# Re-Examining the Sources of Inefficiency in Hub's European ports

Nouha Aloulou, Younes Boujelbene

European ports now face the challenge of handling significant international traffic. Ports need to improve their operating efficiency because of their limited logistics capacity. We employ a non-parametric approach by using the Generalised Method of Moments (GMM), based on data envelopment analysis, to evaluate and compare the performance of European ports. Data from 30 European HUB ports from 2005 to 2019 are included in our study. According to the findings, port development is essential to the prosperity of European ports because it boosts economic growth, particularly in those without container traffic, and it has a significant impact on the major economic sectors by influencing them to address port inefficiencies. By concentrating on fixing inefficiencies, ports with little container traffic can nevertheless be very important. Despite their low direct throughput, these ports can boost economic activity in other sectors with effective administration and expansion.

**KEYWORDS**

~ Performance
~ Port logistics
~ Ports HUB
~ DEA
~ GMM
~ Europe

University of Sfax, Faculty of Economics and Management, Sfax, Tunisia
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# 1. INTRODUCTION

The significance of seaports in both national and international economies is widely acknowledged. It is evident that their efficiency, and even their enduring viability in a highly competitive global landscape, hinges significantly on optimising the input-output ratio. The evaluation of port efficiency is gaining increasing prominence in the sector, given the substantial investments in this domain, where performance is not solely contingent on the scale of investments.

In recent years, with the growth of the national economy and political support, the European Hub shipping industry has rapidly developed. Due to its low-cost advantages, it plays an important role in supporting foreign trade and serving countries' economic and social development.

Nevertheless, challenges persist in the shipping industry concerning resource allocation, leading to issues such as resource wastage and insufficient production. It is crucial to conduct a comprehensive analysis of the overall efficiency and developmental status of port cities in the context of shipping operations. The mention of waterway transport is likely part of the broader context in which shipping operations are being analysed. In this context, inland waterway transport is being highlighted as a crucial component of improving overall efficiency in port cities, which in turn can have a significant impact on a country's global competitiveness. Formulating recommendations for enhancing the efficiency of inland waterway transport in these port cities is essential. This endeavour can contribute to a country bolstering its competitive advantages in global markets and enhancing its resource utilisation position in comparison to other nations (Koengkan et al., 2022).

In the realm of global supply chains and intricate industrial development processes, seaports and port operators assume a crucial and pivotal role. They serve as catalysts for the advancement of the maritime economy and the broader national economy (Wang et al., 2021). Consequently, this article delineates shipping efficiency as the relationship between the input and output of waterborne transport within a port city, encompassing both ports and shipping lines.

The growth of European ports is a fundamental issue for the development of their trade and maritime transport. If they are to continue to gain market share and compete locally and internationally, they will need to adapt their growth levels to those imposed by globalisation and global value chains.

The EU has a comprehensive set of rules addressing the environmental aspects of shipping, many of which go beyond agreed international standards. Ports are frequently found in environmentally sensitive places, particularly in Europe. Pollution, ship emissions, habitat destruction, and the effects of climate change are some examples of environmental challenges. The management and regulation of ports and shipping operations are directly impacted by these environmental concerns. Emissions laws, for instance, may affect the kinds of ships that are permitted to dock at a port or the ways in which cargo is handled. Because they can operate sustainably, ports that are well-equipped to meet regulatory criteria may draw more business, increasing their competitiveness in international markets. A port will have an edge over other ports that have trouble with sustainability or compliance if it can reduce its environmental impact while still operating with high efficiency.

However, future challenges facing policymakers include a predicted increase in global shipping, as well as climate change, (Lindstad et al., 2021) which could make ports vulnerable to rising sea levels and open up new shipping lanes in areas that are currently not open year-round.

Although their sales figures are rising, HUB ports remain less efficient than other ports in the Mediterranean basin. Their logistics capacities remain limited (Song et al., 2019), which handicaps the port service monopolised by European port companies. The latter have undergone a panoply of reforms aimed at upgrading, modernising and improving their performance. The aim of this research paper is to assess the performance of HUB seaports over the period between 2005 and 2019 through the measurement of port efficiency. This enables us to assess the evolution of the port sector in general and to draw up a comparative study between ports.

In order to achieve these objectives, this research paper poses the following problem: Through the geographical proximity of European HUB ports, how can improving the technical efficiencies of ports through their proximity reduce the overall cost of shipping, improve lead times, and enhance global supply chain reliability?

For this purpose, we use a non-parametric method: data envelopment analysis (DEA). The technical efficiency of each European HUB port can be assessed using DEA in a flexible, data-driven way that does not rely on restrictive assumptions about the data. DEA is a perfect tool for evaluating and enhancing the operational efficiency of ports in a competitive, heterogeneous environment because it can handle complex, multi-dimensional data, benchmark relative efficiencies, and measure performance without requiring predefined functional relationships. This method is more relevant in the sense that it offers several advantages, such as reliability of results, flexibility of approach, and explicitness of results. In this research article, we begin by presenting the sample and data sources. We then proceed to the choice of inputs and outputs. In conclusion, we employ data envelopment analysis to assess efficiency across three dimensions: technical efficiency, pure technical efficiency, and scale efficiency.

The rest of our analysis is organised as follows: Section 2 presents the decomposition principle, Section 3 discusses the econometric model, Section 4 presents the data used, Section 5 analyses the main results obtained, and the final section concludes the entire procedure.

## 2. LITERATURE REVIEW

Between the slow recovery of global demand, the uneven growth of developed economies, the management of transport overcapacity, and the need to invest and maintain competitiveness, the maritime sector was at a crossroads. Transport literature was focused on the new network paradigm and the upheavals that went with it: the expansion in the size of container ships, the multiplication of major shipping alliances, and the operation of container terminals by private investors. Clearly, in such circumstances, not all port systems were equally responsive to these events. Indeed, divergences in their performance can be observed on several scales, disparities in growth between ports are palpable, and the process of convergence is open to question.

### 2.1. Economic studies measuring port efficiency and productivity

Research on assessing port performance has conventionally concentrated on the efficiency and productivity of port (terminal) operations. In these studies, a range of research areas and approaches are employed for productivity comparisons and technical and economic optimisation (Koengkan et al., 2022). Nevertheless, ports have often been regarded as isolated nodes primarily engaged in ship-to-shore operations, emphasising costs and technical efficiency, without acknowledging their vital role in international supply chains. Consequently, these studies fall short in establishing a connection between quayside operations and landside systems (Bichou, 2006).

UNCTAD (1976) proposed that numerous researchers have employed productivity and efficiency indicators as a means to gauge port performance. The suggested port performance indicators can be broadly categorised into two groups: financial and operational. Financial aspects quantify the contribution to a port's economic activity, while operational aspects evaluate the efficiency of port operations, encompassing factors such as service time, arrival time, and tons per hour of a ship at berth. UNCTAD's initial study emphasises that a multitude of researchers have utilised these indicators to assess port performance.

Cruz et al. (2013) contended that operational performance indicators and physical capacity indicators were crucial metrics for evaluating port performance. They conducted an empirical study on the performance of Iberian seaports and formulated a linear multicriteria additive analysis (MCA) model, employing weight distribution through principal component analysis (PCA).

Simultaneously, ports have played a role in fostering clusters of economic activity, where handling, logistics, and manufacturing operations coalesce (De Langen, 2004). De Langen (2002) characterised a cluster as "a geographically concentrated and mutually linked population of business units, associations, and public (private) organisations focused on a particular economic specialisation." According to him, clusters yield agglomeration economy effects, such as cost reduction stemming from a substantial labour pool, the presence of numerous suppliers and customers, and knowledge spillovers within the clusters. He further illustrated that the performance of clusters typically hinges on various factors and is gauged in terms of value added. In a case study on the economic impact of a port, the author scrutinised the effects and performance of a port cluster in the Netherlands. Among other findings, he noted that over 70,000 people in Rotterdam and over 40,000 people in Amsterdam are directly and indirectly employed, respectively.

Given the increasing global significance of the shipping industry, evaluating shipping efficiency has emerged as a focal point in current research. To gauge port efficiency in Serbia and pinpoint the underlying causes of inefficiency, Pjevčević et al. (1970) conducted an assessment of port efficiency in five inland river ports in Serbia (Prahovo, Smederevo, Belgrade, Novi Sad, and Pančevo). Their study encompassed a four-year window analysis of port efficiency trends and average efficiencies, culminating in recommendations for enhancing port services and operations. In a separate study, Schøyen et al. (2013) evaluated the technical and scale efficiencies of container ports in Norway, all the Nordic countries, and the UK. Their findings indicated that Norwegian ports exhibit over-performance and under-performance concerning technical and scale efficiencies, respectively.

The analysis brought to light that Norwegian container ports should augment their size to align with the functions they undertake. Wu et al. (2010) asserted that evaluating container port efficiency is instrumental for ports to comprehend and enhance their market and competitive standing. To this end, they employed the cross-efficiency evaluation method to appraise the performance of container ports across 77 countries globally. Additionally, cluster analysis was employed to categorise these ports into seven clusters, characterised by "structural similarity."

Wang et al. (2022, 2021, 2012) directed their attention towards exploring the connection between the internal management level of companies and their economic benefits. Furthermore, they computed the X-efficiency of nine prominent port companies in China, spanning the years 2007 to 2010. In a related study, Sun et al. (2017) utilised non-radial data envelopment analysis in conjunction with a preference model to assess and analyse the efficiency of listed companies within Chinese port enterprises. Utilising efficiency scores, they categorised all ports into four groups based on throughput and efficiency, providing diverse recommendations for the implementation of environmental policies.

The goal of da Silva and Ensslin (2024)'s study is to map the features of publications about port performance evaluation that deal with port efficiency, confirm the kinds and purposes of the metrics used in the studies, and show how performance evaluation has changed in the port industry. It should be highlighted that while metrics' control and communication functions are frequently employed to assess port performance, their improvement function receives less attention. Similarly, it is seen that measures that concentrate on forecasting outcomes are not frequently employed. Even so, it is possible to see that a number of studies in the field have raised management concerns about support for decision-making, the significance of feedback from performance evaluation systems aimed at continuous improvement in the port sector, identifying bottlenecks and suggesting improvements, forecasting productivity and costs, strategic management, and evaluating performance from the perspective of stakeholders. By providing a comprehensive overview of the field being studied, discussing how to position the use of metrics to evaluate the ports' performance, illustrating their types and functions, and highlighting areas for further research, this study makes a theoretical and practical contribution.

As previously highlighted, past research on efficiency evaluation in shipping primarily focused on ports or port companies. However, a port city typically encompasses not only multiple ports and port enterprises but also an entire maritime industry interconnected with the port. In this context, we broaden the scope of evaluation to systematically assess the efficiency of the port-related maritime industry within a port city. In this article, maritime transport efficiency is defined as the ratio between inputs and outputs of the waterborne transport industry in a port city. Additionally, since this assessment aims to gauge the overall efficiency of waterborne transport in port cities, cargo turnover is introduced for the first time as an output variable.

### 2.2. Main methods for assessing port performance

Depending on the evaluation's goals, the data at hand, and the study's focus (such as operational effectiveness, environmental impact, or economic performance), there are wide variations in the approaches used to evaluate port performance. To give a thorough grasp of port operations, productivity measurements, benchmarking approaches (such DEA and SFA), and economic performance metrics are frequently employed. Customer satisfaction surveys and environmental performance metrics are also becoming more significant, which reflects the global shipping industry's increased focus on sustainability and user experience. Every technique provides distinct perspectives, and frequently integrating different methods will result in the most thorough evaluation of port performance.

Europe provides a good example of this evolution (Kavirathna et al., 2018). The stevedoring sector in Antwerp and Rotterdam first experienced an internal concentration in the port, i.e. the merger of stevedores presents in the port (ECT and Unit Centre in Rotterdam, Hessenatie, and Noord Natie in Antwerp). This was followed by external acquisitions, integrating the terminals of these two major European ports into an international network (Lavaud-Letilleul, 2005). In 2001, Hutchinson Port Holding (Hong Kong) acquired the terminals of the two recently merged Rotterdam handlers, handling almost 70% of the port's containers. In 2002, Port of Singapore Authority (PSA) acquired Hesse and Noord Natie, handling over 80% of Antwerp's traffic.

On a more regional scale, the same trend can be noted: in 1998, the merger of the German operators of the port of Hamburg (Eurokai) and Bremen (BLG) gave rise to the Eurogate group, which subsequently acquired the operator Contship, enabling the group to have a presence in Hamburg, Bremen, La Spezia, Gioia Tauro, and Lisbon. This process of concentration and internationalisation has accompanied the growth in container traffic and its spread to all shipping lines. It is based on the multiplication of terminals integrated into the operators' network. The number of terminals controlled by the four main operators, as listed in a recent study (Rodrigue et al., 2010), provides an indication of this internationalisation of practices: 47 terminals for Hutchinson, 50 terminals for Dubai Ports, 38 terminals for PSA, and 42 terminals for AP Moller Terminal.

In Slack's words, the disconnection between port and territory means that these two categories of operator are finally on the chessboard: "pawns in the game: ports in a global transportation system" (Slack, 1994). And this chessboard is based on a multi-level hub hierarchy that enables the generalised servicing of the world's coastlines. This transformation is not without impact on relations between ports and their hinterlands. The trend towards terminalisation, defined as the takeover of terminals throughout the world by liner companies and port operators, enables a dissociation of functions between the operator's internal network organisation (transshipment) and the network's external function (serving markets). In other words, some port traffic handled at terminals located in port cities is not destined for the surrounding areas. This dissociation reinforces the phenomenon of city/port disconnection, and raises the question of the metropolitan dimension of a port object fragmented into terminals.

The three portraits that follow will illustrate the morphology of this global network (portrait 2 on Maersk-Sealand), the corporate games involved in this concession arrangement that characterises the port game and their financial organisation (portrait 3 on Port of Singapore and Hutchison Port Holding), as well as the transposition of this network to secondary but now competitive façades (portrait 4 on the games played by players on the West African façade) (Martínez et al., 2017).

The DEA is a strong, adaptable, and effective instrument for assessing the technical effectiveness of HUB ports in Europe. Because it is non-parametric, it can handle complex data with multiple inputs and outputs, without requiring constrictive assumptions. Furthermore, DEA is especially well-suited for examining the operational dynamics of ports that are close to one another geographically because of its capacity to handle heterogeneous data, assess performance against peers, and directly detect inefficiencies. This study can offer important insights into how ports might increase their technological efficiency and competitiveness in the global shipping market by implementing DEA.

In the literature on measuring port efficiency, Data Envelopment Analysis (DEA) techniques have gained prominence. This method aims to assess a port's efficiency by gauging its distance from the production frontier, which signifies the technological level in the sector at a specific point in time. Production units not situated on this frontier are considered more or less inefficient. Roll and Hayuth (1993) were pioneers in using this method to measure relative efficiency in the port sector. Martinez-Budria et al. (1999) employed the DEA BCC model (variable returns) to quantify the relative efficiency of 26 Spanish ports, categorised into three levels of managerial complexity, from 1993 to 1997. The results indicated a positive correlation between the degree of complexity, output level, and efficiency ranking. Tongzon (2001) endeavoured to measure the relative efficiency of 16 container ports in 1996, utilising DEA analysis in both its CCR (constant returns to scale) and additive forms.

In the same literature, the two predominant variants of the DEA method are the Constant Returns to Scale (CRS) model presented by Charnes, Cooper, and Rhodes (Charnes, Cooper and Rhodes, 1978) and the Variable Returns to Scale (VRS) model proposed by Banker, Charnes, and Cooper (Banker, Charnes and Cooper, 1984). The CRS model assumes that an increase in the quantity of inputs consumed will result in a proportional increase in the quantity of outputs produced. Conversely, the VRS model allows for variable returns to scale, meaning that the quantity of outputs produced is assumed to increase more or less proportionally than the increase in inputs in cases of variable returns to scale, whether increasing or decreasing.

The results reveal a problem of over-specification, leading to the identification of more efficient than inefficient ports.

Valentine and Gray (2001) utilised the DEA CCR model to assess 31 of the world's 100 largest container ports in 1998, aiming to analyse the relative efficiency based on management mode and organisational structure. Subsequently, Barros and Athanassiou (2004) selected two Greek and four Portuguese ports, spanning from 1998 to 2000, applying the DEA model in both CCR and BCC forms. Their findings indicated that the primary source of port inefficiency is associated with the scale of production. In a study by Cullinane et al. (2005), the relative efficiency of 57 container terminals in 1999 was estimated using two non-parametric methods: DEA (in CCR and BCC form) and Free Disposal Hull (FDH). These authors recommended the use of panel data to mitigate potential bias induced by a one-off shock in efficiency estimation. Building on this approach, Cullinane et al. (2004) applied a panel version of the DEA model (Window analysis) to 25 container ports, revealing that efficiency fluctuates over time and that port size is not the primary source of inefficiency.

Subsequently, Cullinane et al. (2006) applied DEA and stochastic frontier analysis to the same sample to quantify port efficiency. The estimate obtained from these two approaches leads to relatively similar results in terms of efficiency score. For a more comprehensive review of this literature, see Gonzalez and Trujillo (2009). The literature examining the determinants of efficiency scores in the second stage posits that variations in scores can be attributed to several factors. These factors include the institutional environment, delineated by the extent of private versus public participation, technical or scale efficiency, and macroeconomic elements like national or regional GDP, the population of the port city, and connections to the hinterland. Nevertheless, several questions persist, particularly regarding the influence of ports' accessibility to networks.

The CCR model is the reference model for the DEA method. It assumes constant returns to scale, except for the CRR model used for a sole output, applied specifically to containerised transport, as discussed by Pierre Cariou and Gabriel Figueiredo de Oliveira in their work. Turner, Windle & Dresner (2004), for example, use Tobit regression to estimate the determinants of efficiency in 26 North American container ports (1984-1997). Five variables are taken into account: port industry structure, port authority status, shipping line structure, location factors, and control variables.

They deduce that factors such as terminal size, type of concession contract, average size of calling ships, and rail connection significantly impact port efficiency. In the case of Barros and Managi (2008), who employed the method by Simar and Wilson (2007) for 39 Japanese ports during the period 2003-2005, the explanatory variables for efficiency included the country's GDP, hub status, and population. Their findings suggest that efficiency increases over time, correlating positively with GDP and port status (HUB or not), while population exerts no significant influence. Meanwhile, Bergantino and Musso (2011) used a second-stage stochastic frontier method for 18 Southern European ports, spanning the period 1995-2007. They concluded that regional GDP, employment rate, population density, and accessibility positively contribute to efficiency, except for employment levels.

Lastly et al. (2011) discern the primary determinants of technical efficiency in container ports across Southeast Europe. Their findings indicate that larger ports tend to exhibit greater efficiency. Moreover, the privatisation of terminals, particularly when coupled with the involvement of international operators, enhances port performance, a result consistent with the research of Cullinane and Song (2003), Estache et al. (2002), and Tongzon and Heng (2005). Additionally, factors such as distance from the main road, the region's GDP, and population size positively influence efficiency.

The concept of efficiency has become fundamental to the study of firm performance. Performance is an overriding objective for any firm, and this concept means an efficient and effective allocation of available resources, taking into account the constraints imposed by technology, market structure, and the objectives set by entrepreneurs (Tuljak, 2018).

A broad range of tools, such as productivity measurements, economic performance indicators, benchmarking techniques (e.g., DEA, SFA), and environmental assessments, are used to analyse the efficiency and competitiveness of ports, according to the literature on port performance assessment. These methods offer insightful information about the financial, environmental, and operational facets of port performance. Numerous studies have found important variables of port performance, including scale, infrastructure quality, technology uptake, privatisation models, and regulatory frameworks.

Additionally, little is known about how ports' geographic proximity affects their overall efficiency, especially in European HUB ports. This disparity explains why more research is necessary to fully comprehend how cooperative tactics or shared infrastructure could improve technical efficiency across nearby ports. By concentrating on the potential for enhancing port efficiencies through a combination of technological advancements, resource-sharing models, and sustainability practices within a regionally connected port system, the research hypotheses put forth in this study seek to close these gaps.

By combining these results, it is evident that a wide range of parameters, many of which have not received enough attention in the literature to far, affect port performance. By offering a more thorough and comprehensive knowledge of how European HUB ports might increase technological efficiencies through innovative and strategic collaboration, the research hypotheses put forth seek to close these gaps.

To address our problem, we have develop the following two hypotheses:

(H1): Hub seaports are on average technically inefficient.

The idea that hub seaports are generally technically inefficient is supported by the literature now in publication. The operational difficulties of operating large, crowded ports, such as bottlenecks, antiquated infrastructure, and intricate operational structures, frequently lead to technical inefficiencies, despite their crucial role in international trade and the possibility of economies of scale. The investigation of these inefficiencies serves as the basis for this study, which looks for ways to increase port efficiency through resource management, technology innovation, and cooperation amongst nearby ports (da Silva and Ensslin, 2024).

(H2): There is some convergence between HUB ports in terms of technical efficiency.

Numerous variables, such as the broad adoption of technology, competitive pressures, the exchange of best practices, and the development of regional port clusters, support the premise that there is some technical efficiency convergence among HUB ports. The move towards standardisation and the sharing of innovations has helped to reduce the efficiency gaps between hub ports, even though local factors, infrastructure, and management models will probably continue to cause variances in port efficiency. Economic and regulatory frameworks that encourage all ports to enhance their operations in order to stay competitive in the global shipping market may also be the driving forces behind this convergence (Koengkan et al., 2022).

## 3. METHODOLOGY

In order to study the question of the performance of European ports, we have chosen to evaluate the quantitative dimension of performance: efficiency. We then evaluate the efficiency of 30 European ports operating between 2005 and 2019 by determining their technical efficiency, after which we choose our research's inputs and outcomes. To this end, we have used a non-parametric approach. This is the Data Envelopment Analysis (DEA) method. This method considers ports as production units that use inputs in different combinations to produce outputs at different levels. The method therefore requires a selection of inputs and outputs. After data collection from statistical yearbooks, these inputs and outputs should first be studied statistically, before contributing secondly to the measurement of efficiency. The discussion below gives more details on the method used, the choice of inputs and outputs, and the statistical study of the latter (Stopka et al., 2020).

Certainly, the prevalent trend in the literature favours measures of productivity and efficiency that encompass all inputs and outputs. Two principal categories have emerged: i) gauges of total factor productivity and ii) indices of productive efficiency. In the context of measuring productive efficiency, the methodology primarily adheres to the framework introduced by Farrell (1957). The holistic efficiency is dissected into technical efficiency (aimed at maximising production capabilities) and allocative efficiency (focused on minimising input ratio costs or maximising profits, contingent on the behavioural hypothesis) (Kopp and Diewert, 1982). The evaluation of the reference technology involves estimating a production possibility (or cost-minimisation) frontier, followed by an assessment of the performance of existing seaports in relation to this frontier. The two most extensively employed methods for estimating efficiency frontiers are non-parametric data envelopment analysis and parametric stochastic frontier analysis.

### 3.1. Technical efficiency versus allocative efficiency

The production frontier approach (Farrell, 1957) distinguishes between technical efficiency (producing the maximum output with a given quantity of inputs) and allocative efficiency (choosing the best productive combination of inputs given their prices). Figure 1 below clarifies these points, assuming that the measurement of efficiency/ineffectiveness is output-oriented.

Thinking about the Figure 1-defined production frontier PP'. At D, where the efficiency frontier meets the input price ratio that defines the cost restriction tt', you will find the most technically and allocatively efficient microfinance institutions (MFIs). Given the efficiency frontier and the cost constraint, the technically inefficient MFI producing at point A is one whose level of output is lower than the theoretically attainable level of production at point B. However, production at level A is also allocatively inefficient because the cost that the MFI working at level A should pay is the one that is dictated by the tangent to the production frontier at (B). The real cost that the MFI incurs when producing at point B, which is equal to the tangent tt', is more than this theoretical cost, as measured by the tangent r'r. The technical efficiency of the MFI at point A can be measured by the ratio of operating expenses to operating profits. Since the MFI should have produced OB, it actually produces OA, which is less than OB, and the ratio OA/OB is less than 1. Similarly, allocative inefficiency can be measured by the ratio of operating costs to operating profits. Since the MFI should have borne the cost of operating profits, it actually bears the cost of operating capital, which is greater than operating profit. Because it starts production at point A, the MFI is technically and allocatively inefficient. The complete efficiency or inefficiency of it is indicated by the ratio OA/OC, which is equal to OA/PB * OB/OC.

Which of technical efficiency and allocative efficiency best suits the situation of microfinance institutions? While allocative efficiency is debatable because it refers to the profit-optimisation perspective, technical efficiency is less debatable because, whatever the objectives assigned to a productive structure, whatever the weightings, there is no justification for technical inefficiency (Gathon and Pestiau, 1992). In the name of poverty reduction, MFIs must not sacrifice the quest for technical efficiency at the risk of being unable to sustainably support their actions in favour of the poor. This analysis uses technical efficiency as an appropriate measure of performance for a social economy institution, such as a microfinance one.

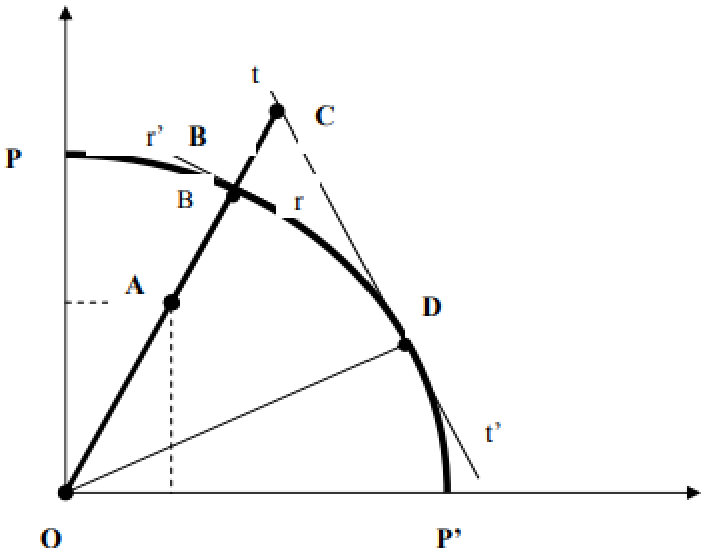


Figure 1. Graphical representation of technical and allocative efficiency (Source: Farrell, 1957; Coelli, 1996).

Financial evaluation of MFIs (MicroRate, 2003), widely adopted by international organisations, practitioners, and policy-makers (Léon, 2001), is a more common practice than measurement by efficiency frontiers. The use of financial ratios is useful for dealing with issues relating to portfolio quality, return on capital, factor productivity, and governance quality, but this method fails when looking for a synthetic indicator of efficiency, which is why the trend in four recent years has been to measure the efficiency of financial institutions using the efficiency frontier method. The financial ratio approach will not be considered in this analysis. Instead, the production frontier approach will be used. The method is of very general application, appropriate for any productive unit (Farrell, 1957), including those in the microfinance sector.

A review of the literature reveals the existence of several attempts to empirically measure the efficiency of financial institutions, particularly banks, using the efficiency frontier method in Asian and Latin American countries: Mahadzir (2004) on the analysis of the comparative performance of Malaysian banks with state, foreign and private national ownership, Hasan (2004, 2005) on the relevance of measuring the efficiency of Islamic banks by conventional methodologies including the frontier method, Iimi (2002) on the efficiency of the Pakistani banking industry after the 1990 structural adjustment program, Grigorian et al., (2005) on the comparative analysis of the efficiency of Bahrain's banking system in relation to that of other Middle Eastern countries and Hong Kong, Léon (2001) on the efficiency of microfinance, such as Peruvian municipal banks, Qayyum et al. (2000), on the efficiency and sustainability of microfinance in South Asia (Pakistan, Bangladesh, India).

Lamberte et al. (2002) on the efficiency of rural cooperative banks in the Philippines, Nieto et al. (2004) on the efficiency of microfinance institutions in eight (8) Latin American countries (Bolivia, Colombia, Dominican Republic, Ecuador, Mexico, Nicaragua, Peru, Salvador) and, of course, in developed countries, such as Worthington's analysis of the cost-efficiency of Australian non-bank financial institutions, Drake et al. (2003) on competition and efficiency in banks in the United Kingdom (impact of the corporatist form of ownership) or Rouabah (2002) on economies of scale, diversification economies and productive efficiency of Luxembourg banks, a comparative analysis of stochastic frontiers on panel data; we can cite a few rare empirical analyses of financial institutions in the UEMOA zone: Igué (2006) on financial system reform, banking efficiency and economic growth, a reference to the UEMOA zone, of Mahamadou (2005), performances of decentralised financial systems (SFD) in Niger, a comparative analysis according to the typology of microfinance institutions, of Dao (2007) on the technical efficiency and performance of banks in Burkina Faso, estimation of a stochastic cost frontier on panel data.

Authors generally stress the advantage of the frontier method over the financial ratio method. They calculate relative efficiency scores and carry out a comparative analysis, either of a firm's efficiency within an industry, or of an industry's efficiency between countries, etc. While empirical evaluations refer to the same theoretical framework (Koopmans, 1951; Debreu, 1951; Farrell, 1957) for the definition of the concept of efficiency and its empirical measurement, they differ in the method of estimating the frontier (parametric, non-parametric, deterministic, non-deterministic) and in the choice of inputs and outputs.

## 3.2. The DEA (Data Envelopment Analysis) method

A number of industries have made extensive use of DEA in recent decades, including banking, healthcare, education, and, most notably, logistics and transport (Emrouznejad and Yang, 2018). Ports are especially essential since they have become hubs in global supply chains; therefore, evaluating their operational efficiency is crucial.

Formally, we consider N microfinance institutions (n = 1 to N) producing M outputs Y with inputs X. The European ports use K variable inputs (k = 1 to K) to produce M outputs (m = 1 to M). The aim is to determine the relative efficiency of the target European ports. This efficiency can be measured in terms of output orientation or input orientation; in the first case, the aim is to maximise output under input constraints, and, in the second case, to minimise the quantity of input under the constraints of a given output level.

In order for DEA to accurately reflect the unique aspects of port operations in Europe, it needs to be fine-tuned. Ports, in contrast to factories, are service industries that deal with complicated flows involving numerous stakeholders. This highlights the significance of picking the right inputs and outcomes. It is important to consider the operational control and strategic objectives of the ports being evaluated, while deciding between input-oriented and output-oriented DEA models. Port authorities who have limited control over demand but are able to manage costs and resource allocation could consider an input-oriented model, which aims at minimising resource utilisation for a given level of output. In contrast, the port environment is frequently better served by an output-oriented model, which aims to optimise outputs given a set of inputs. Because of fixed infrastructure and labour arrangements, European ports, especially those operating under landlord models, usually have little direct control on inputs. However, they can impact throughput through digitalisation, marketing strategies, and service quality (Koengkan et al., 2022).

The K × N matrix of inputs and M × N of outputs represent the data from the European ports set. The formulation of the objective function as a ratio (Eq. 1) is the most common form, as it is easier to process. In this case, for each European ports we seek to obtain the ratio of total output to total input, i.e. the ratio ($\left(\frac{u' y_i}{v' x_i}\right)$) where u' is the M × 1 vector of output weights and v' is the K × 1 vector of input weights.

Because it permits comparisons across ports with varying operational dimensions and configurations and may assess efficiency without necessitating a preset functional form, DEA is particularly well-suited to the setting of seaport operations.

Building the production frontier and quantifying the efficiency of each unit in relation to this frontier entails determining the values of u and v that maximise the output of each productive unit under the constraint that all efficiency measures are less than or equal to 1, representing the efficiency frontier. This task involves solving the following optimisation programme:

$$Max\ \left(\frac{u'y_i}{v'x_i}\right) S/C \frac{u'y_i}{v'x_i} \leq 1, j = 1, \dots, N \qquad (1)$$

The multiplicative form of the programme (Coelli, 1996) is shown below with the transformation of u and v:

$$Max(u'y_i)\ S/C v'x_i = 1;\ u'y_i - v'x_i \leq 0, j = 1, \dots, N\ and\ u, v \geq 0 \qquad (2)$$

We derive an equivalent form:

$$Max\theta\ S/C - \theta y_j + y_\lambda \geq 0;\ x_i - x_\lambda \geq 0; N1'\lambda = 1;\ \lambda \geq 0 \qquad (3)$$

Eq.1 represents the objective function to be maximised, expressed in different ways. Also, Eq.2 represents the constraints expressed in different ways. Eq.3 expresses the constraint on firm i's output, which cannot exceed the efficiency frontier. This reflects the constraint on input use (firm i's consumption of inputs is at best equal to that of the efficient firm), and also the convexity constraint, which introduces the assumption of variable returns to scale, instead of constant returns.

θ is the measure of firm i's inefficiency. It is such that $1 \leq \theta < \infty$ and in effect represents the factor by which firm i's output would have to be multiplied (a factor that is at least equal to firm i's output, i.e. equal to 1) so that, with the same level of inputs, it could produce an output equal to that of the efficient firm. It follows that θ - 1 is the proportion by which outputs can be increased for the reference MFI, while keeping the level of inputs constant.

Considering the definition of θ, which is a measure of the reference firm's inefficiency, the technical efficiency score (desired result) of the reference firm is measured by the inverse of θ, i.e. 1/θ. This efficiency ratio varies between 0 and 1.

When 1/θ < 1, the reference firm is not on the efficiency frontier. When 1/ θ = 1, θ = 1, the reference firm is efficient and on the efficiency frontier.

The literature review shows that the DEA method has been generally used to analyse the technical efficiency of production units in various sectors of activity, notably in the education sector in Quebec (Broussau et al., 2004), the press in Côte d'Ivoire (Nuama, 2002), livestock breeding in Côte d'Ivoire (Nuama, 2003), rail transport in certain African countries south of the Sahara (Ambapour, 2001), in the banking sector in the UEMOA zone in West Africa, Asia and Japan (Igué, 2006; Grigorian, 2005 and Iimi, 2002), and by extension in the microfinance and cooperative banking sectors (Qayyum et al., 2000; Singh et al., 2000; Nieto et al., 2004; Léon, 2001; Ferro Lurri et al., 2006; and Hasan, 2004). Singh et al. (2000) used the DEA method to measure technical, allocative, and cost efficiency in 13 Indian dairy cooperatives between 1992 and 1997 to discuss the impact of liberalisation on the performance of these cooperatives. The method was then successfully applied to the microfinance sector, particularly in Asian and Latin American countries, resulting in the calculation of MFI efficiency scores.

The method was successfully used (Qayyum et al., 2000) to carry out a comparative analysis of the efficiency of MFIs in Pakistan, India, and Bangladesh; among other interesting results, the authors were able to calculate and compare technical efficiency, pure technical efficiency and efficiency of scale, showing the superiority of Bangladesh over the other countries and the share of pure technical inefficiency in the measurement of total MFI inefficiency. The same applies to the analysis by (Nieto et al., 2004) of 30 microfinance institutions in eight Latin American countries: Bolivia, Colombia, Dominican Republic, Ecuador, Mexico, Nicaragua, Peru, and El Salvador, and to the analysis by Cornée (Cornée, 2006) of 18 Peruvian microfinance institutions. After demonstrating and emphasising the sensitivity of the DEA method's results to the choice of outputs and inputs (nature and number), the authors rejected an *a priori* specification and advocated a two-stage analysis: measurement of the MFIs' efficiency scores by considering all possible combinations of outputs and inputs, and multivariate analysis by considering the efficiency scores as dependent variables to be explained.

It was possible to explain the efficiency of MFIs by means of four principal components and to understand why the efficiency scores measured by the DEA method differ and what convergence there is between the scores obtained by the DEA method and the financial ratios method. The analysis of a sample of twelve Peruvian municipal banks, which the author (Leon, 2001) classifies as microfinance institutions, was carried out using the parametric, non-parametric, and financial ratio methods to show that the two parametric and non-parametric methods are complementary. While the practice of evaluating MFIs using the efficiency frontier method is growing in Latin America and Asia, it is not commonplace in MFI evaluation procedures within the West African Economic and Monetary Union (UEMOA).

The literature shows that the DEA method has been frequently used to evaluate the effectiveness of MFIs. It is regrettable, however, that in the choice of outputs and inputs, as well as in the choice of evaluation method - output-oriented or input-oriented - particular attention is not always paid to the specific nature of microfinance institutions, which pursue both an economic and a social optimum. In the case of MFIs not pursuing a commercial objective, allocative efficiency and cost-effectiveness are not *a priori* objectives to be pursued. Furthermore, the choice of outputs must take into account the nature of the structures: a savings and credit cooperative produce at least two outputs, a credit output and a savings output. These two elements must necessarily be taken into account when measuring its efficiency.

After selecting the inputs and outputs for our research, we proceed to assess the performance of European ports by calculating the technical efficiency of thirty (30) ports, spanning the period from 2005 to 2019. For this evaluation, we have employed the non-parametric method known as Data Envelopment Analysis (DEA), utilising Max DEA Pro software. This tool facilitates the decomposition of technical efficiency into pure technical efficiency and scale efficiency. To clarify, an entity is deemed technically efficient, following Atkinson & Cornwell (1994), if it maximises the output from its set of inputs or, when producing a given output quantity, uses the smallest possible input quantities. Taking returns to scale into consideration allows the breakdown of technical efficiency into scale efficiency, reflecting the appropriateness of sectors to their optimal production size, and pure technical efficiency, indicating how a production unit manages its resources. As per Chaffai (1989), scale efficiency reflects the sector's adequacy to its optimal production size, while pure technical efficiency, according to Borodak (2007), represents a company's ability to optimise production for a given level of inputs and, conversely, to minimise resource consumption for a given level of output.

Our investigation centres on elucidating the interplay between output and input variables across thirty (30) European Hubs from 2005 to 2019 (Table 1). To further delineate their relationship, we will strive to present the various variables statistically in the subsequent section.

| Variables | Symbol | Definition | Source |
|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Total freight traffic in tonnes | | **Output** | All goods arriving, being shipped or transited through a port. Port traffic is measured in millions of tons. | Data Stream |
| **Inputs** | Total platform length | **Quais** | Dedicated space where products and goods are stored for a certain period of time before being loaded or unloaded onto a transport vehicle. | Data Stream |
| | Median strip surface | **Surface** | Artificial expanse of land reclaimed from the sea by filling, often with waste, rubble and sand, with an elevation higher than sea level. | Data Stream |
| | The number of cranes | **Grues** | Machines that can move on rails or along docks. They are used to load or unload goods from ships. There are also floating cranes for handling loads from the ship's hold to the quay, or from ship to ship. | Data Stream |
| | The number of staff | **Personnel** | These personnel are employed or placed under the control of the port state, the port authority (port stakeholders) or the local authorities. | Data Stream |

Table 1. Variable definitions and data sources

The chosen variables in this study represent the most suitable input parameters in DEA applications for seaports, a selection supported by several preceding studies (Kammoun and Abdennadher, 2022; Tangzon, 2001; Culliance et al., 2005; Bergantino and Musso, 2000; Niavis and Tsekeris, 2012, etc.). The selected inputs include the total length of quays, the surface area of medians, the number of cranes, and the personnel count. Additionally, the total goods traffic in tonnes serves as the output variable.

## 4. EMPIRICAL ANALYSIS

### 4.1. Estimating the efficiency of European ports

Initially, we will provide an interpretation of the primary descriptive statistics for the diverse variables as presented in Table 2.

| Designations | Output | Quais | Surface | Grues | Personnel |
|---|---|---|---|---|---|
| **Average** | 6.65e+07 | 22146.33 | 3.28e+07 | 48.359 | 6024.7 |
| **Standard deviation** | 7.29e+07 | 30981.67 | 6.34e+07 | 67.275 | 11898.97 |
| **Maximum** | 4.74e+08 | 163000 | 3.20e+08 | 353 | 61496 |
| **Minimum** | 1.40e+07 | 1179 | 1500000 | 2 | 157 |
| **Median** | 4.54e+07 | 12958 | 8260000 | 24 | 2000 |
| **Coefficient of Variation** | 1.095 | 1.398 | 1.934 | 1.391 | 1.975 |
| **Skewness** | 3.765 | 3.360 | 3.316 | 3.201 | 3.623 |
| **Kurtosis** | 18.177 | 14.930 | 14.515 | 14.373 | 16.395 |
| **Jarque-Bera (JB)** | 5383 | 3516 | 3312 | 3194 | 4349 |
| **JB Probability** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **Born et Breitung (BB)** | 13.57 | 3.58 | 3.04 | 1.46 | 0.000 |
| **BB probability** | 0.001 | 0.167 | 0.219 | 0.483 | 1.000 |

Table 2. Summary of key descriptive statistics for variables

Certainly, upon inspecting the data, it becomes evident that the majority of them exhibit a right-skewed distribution with a leptokurtic shape. Additionally, we refute the assumption of normality in the series based on the Jarque and Bera (1987) test. The autocorrelation test on the Panel Born and Breitung (2016) data unmistakably reveals the presence of serial autocorrelation issues across all variables.

We take an example of descriptive analysis of our variables, the output of our model total goods traffic in tonnes (Output), from Table 2, our series presents an overall mean of 6.65e+07 with a standard deviation of 7.29e+07, showing the high heterogeneity of the observations (CV = 1.095). The 450 observations range from 1.40e+07 (LISBON Port) to 4.74e+08 (ROTTERDAM Port), with a high concentration around 4.2704.54e+07. The sample distribution of Output is slightly non-symmetrical to the right (skewness = 3.765) and leptokurtic (Kurtosis = 18.177). Overall, this variable rejects the normality hypothesis, since the probability of the Jarque-Bera statistic is less than 5%. Similarly, with reference to Born and Breitung (2016), we reject the null hypothesis at the 1% threshold as it presents a serial autocorrelation problem.

In general, all series present autocorrelation problems and the persistence of strong heterogeneity, which will affect subsequent estimation results.

In the next phase of our analysis, we delve into the interplay among a set of variables, gauging the efficiency of European ports, spanning the period from 2005 to 2019, with a focus on measuring total factor productivity. Subsequently, we aim to provide a statistical presentation of the various model variables, laying the groundwork for elucidating their relationships in the ensuing stages. The variables under scrutiny in our study, encompassing efficiency measures (CRS_TE, VRS_TE, NIRS_TE, and SCALE), involve thirty (30) European Hubs during the period from 2005 to 2019.

The Data Envelopment Analysis (DEA) method employs two models for constructing the efficiency frontier: the CCR model and the BCC model. The CCR (Charnes, Cooper, Rhodes) model, also known as the CRS (Constant Returns to Scale) model, was introduced by Charnes, Cooper and Rhodes (1978). It assesses the minimum required inputs to generate the maximum achievable outputs, while assuming constant returns to scale. This model has significantly influenced research in the port sector. In contrast, the VRS (Variable Returns to Scale) model was proposed by Banker, Charnes & Cooper (1984). It introduces flexibility in determining returns to scale, allowing for a choice between economies of scale and diseconomies of scale. This model adds a convexity constraint to the VRS model (W. Cooper et al. 2006). It is important to note that the CRS model is complemented by the VRS model, as the former calculates proportional efficiency but does not account for input surpluses and production deficits. Additionally, the VRS model introduces the concept of Non-Increasing Returns to Scale (NIRS) for organisations operating in a situation of increasing returns to scale, along with a measure of scale efficiency (SCALE).

The initial step in our analysis involves interpreting the key descriptive statistics for the various variables, as presented in Table 3.

| Designations | CRS-TE | VRS-TE | NIRS-TE | SCALE |
|---|---|---|---|---|
| **Average** | 0.109 | 0.232 | 0.159 | 0.520 |
| **Standard deviation** | 0.153 | 0.253 | 0.214 | 0.233 |
| **Maximum** | 1.000 | 1.000 | 1.000 | 1.000 |
| **Minimum** | 0.006 | 0.029 | 0.006 | 0.084 |
| **Median** | 0.055 | 0.117 | 0.073 | 0.513 |
| **Coefficient of Variation** | 1.399 | 1.092 | 1.345 | 0.448 |
| **Skewness** | 2.894 | 1.732 | 2.272 | 0.036 |
| **Kurtosis** | 11.238 | 5.059 | 7.460 | 2.261 |
| **Jarque-Bera** | 1901 | 304.8 | 760.3 | 10.32 |
| **JB Probability** | 0.000 | 6.6e-67 | 8.e-166 | 0.005 |
| **Born and Breitung test (BB)** | 6.18 | 2.41 | 3.83 | 19.45 |
| **BB probability** | 0.046 | 0.300 | 0.148 | 0.000 |

Table 3. Summary of key descriptive statistics for variables

With regard to this model, let us take an example of the VRS-TE variable. With reference to Table 3, our series shows an overall mean of 0.232 with a standard deviation of 0.253. Total values range from 0.029 (DUISBOURG Port) to 1.000 (ROTTERDAM, LONDON and HARTLEPOOL Ports), and the high concentration is around 0.177. There is considerable heterogeneity (CV = 1.092). The sample distribution of the VRS-TE variable is asymmetrically spread to the right (skewness = 1.732) and leptokurtic (kurtosis =5.059). We reject the null hypothesis of normality using the probability of Jarque-Bera normality test. With reference to the Born and Breitung (2016) test, we reject the null hypothesis of the presence of a serial autocorrelation problem at the 1% threshold.

Overall, we can state that all model variables are non-stable over time, which suggests that they are approximately non-stationary.

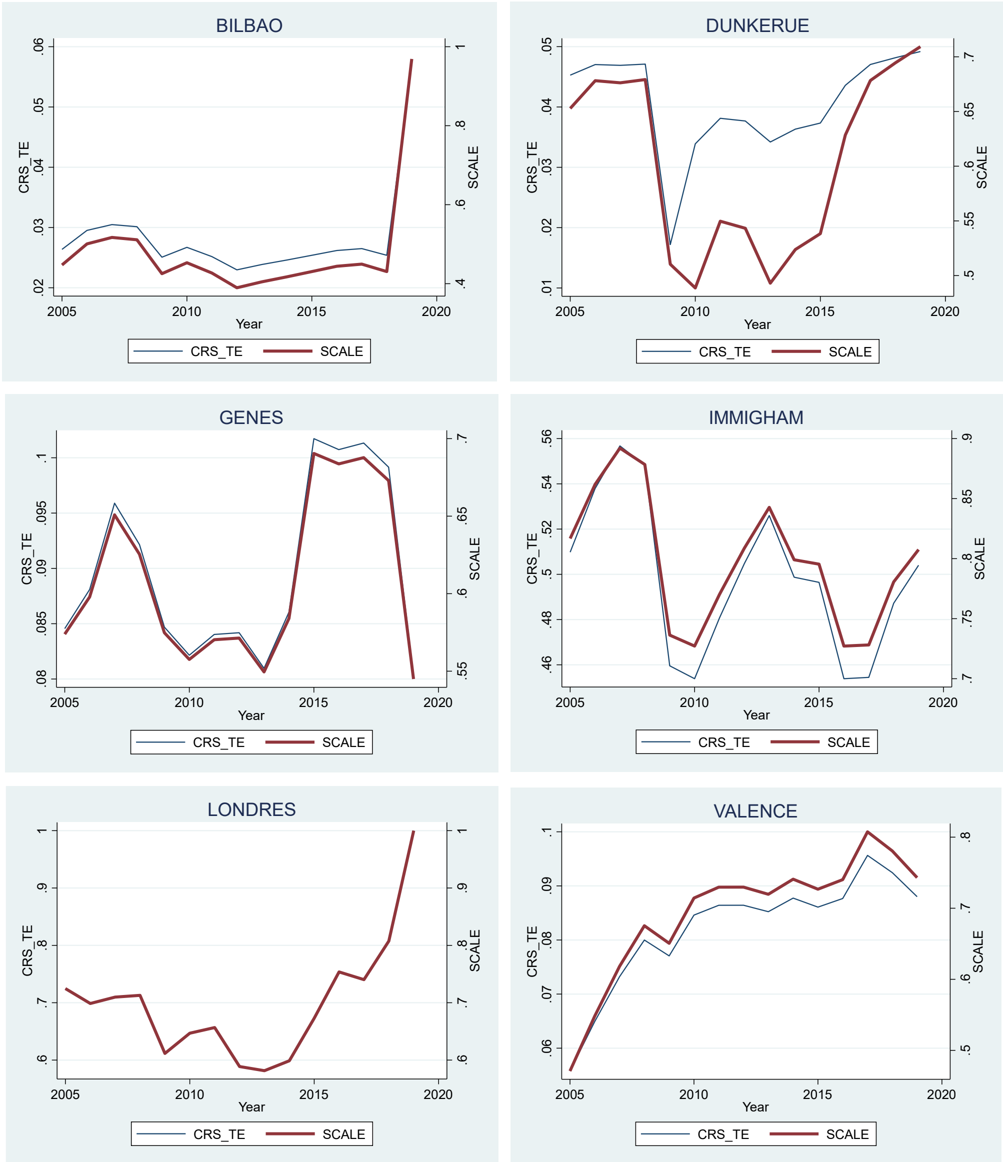


Figure 2. The efficiency frontier of European ports hub

Similarly, the model in this study will be output-oriented, since port operators' efforts are geared more towards maximising outputs while minimising the inputs used in port operations. Moreover, this choice is supported by the empirical review dealing with the said issue H. Kuang and H. Li (2009), da Cruz, P. and de Matos J. J. (2016), João José de Matos Ferreira (2016) and Birafane and El Abdi (2019), regarding the origin of our database containing information about port authorities and port operating companies in various countries.

Figure 2 shows the results of the non-parametric DEA-CRS and DEA-VRS model in terms of port efficiency, presenting the six most efficient European Hub ports.

The DEA model shows that the six most efficient ports are (BILBAO, DUNKERUE, GENES, IMMIGHAM, LONDON, and VALENCIA), as the seaport with a score of 1.00 is considered the most efficient (see Figure 2). The port authorities of the ports in question have made colossal efforts to achieve high efficiency scores, particularly in terms of developing port infrastructure and superstructure.

However, achieving a high efficiency score depends on a number of criteria linked to the port's internal and external environment. The score achieved by the Port of London, for example, can be justified by the continuous efforts made by the European Port Authority to steer the port towards achieving outstanding performance. On the other hand, urgent measures need to be put in place to alleviate port congestion, accommodate the latest generation of ships, and boost docking capacity.

This paper emphasises how crucial port efficiency and growth are to European ports' ability to compete in the face of increasing international traffic. Achieving greater efficiency levels requires strategic investments in technology, infrastructure, and operational management—especially for ports with lower container volume. According to our research, increasing port efficiency has a favourable economic impact on a number of industries, in addition to enhancing port performance on its own.

Notwithstanding these revelations, the study has some drawbacks, including its dependence on a small number of inputs and outputs and its omission of other factors, such as labour efficiency and environmental sustainability. By examining the effects of automation, digitisation, and external shocks and broadening the sample to cover a wider variety of ports, future studies could fill up these gaps (Koengkan et al., 2022).

Therefore the study recommends that strategic expenditures be given top priority in European ports in order to improve operational efficiency, particularly through technological advancements and infrastructure improvements. European ports may increase their competitiveness and promote more economic growth by tackling the causes of inefficiency and implementing best practices.

### 4.2. Estimating the inefficiency of European ports

As a second step in our study, we present an estimate of the inefficiency of the thirty (30) European hubs, using a series of variables presented in the DEA section as CRS_TE, VRS_TE and NIRS_TE. Thus, the competitiveness of ports, the variable (HHI), presents the level assessment of concentration on the market by measuring the concentration, and here we use the Herfindahl-Hirschman index, as macroeconomic variables economic growth (GDPC), as well as the distribution of Hubs, diversification, Tiranteau, rank, and class of ports.

As a first step, we present the main descriptive statistics of the different variables of the predefined variables in Table 4. Indeed, after viewing the data presented in Table 4, we can see that most of them are asymmetrical and have different shapes, but have produced a clear normality.

From the diagnosis in Table 4, our example of the COMPETITIVENESS variable shows an overall mean of 0.604 with a low standard deviation of 0.203, demonstrating the low heterogeneity of the observations. The 450 observations are bounded between 1.00e-06 (LAS PALMAS Port) and 1 (BREME Port), with a high concentration around 0.625. The sampling distribution is slightly non-symmetrical to the left (Skewness=-0.381<0) and leptokurtic (Kurtosis=2.408>0). Overall, this variable accepts the normality hypothesis, since the probability of the Jarque-Bera statistic is greater than 5%.

| Designations | COMP | IHH | POP | GDPC | HUBDIS | DIVER | TIRANTEAU | RANGE | CLASS |
|---|---|---|---|---|---|---|---|---|---|
| **Average** | 0.604 | 0.095 | 1.25e+07 | 0.916 | 621.546 | 0.733 | 17.283 | 1.466 | 2.133 |
| **Standard deviation** | 0.203 | 0.037 | 1.89e+07 | 1.396 | 641.534 | 0.442 | 2.588 | 0.499 | 0.922 |
| **Maximum** | 1 | 0.18 | 6.07e+07 | 8.870 | 2467 | 1 | 24 | 2 | 4 |
| **Minimum** | 1.00e-06 | 0.03 | 10750 | 0.001 | 74.4 | 0 | 13.7 | 1 | 1 |
| **Median** | 0.625 | 0.086 | 920075.5 | 0.269 | 293 | 1 | 16.5 | 1 | 2 |
| **Coefficient of Variation** | 0.336 | 0.388 | 1.511 | 1.524 | 1.032 | 0.603 | 0.149 | 0.340 | 0.432 |
| **Skewness** | -0.381 | 0.032 | 1.301 | 3.073 | 1.266 | -1.055 | 0.913 | 0.133 | 0.500 |
| **Kurtosis** | 2.408 | 1.752 | 3.162 | 15.131 | 3.663 | 2.113 | 3.002 | 1.017 | 2.452 |
| **Jarque-Bera (JB)** | 17.48 | 29.28 | 127.5 | 3468 | 128.5 | 98.25 | 62.61 | 75.01 | 24.41 |
| **JB Probability** | 1.6e-04 | 4.4e-07 | 2.1e-28 | 0.000 | 1.3e-28 | 4.6e-22 | 2.5e-14 | 5.2e-17 | 5.0e-06 |
| **Born et Breitung (BB)** | 38.74 | 85.90 | 53.17 | 11.65 | 0.000 | 0.000 | 1.84 | 0.000 | 0.000 |
| **BB probability** | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.399 | 1.000 | 1.000 |

Table 4. Summary of key descriptive statistics for variables

Panel data offer a dual advantage, capturing both the heterogeneity of individuals and behavioural dynamics over time. Additionally, the use of a substantial sample size enhances the precision of parameter estimates, approaching the true values. Recent advancements in panel data econometrics, particularly in unit root, causality, and cointegration tests, are of special interest in this section.

| Variables | Ineff_CRS_TE | Ineff_VRS_TE | Ineff_NIRSTE | COMP | IHH | LnPOP |
|---|---|---|---|---|---|---|
| In Level | | | | | | |
| First generation | | | | | | |
| LLC (1992) | 3.968*** | 9.090** | 5.419*** | 0.046 | 1.716** | 1.353*** |
| IPS (2004) | 6.508*** | - | 8.322*** | 1.336 | 4.993*** | 4.868*** |
| Breitung (2000) | 3.579*** | 1.173*** | 3.297*** | -1.995 | -0.582 | -0.086** |
| Hadri (2000) | 17.401** | 24.405 | 22.665 | 19.308 | 28.151 | 32.014 |
| Second-generation | | | | | | |
| Pesaran (2003) | | | | | | |
| Constant | 2.762** | 13.133*** | 3.934*** | -1.934 | 6.235*** | -1.819** |
| Constant & Trend | 0.277** | 12.079*** | 2.101 | -2.460 | 11.022* | -2.999** |
| Pesaran (2007) | | | | | | |
| Constant | -1.301 | 1.016* | -1.185 | -3.420* | -0.976 | -3.663* |
| Constant & Trend | -2.282 | 0.242* | -2.143* | -3.660 | -1.093 | -5.019* |
| Maddala and Wu (1999) | | | | | | |
| Constant | 118.954 | 13.251 | 66.290 | 15.949 | 332.891 | 11.343 |
| Constant & Trend | 91.094 | 23.082 | 52.353 | 28.601 | 126.444 | 78.358 |
| Pesaran (2007) | | | | | | |
| Constant | 21.560 | 19.861 | 21.560 | 21.560 | 21.560 | 21.560 |
| Constant & Trend | 19.366 | 19.366 | 19.366 | 19.366 | 19.366 | 19.366 |
| Decision | NS | NS | NS | NS | NS | NS |
| In First Difference | | | | | | |
| First-generation | | | | | | |
| LLC (1992) | -4.517 | 7.566*** | -1.954*** | -9.582 | -7.945 | -8.228 |
| IPS (2004) | -6.211 | - | -4.627 | -9.378 | -8.715 | -9.071 |
| Breitung (2000) | -9.524 | -6.229 | -8.883 | -7.297 | -13.451 | -10.968 |
| Hadri (2000) | 10.925 | 3.829 | 6.560 | 0.122 | -0.889 | -1.989** |
| Second-generation | | | | | | |
| Pesaran (2003) | | | | | | |
| Constant | -2.360 | 11.564*** | -1.327 | -8.362 | 6.218 | -10.246 |
| Constant & Trend | 0.431* | 11.650*** | 1.559 | -4.320 | 1.495 | -7.718 |
| Maddala and Wu (1999) | | | | | | |
| Constant | 118.954 | 13.251 | 66.290 | 15.949 | 332.891 | 11.343 |
| Constant & Trend | 91.094 | 23.082 | 52.353 | 28.601 | 126.444 | 78.358 |
| Pesaran (2007) | | | | | | |
| Constant | -3.115 | 0.152* | -3.004 | -4.395 | -2.854 | -5.805* |
| Constant & Trend | -3.138* | -0.230* | -3.027* | -4.015 | -4.289 | -5.944 |
| Decision | S | S | S | S | S | S |
| **Variables** | **LnGDPC** | **HUBDIS** | **DIVER** | **TIRANTEAU** | **RANGE** | **CLASS** |
| In Level | | | | | | |
| First-generation | | | | | | |
| LLC (1992) | 0.461*** | - | - | 11.002*** | - | - |
| IPS (2004) | 3.567*** | - | - | - | - | - |
| Breitung (2000) | -0.603*** | - | - | 0.185 | - | - |
| Hadri (2000) | 31.912** | - | - | 34.242 | - | - |
| Second-generation | | | | | | |
| Pesaran (2003) | | | | | | |
| Constant | -10.663** | 21.560*** | 21.560*** | 19.097 | 21.560*** | 21.560** |
| Constant & Trend | -9.851** | 19.366*** | 19.366 | 17.645 | 19.366* | 19.366** |
| Pesaran (2007) | | | | | | |
| Constant | -4.032* | 2.610* | 2.610* | 2.152* | 2.610* | 2.610* |
| Constant & Trend | -4.706* | 1.700* | 1.700* | 1.361* | 1.700* | 1.700* |
| Maddala and Wu (1999) | | | | | | |
| Constant | 21.275 | 0.000 | 0.000 | 2.306 | 0.000 | 0.000 |
| Constant & Trend | 28.351 | 0.000 | 0.000 | 0.691 | 0.000 | 0.000 |
| Pesaran (2007) | | | | | | |
| Constant | 21.560 | 21.560 | 21.560 | 21.560 | 21.560 | 21.560 |
| Constant & Trend | 19.366 | 19.366 | 19.366 | 19.366 | 19.366 | 19.366 |
| Decision | NS | NS | NS | NS | NS | NS |

| | | | | | | |
|---|---|---|---|---|---|---|
| **In First Difference** | | | | | | |
| **Première generation** | | | | | | |
| **LLC (1992)** | -6.837 | - | - | 21.918** | - | - |
| **IPS (2004)** | -9.456 | - | - | - | - | - |
| **Breitung (2000)** | -12.417 | - | - | -4.242 | - | - |
| **Hadri (2000)** | -2.816** | - | - | -0.889** | - | - |
| **Second-generation** | | | | | | |
| **Pesaran (2003)** | | | | | | |
| **Constant** | -12.990 | 21.560 | 21.560 | 19.354*** | 21.560 | 21.560 |
| **Constant & Trend** | -11.001 | 19.366 | 19.366 | 17.725*** | 19.366 | 19.366 |
| **Maddala and Wu (1999)** | | | | | | |
| **Constant** | 21.275 | 0.000 | 0.000 | 2.306 | 0.000 | 0.000 |
| **Constant & Trend** | 28.351 | 0.000 | 0.000 | 0.691 | 0.000 | 0.000 |
| **Pesaran (2007)** | | | | | | |
| **Constant** | -5.041* | 2.610* | 2.610* | 2.042* | 2.610* | 2.610* |
| **Constant & Trend** | -5.379* | 1.700* | 1.700* | 1.240* | 1.700* | 1.700* |
| **Decision** | **S** | **S** | **S** | **S** | **S** | **S** |

Notes : *, **, *** significant at 10%, 5%, 1%. NS denotes non-stationary; S denotes stationary.

Table 5. Unit root tests

One central aspect in panel unit root testing is the consideration of heterogeneity in the model employed for the unit root test. The simplest form of heterogeneity involves introducing constants specific to each individual. This model, incorporating individual effects (specified either as fixed or random), primarily captures heterogeneity in the mean level while maintaining the assumption of homogeneity in other model parameters, particularly the autoregressive root. Levin and Lin (1992) initially utilised this modelling approach in their unit root tests. However, this notion of heterogeneity, confined to individual effects or deterministic trends, was soon deemed inadequate in macroeconomic applications.

Nevertheless, considering the diverse issues noted in the various series, it is logical to explore a dynamic relationship between the different variables. To address this, we have conducted unit root tests using the LLS, IPS, and Hadri tests for both levels and first differences, as outlined in Table 5.

Table 5 indicates that all tests for unit roots were unsuccessful. Evidently, the Maddala and Wu (1999) and Pesaran (2007) tests are particularly pertinent, revealing the presence of unit roots in all series at the level (thus rejecting H0). Conversely, the same series accept the hypothesis of stationarity in first-order differences. Therefore we can conclude that all series can be considered integrated of the 1st order (I(1)).

With reference to Table 6 below, in panel data studies, it appears necessary to ensure the homogeneous or heterogeneous specification of the data-generating process, (Doucouré, 2008). With reference to Table 6 below, from the null probability of the Breusch-Pagan serial autocorrelation statistics, it is clear that the inefficiency model shows strong serial autocorrelation along the study period between 2005 and 2019. Likewise, Bhargava, A., Franzini, L., and Narendranathan's test indicates the existence of first-order autocorrelation through the Durbin-Watson test on panel data, providing additional support for employing a dynamic model.

| Tests | Chi-2 | Probability |
|---|---|---|
| **Wald Test for heteroscedacticity** | 1549.455 | 0.000 |
| **Breusch-Pagan Test for autcorrelation** | 81479.09 | 0.000 |

Table 6. Serial autocorrelation and heteroscedasticity tests

Similarly, the null probability of the Wald statistics to test for the presence of a heteroscedasticity problem, shows that the latter cannot be rejected, leading us to accept the heteroscedasticity problem. Thus, our panel of thirty (30) European hub ports is highly heterogeneous.

Given that most variables exhibit stationarity in the first difference, it is crucial to explore the possibility of cointegration among them. To achieve this, we have employed three tests: Kao ADF (1999), Pedroni ADF (2004), and Westerlund (2007) in this subsection.

Table 7 presents the primary statistical outcomes of the cointegration test. All these tests affirm the existence of at least one cointegrating relationship among the various variables in the growth model, constituting the fundamental framework of our study, except for the Pedroni test. Therefore, at a 5% significance level, the various statistics lead to the rejection of the null hypothesis of non-cointegration.

| Tests | t-Statistic | Probability |
|---|---|---|
| **Kao** | 5.8872 | 0.000 |
| **Westerlund** | 41.338 | 0.066 |
| **Pedroni** | **Panel** | **Group** |
| **v** | -1.135 | - |
| **rho** | 5.582 | 7.741 |
| **t** | -3.841 | -4.766 |
| **adf** | -2.85 | -2.4 |

Table 7. Cointegration tests

Based on this descriptive diagnosis and the integration of various variables in our model, we have derived significant findings regarding variable instability and pronounced heterogeneity and interdependence among the thirty (30) European Hub ports in our study.

We will now try to develop the dependency analysis between the variables in our study. Table 8 shows the main statistical results of the Pesaran (2006) dependency test.

| Tests | t-Statistic | Probability |
|---|---|---|
| **Pesaran (2006)** | 13.095 | 0.000 |
| **Friedman (1937)** | 64.420 | 0.000 |
| **Frees (2004)** | 5.678 | 0.478 |

Table 8. Dependency tests

All these tests confirm that the thirty (30) European Hub ports are not independent: there is a strong relationship between them.

| | Ineff_CRS_TE | | Ineff_VRS_TE | | Ineff_NIRS_TE | |
|---|---|---|---|---|---|---|
| **Variables** | **Coefficient** | **p-value** | **Coefficient** | **p-value** | **Coefficient** | **p-value** |
| **Ineff_CRS_TE $_{it-1}$** | 0.827 | 0.000 | ***** | ***** | ***** | ***** |
| **Ineff_VRS_TE $_{it-1}$** | ***** | ***** | 0.961 | 0.000 | ***** | ***** |
| **Ineff_NIRS_TE $_{it-1}$** | ***** | ***** | ***** | ***** | 1.083 | 0.000 |
| | | | | | | |
| **COMPETITIVITE$_{it}$** | -0.014 | 0.000 | 0.321 | 0.000 | -0.049 | 0.082 |
| **HHI$_{it}$** | 0.205 | 0.001 | -1.68 | 0.001 | -0.018 | 0.949 |
| **LnPOPULATION$_{it}$** | 0.001 | 0.026 | -0.004 | 0.029 | -0.006 | 0.010 |
| **LnGDPC$_{it}$** | 0.001 | 0.078 | -0.001 | 0.986 | -0.004 | 0.053 |
| **HUBDIS$_{it}$** | -0.001 | 0.282 | -0.001 | 0.003 | 0.000 | 0.091 |
| **DIVERSIFICATION$_{it}$** | -0.064 | 0.938 | -0.006 | 0.930 | -0.002 | 0.953 |
| **TIRANTEAU$_{it}$** | 0.013 | 0.000 | 0.007 | 0.097 | 0.011 | 0.094 |
| **RANGE$_{it}$** | 0.074 | 0.008 | 0.176 | 0.052 | -0.056 | 0.068 |
| **CLASS$_{it}$** | 0.012 | 0.085 | -0.035 | 0.027 | -0.009 | 0.045 |
| **Constant** | -0.098 | 0.003 | -0.182 | 0.679 | 0.065 | 0.862 |
| | | | | | | |
| **Arellano-Bond test for AR(1)** | -1.73 | 0.083 | -1.66 | 0.096 | -1.95 | 0.051 |
| **Arellano-Bond test for AR(2)** | -0.12 | 0.907 | 1.19 | 0.235 | 1.14 | 0.252 |
| **Hansen Test** | 8.17 | 0.772 | 12.29 | 0.422 | 13.70 | 0.320 |

Table 9. Dynamic two-stage GMM-system estimation

In order to estimate the origins of inefficiency in the 30 European Hub ports, we consider the three models represented by the three dependent variables Ineff_CRS_TE, Ineff_VRS_TE and Ineff_NIRS_TE in relation to the other macroeconomic variables. The results report the regression of the model with the variables, estimated separately to limit difficulties due to the problem of multi-colinearity. The inclusion in the model of one or more lagged values of the endogenous variable is necessary, as this is a dynamic model of the autoregressive type. Introducing the lag allows us to check whether poverty in one year is influenced by poverty in previous years. Table 9 shows the results of these estimates of our Ineff_CRS_TE model, using the GMM dynamic panel system.

With regard to this method (GMM system), Arrellano and Bond's (1992) first-difference and second-difference autocorrelation tests for residuals and Hansen's over-identification test, shown in the third panel of Table 9, provide important information. As can be seen, Arrellano's serial autocorrelation test of the residuals and Bond's first-difference test validate the GMM specification of the models, hence the absence of second-order autocorrelation. Hansen's test statistics validate the choice of instruments, enabling us to affirm that the instruments used are significant and valid. The GMM system model can then be used to analyse the relationship between the three dependent variables (Ineff_CRS_TE, Ineff_VRS_TE and Ineff_NIRS_TE) with the other model variables for the case of thirty European HUB ports in our study between 2005 and 2019.

Overall, the estimation results show that the effects of our explanatory variables are in line with theoretical predictions. The coefficient of lagged Ineff_CRS_TE is positive (and statistically significant). Similarly, we find a positive and significant effect of IHH, TIRANTEAU, RANG and CLASS on the Ineff_CRS_TE, but a negative sign of the term HUBDIS and DIVERSIFICATION, thus highlighting the existence of a complementarity effect between the port quality proxy and inefficiency. However, in Table 9 we find a non-significant effect of two macroeconomic variables: population and economic growth. This implies that the relationship between Ineff_CRS_TE and the other variables in the model is not linear. According to the results, it can be argued that an increase of 1% in the HHI variable, for example, increases Ineff_CRS_TE by 0.205% in the GMM. Controlling for endogeneity problems, in the case of the GMM estimator, increases the effect of Ineff_CRS_TE on the other variables in the model at the level of European HUB port output.

Moving on to the second Ineff_VRS_TE model, we present the results of these estimates of our Ineff_VRS_TE model by the GMM dynamic panel system in the second part of Table 9. The lagged Ineff_VRS_TE coefficient is positive (and statistically significant). Similarly, we find a negative and significant effect of IHH, POPULATION, HUBDIS and CLASS on the Ineff_VRS_TE, but a positive and significant sign of the TIRANTEAU and RANG terms, thus highlighting the existence of a complementarity effect between the port quality proxy and inefficiency. However, as shown in Table 9, we find a non-significant effect of two macroeconomic variables, namely Diversification and economic growth. This implies that the relationship between Ineff_VRS_TE and the other variables in the model is not linear. According to the results, it can be argued that an increase in the HUBDIS variable of 1%, for example, decreases Ineff_VRS_TE by 0.001% in the GMM. Controlling for endogeneity problems, in the case of the GMM estimator, increases the effect of Ineff_VRS_TE on the other variables in the model at the level of European HUB port output.

Our last independent variable Ineff_NIRS_TE is presented in the third part of Table 9. The results of these estimates of our Ineff_NIRS_TE model by the GMM dynamic panel system show a positive and significant effect of the latter. Similarly, we find a negative and significant effect on the majority of the variables in our model, with the exception of the HUBDIS variable, which has a positive and significant effect at 10% on Ineff_NIRS_TE. This implies that the relationship between Ineff_NIRS_TE and the other variables in the model is non-linear. According to the results, it can be argued that an increase of 1% in the variable COMPETITIVITY, for example, decreases Ineff_NIRS_TE by 0.049% in the GMM. Controlling for endogeneity problems, in the case of the GMM estimator, increases the effect of Ineff_NIRS_TE on the other variables in the model at the output level of European HUB ports.

### 4.3. Discussion of results

These outcomes align with the conclusions drawn in various related studies.

It is therefore appropriate to examine the current dynamics of European maritime hub activity worldwide, firstly by describing how it is configured to achieve a high level of efficiency. The second part will look at competition and port governance, highlighting some of the criteria that shipowners may consider when choosing a port (Hub), and examining the strategic responsibilities of port authorities, both in terms of the conditions under which a port may decide to enter the transaction market to avoid inefficiency, and in terms of its competitiveness and possible comparative advantages. Lastly, the geography of trade flows will be analysed, i.e. connections at different scales, exploring in particular the current structure of maritime transport, then the various markets, their rise or decline, as well as emerging regional markets (Kavirathna et al., 2018).

Ports are an integral part of the economy of a state or region, and are essential cogs in global trade and supply chains (Pallis, 2022). The same is true of transshipment hubs, which generate traffic and capital, occupy a part of the territory, involve numerous players and generate both positive and negative externalities (Pallis, 2022). As a result, the port sector is adapting to trends in the global economy, with port authorities adopting strategic and competitive orientations in order to establish themselves in the international environment (Gonzalez Laxe, 2008; Pallis, 2022). Pallis (2022) defines port governance as "the adoption and application of rules governing the conduct and exercise of institutional authority and resources to develop and manage port activities for the benefit of society and the economy".

To this list could be added the consideration of environmental issues and port procedures in harmony with the main principles of sustainable development, enhancing the reputation and attractiveness of a hub in an era of greater ecological awareness (Notteboom and Pallis, 2022; Cheng and Tsai, 2009). Similarly, historical, psychological, political, and personal factors can all play a part in shipowners' decision-making criteria, making such analysis all the more complex for port authorities seeking to increase their market share (Notteboom, 2022a). In fact, a simple drop in handling costs does not automatically mean the influx or movement of large quantities of freight to a hub, since other criteria also come into play. Similarly, actors have limited rationality and opportunistic behaviour, meaning that just because a destination seems optimal does not mean it will automatically be selected (Notteboom, 2022a). Among other things, this may explain the vulnerability of transshipment activities in a port, the emergence of certain players, and the decline of their opponents.

A notable surge in maritime trade has been observed along the trade route connecting Europe to the Far East. This upswing is attributed to the economic growth in the Far East and the relocation of production processes to these nations, fostering increased trade flows between China, South Korea, or Japan and Europe (Ewell et al., 2017; Kantere Christoforidou, 2019). Due to the unique geography of the region, several hubs provide interline or relay services to larger hub-and-spoke hubs in northern Europe (Notteboom, Parola and Satta, 2019). Notably, the Spanish port of Algeciras and its Moroccan counterpart, Tanger-Med, exemplify this trend (Notteboom, Parola and Satta, 2019; Valentine 2020). Additionally, Alix, Montier and Faury (2020) have underscored the emergence of new port hierarchies in the Mediterranean, influenced by the evolving realities brought about by the COVID-19 pandemic.

As far as European hub ports are concerned, it has been possible to move up the international rankings in recent years thanks to various physical and human capital development measures, as well as to the various partnerships entered into with companies specialising in this field. However, a port needs to adapt its port strategies in order to withstand the fierce competition from other seaports in the Mediterranean basin, and improve its governance so that it is able to meet the demands of port customers. European hub ports must also focus their efforts on increasing maritime connectivity with other international ports and with their port hinterlands, gradually digitising port operations, modernising port infrastructure and developing a decision-making centre capable of reaching decisions leading to the optimisation of port operations in order to achieve high efficiency scores and reduce inefficiency.

## 5. CONCLUSION AND POLICY IMPLICATIONS

In conclusion, this article has sought to evaluate the port efficiency of European Hub ports through a non-parametric data envelopment analysis (DEA) approach, leveraging various port operating variables. The empirical findings from this analysis reveal that several European hub ports exhibit higher efficiency compared to other maritime hubs considered in the study. Consequently, it is inferred that the efficiency score is contingent on a range of logistical, economic, political, technological, and social criteria.

This article emphasises that in order to meet growing demands, European ports—especially those that handle significant international traffic—must consistently invest in operational efficiency. The results show that strategic port growth is essential to port success, especially when it comes to expenditures in technology, infrastructure, and efficient logistics. Increased operational efficiency at ports has a major positive impact on both regional and national economic growth, especially in areas with reduced container traffic. These ports stimulate other economic sectors, including manufacturing, trade, and services, producing beneficial knock-on effects that go beyond the port itself.

The study also emphasises the significance of resolving inefficiencies in ports with lower container throughput, even though the results show that port growth is essential to enhancing operational performance. Even ports with little traffic can be important economic centres by encouraging more extensive economic growth in the communities around them.

Specifically, these criteria may relate to market accessibility, the abundance of production factors, the development of commercial relations with the various organisations that tend to integrate the port logistics chain, the implementation of a high-performance port information system, and the establishment of a human capital development policy.

Empty container" status is the result of imbalances in the distribution of world trade on the main shipping routes. Poor management of these containers can affect not only terminal efficiency, but also that of the entire transport logistics chain. In this respect, it would be interesting to examine the question of port efficiency in Europe based on empty container repositioning solutions, and then explore the impact this has on the land and sea transport network.

This conclusion was deduced from the result of the impact of hinterland accessibility on the throughput of peripheral ports. Unlike those geographically close to the main inland markets, peripheral regions have a lower market potential. Nevertheless, access to the hinterland from their ports has a very significant impact on their throughput. They benefit from an uncompetitive, niche market. These areas offer considerable potential for port development.

Policy-makers in Europe's Hub ports need to consider that improving maritime connectivity, hinterland accessibility, and port competitiveness are interdependent. Certainly, access to the hinterland and integration into the global transport network are largely influenced by shipping line strategies. However, national policies could circumvent this constraint by taking action to improve port growth through hinterland access. Improving maritime access can, wherever possible, be achieved through internal management strategies aimed at reducing port waiting times, or through policies designed to improve the business environment in the country in question. In this respect, sea transport is essential as the main medium for world trade.

A more thorough understanding of the dynamics that contribute towards port efficiency across various scales could be obtained by future research that expands the sample to include a wider range of ports, especially smaller ports and those outside major HUBs. Other factors that could be included in future studies include labour efficiency, automation and digitalisation in port operations, and environmental sustainability practices.

Future studies should look into how external shocks affect port operations and efficiency and whether some development models are more resilient to such difficulties, given the worldwide disruptions brought on by the COVID-19 pandemic and other geopolitical variables. Insights into international best practices and additional guidance for improving operational efficiency in European ports could be obtained by broadening the analysis to include comparisons between European ports and ports in other regions, such as Asia or the Americas. Understanding the changing function of European ports would benefit from research using more recent data, especially in light of continuous technical improvements and changing patterns of international trade.

## GLOSSARY OF ABBREVIATIONS

CRS: Constant Returns to Scale

DEA: Data Envelopment Analysis

FDH: Free Disposal Hull

GMM: Generalised Method of Moments

MCA: Multicriteria Additive Analysis

MFI : Microfinance Institutions

PCA : Principal Component Analysis

SFD: Performances of Decentralised Financial Systems

VRS: Variable Returns to Scale

## CONFLICT OF INTEREST

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