordination. These improvements may be attributed to factors such as effective port governance, streamlined customs procedures, better workforce training, and enhanced logistics coordination. Conversely, some ports such as Dammam and Damietta experienced declines or inconsistent gains in pure efficiency, highlighting underlying challenges in management or operational practices. For instance, these ports may have faced issues related to bureaucratic inefficiencies (source), labor disputes (source), or suboptimal resource allocation, which could have impeded their ability to achieve productivity gains. The fluctuating patterns in PECH indicate that while some ports are successfully implementing practices that move them closer to the production frontier, others are lagging due to persistent inefficiencies.

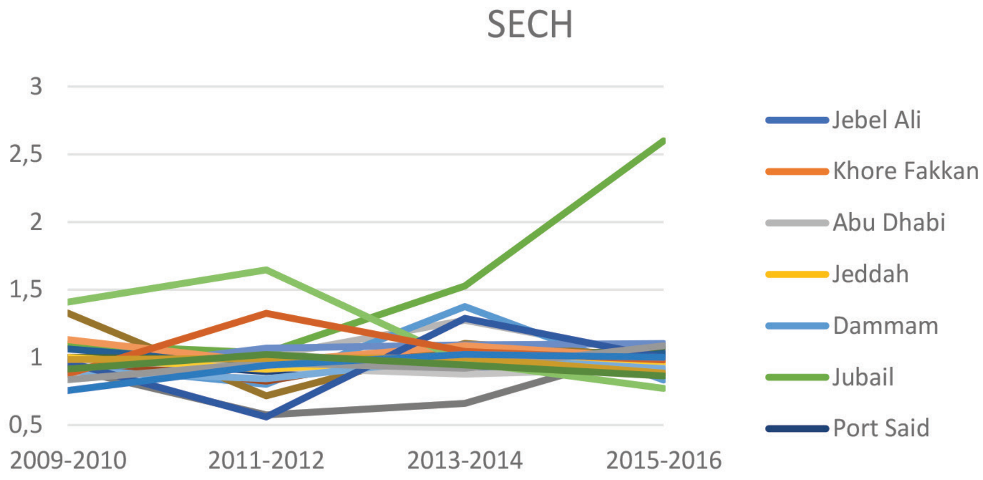

Figure 6. Evolution of SECH by port. The chart illustrates how optimizing the scale of operations contributed to productivity gains in specific terminals

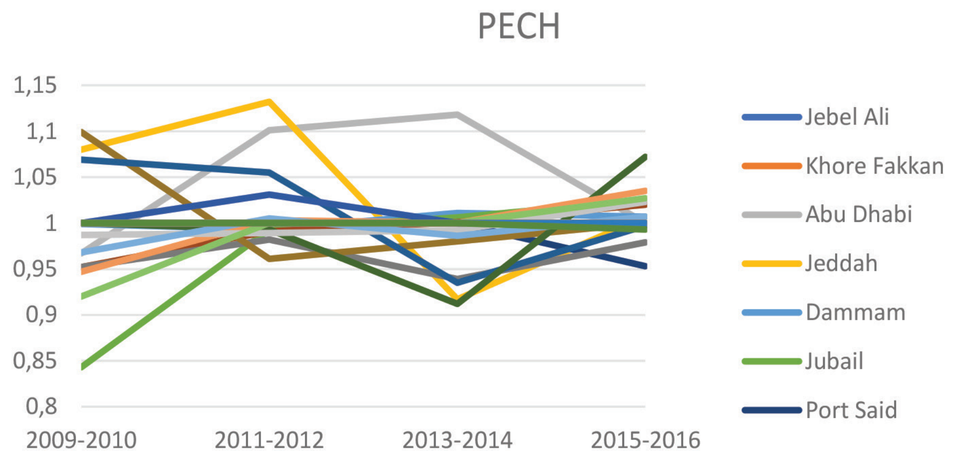

Figure 7. Evolution of PECH by port, isolating the impact of managerial effectiveness from scale effects

5. Discussion

The findings from this study highlight the significant heterogeneity in productivity performance and efficiency levels across Middle Eastern container ports. The results of the DEA-MPI decomposition reveal distinct drivers of productivity changes, including technological advancements, operational efficiency improvements, and SECH optimization.

The results underscore the critical role of port connectivity, as measured by the PLSCI, in influencing port productivity. Ports with higher PLSCI values, such as Jebel Ali and Khor Fakkan, exhibit sustained productivity growth primarily driven by technological change. This aligns with findings from Tovar & Wall [20] who demonstrated that improved maritime connectivity directly enhances port efficiency. Conversely, ports with lower connectivity indices, like Latakia and Aden, experienced stagnation or decline in productivity, highlighting the need for strategic investments in global shipping network integration.

The decomposition of TFP growth into TECHCH and EFFCH illustrates varying patterns rooted in specific strategic choices. Ports such as Jebel Ali and Khor Fakkan achieved productivity gains through technological advancements (TECHCH > 1), reflecting substantial capital investments to accommodate mega-ships. For instance, Jebel Ali's implementation of automated terminal operations and Khor Fakkan's deployment of Super-Post-Panamax cranes enabled these hubs to handle higher volumes efficiently, decoupling throughput growth from labor expansion. This mirrors previous studies, such as Bichou [6] and Cullinane et al. [42], which emphasized the importance of advanced infrastructure in achieving efficiency.

In contrast, ports like Abu Dhabi and Jubail experienced productivity gains primarily due to improvements in scale SECH and PECH. This trajectory corresponds to major operational reforms, most notably Abu Dhabi's strategic transition of container traffic from Mina Zayed to the state-of-the-art, semi-automated Khalifa Port in 2012, and Jubail's deeper integration with the Royal Commission's industrial city logistics. These initiatives optimized the scale of operations and resource utilization. Similar trends were observed in the studies of Cabral and Ramos [40] and Iyer & Nanyam [35] where managerial practices and operational efficiency improvements drove performance in Brazilian and Indian ports, respectively.

The heterogeneity observed across ports reflects the complex dynamics of the Middle Eastern port sector, where performance is heavily contingent on local stability and investment cycles. High-growth ports such as Jubail and El Sokhna demonstrate that strategic investments in both infrastructure and connectivity can yield substantial improvements. However, ports like Dammam and Damietta highlight challenges of inefficient management and suboptimal scale. Furthermore, the stagnation in Latakia and Aden correlates directly with the onset of severe geopolitical conflicts in Syria and Yemen during the study period, which severed hinterland connectivity and halted development. These findings align with Nguyen et al. [39], who identified similar performance disparities among Southeast Asian ports driven by divergent local operating environments.

This study demonstrates that enhancing port connectivity through integration into global liner networks is vital for improving productivity. However, the divergence in productivity drivers—TECHCH versus EFFCH—implies that a "one-size-fits-all" policy is ineffective. Consequently, port authorities should adopt a dual-track strategic framework tailored to their specific operational maturity and network position. First, for established transshipment hubs such as Jebel Ali and Khor Fakkan, where productivity is driven by technological change, policy must prioritize capital-intensive infrastructure resilience. This involves continuous investment in automated terminal operations and deep-water berth maintenance to accommodate the cascading deployment of ultra-large container vessels. For these ports, maintaining a high PLSCI score requires proactive engagement with global shipping alliances to ensure they remain preferred nodes in East-West liner services [2]. Second, for emerging or gateway ports like Jubail and Abu Dhabi, where gains stem from EFFCH, the strategic focus should shift towards "soft infrastructure" and managerial optimization. Rather than solely expanding physical capacity, authorities in these ports should implement digital port community systems, streamline customs procedures, and enhance workforce training to maximize the utilization of existing assets. This approach aligns with the findings that managerial effectiveness (PECH) and scale optimization (SECH) are immediate drivers of growth for non-hub ports [64]. Finally, the strong correlation between PLSCI and efficiency underscores that connectivity functions as a critical production resource. Policymakers must treat liner network integration not merely as a commercial outcome but as a strategic input. This requires targeted incentive programs to attract diverse liner services and regional cooperation mechanisms to mitigate destructive competition. By coordinating hinterland logistics and specializing in complementary roles—hub-and-spoke versus direct gateway access—regional ports can collectively address capacity constraints and navigate the geopolitical challenges that have historically impacted ports like Latakia and Aden.

6. Conclusion

This study assessed the technical efficiency and productivity evolution of 24 container ports in the Middle East from 2009 to 2016. By integrating the PLSCI as a primary input within the DEA-Malmquist framework, this work provides a quantitative link between a port's position in the global liner network and its operational performance. The importance of these outcomes lies in the demonstration that shipping connectivity functions as a critical resource that drives throughput, rather than merely reflecting it. This distinction is vital for understanding regional port dynamics, where strategic geographic advantage alone is insufficient to guarantee efficiency. The empirical results reveal a clear divergence in productivity drivers across the region. High-connectivity ports such as Jebel Ali and Khor Fakkan sustained productivity growth primarily through technological change, leveraging infrastructure investments to handle mega-ships. Conversely, ports such as Abu Dhabi and Jubail achieved substantial gains through EFFCH, indicating successful optimization of managerial practices and scale operations. This synthesis suggests that productivity is multidimensional; ports can compete effectively through operational excellence even if they lack the massive scale of regional leaders. Consequently, the findings advocate for a dual-track development strategy: infrastructure-heavy investments for established hubs aiming to maintain network centrality, and process-optimization reforms for emerging ports to maximize resource utilization.

Several limitations of this study must be acknowledged to contextualize these findings. First, the reliance on physical proxies for labor due to data unavailability may omit nuances in workforce productivity. Second, while PLSCI captures maritime connectivity, land-side hinterland connectivity was not explicitly modeled, potentially underestimating the efficiency of ports with strong inland logistics networks. Third, the DEA approach, while robust for benchmarking, is deterministic and sensitive to outliers, meaning that measurement errors in reported throughput could influence efficiency scores. Future research should address these limitations by incorporating labor cost data and hinterland connectivity metrics to provide a holistic view of supply chain integration. Additionally, applying SFA could offer a parametric alternative to validate these efficiency scores and account for statistical noise. Beyond methodological refinements, a distinct research agenda must address the region's strategic volatility, particularly regarding choke points like the Bab al-Mandab Strait. Future investigations should quantify the resilience of port efficiency to geopolitical disruptions by modeling shock propagation through the liner network and analyzing rerouting strategies during security crises in the Red Sea. Such analysis would offer critical insights for policymakers navigating the intersection of maritime economics and regional stability.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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