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DETERMINANTS OF SEAPORT PRODUCTION: ANALYSIS OF EU PORT REGIONS

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ABSTRACT

Seaports play an important role in the global economy, serving as international hubs for the transportation of goods, trade, economic growth, job creation, and strategic interests. Their continuous development and modernization are critical to supporting economic growth and addressing new challenges in the maritime industry. Adequate economic performance can contribute to efficient seaport production. The aim of this research is to analyse the impact of economic, human capital, and infrastructural factors influencing seaport production on a sample of 86 European Union (EU) port regions observed from 2009 to 2019. The Pooled Ordinary Least Squares (POLS), Fixed Effects (FE), and Random Effects (RE) estimation techniques were used as the estimation strategy. The results confirm that all three groups of factors have a significant impact on seaport production. Firstly, GDP per capita, which is the economic factor, shows a significant positive effect. Secondly, within the human capital category, education and innovation capacity prove to be important factors for the seaports' performance. Finally, the motorways' length, as an indicator of infrastructure, significantly impacts seaport production. Based on these findings, the policies that promote economic growth, stimulate consumption, and support international trade are recommended. In addition, policies that promote digitalization and innovative technologies in seaport operations, strengthen workforce development, foster collaboration with educational institutions, and enhance multimodal connectivity are encouraged.

1. INTRODUCTION

Seaports serve as connecting hubs in international trade, enabling the exchange of goods between countries and supporting global supply chains. They support and facilitate global trade, connect different modes of transportation, promote economic integration, and contribute to regional economic development. Seaport performance and trade facilitation are essential for efficient maritime transport and seamless supply chains, both in seaports and in their connections to inland areas (UNCTAD, 2022, 2023).

Numerous researchers have analysed the impact of seaports on economic growth and the benefits that seaports bring to their economies, including the increase in GDP in the areas where they are located (Ayesu et al., 2023; Bottasso et al., 2014; Fratila et al., 2021; Mudronja et al., 2020; Özer et al., 2021; Shan et al., 2014), the promotion of direct employment through seaport operations and indirect employment through related industries (Ayesu & Boateng, 2024; Bottasso et al., 2013; Hidalgo-Gallego & Núñez-Sánchez, 2023; Seo & Park, 2017), trade enhancement (Ayesu et al., 2022; Mlambo, 2021), and the creation of other port-related activities (Ferrari et al., 2010). The economic importance of seaports extends far beyond the seaport regions and can have spillover effects on neighbouring regions (Bottasso et al., 2014). Moreover, seaports influence the growth of their regional economies, and the growth of regional economies affects the development of seaports. Given that seaports positively affect local economies, understanding what drives their success is essential. Identifying these factors can help improve seaport performance, leading to additional beneficial outcomes.

While seaports' impact on economic growth is well-studied, few researchers have explored how regional economies affect seaport productivity. Given the seaports' complex structure, appropriate economic performance can support their development and adaptability to changing business conditions (Huang et al., 2022). Various variables, including logistics performance, trade statistics, infrastructure quality, operational expenses, GDP *per capita*, population statistics, etc., have been used to study seaport performance (Bocheński et al., 2021; Caldas et al., 2024; Mahpour et al., 2023; Munim & Schramm, 2018; Xing, 2021). However, the empirical literature lacks a thorough examination of regional factors influencing seaport production.

Recent policies on seaport production in port regions have largely focused on sustainability, energy transition, and boosting competitiveness through innovation and infrastructure development (ESPO, 2023; European Sea Ports Organisation (ESPO), 2023), which led this study into researching the impacts of innovations and infrastructure development on seaport production, among other factors. The European Sea Ports Organisation (ESPO) noted that seaports are becoming both trade hubs and centres for sustainable energy and innovation, with an €80 billion investment needed for decarbonization and seaport infrastructure modernization over the next decade (ESPO & De Langen, 2024). Smart Port initiatives in the European Union (EU) aim to enhance seaports' efficiency, sustainability, and competitiveness through digital technology, automation, and data-driven solutions. These initiatives are part of broader efforts to modernize maritime infrastructure and align with the EU's sustainability and digital transformation goals, using technologies such as the Internet of Things (IoT), artificial intelligence (AI), self-driving vehicles, robotics, blockchain technology, and Port Community System (PCS) (European Sea Ports Organisation (ESPO) & De Langen, 2024). The above provides a basis for researching the impact of innovation capacity and educational achievements on seaport production.

Only a study by Cheung and Yip (2011) examines port cities' effects on seaport production in China, but no empirical studies exist on regional factors affecting EU seaports, to the best of our knowledge. This paper is the first to analyse how regional factors impact seaport production in EU port regions, examining variables like GDP per capita, population change, employment, education, innovation capacity, and infrastructure. Understanding what drives seaport production helps policymakers and seaport managers to optimize resource allocation and develop strategies aimed at improving seaport production in the EU, particularly for seaports with lower freight turnover that are aiming to expand and grow their operations.

The aim of this research is to analyse the impact of economic, human capital, and infrastructural factors influencing seaport production. This paper proposed a model for determining the impact of port regions on seaport production, offering better insight into its key determinants. The remainder of the paper is organized as follows: Section 2 reviews the literature, Section 3 describes the methodology, Section 4 presents results and discussion, and Section 5 gives concluding remarks.

2. LITERATURE REVIEW

This section provides an overview of the theoretical and empirical literature relevant to the research. The theoretical review examines key concepts and frameworks offering a foundation for understanding the influence of regional factors on seaport production. The empirical review focuses on previous studies analysing findings from existing research.

2.1. Theoretical review

Several economic theories support the analysis of factors influencing seaport production, including production function theory, New Economic Geography, the balanced theory of port competitiveness, and cluster theory (de Langen, 2004; Ducruet et al., 2009; Hales et al., 2016). The New Economic Geography proposed by Krugman (1991) explains how and why economic activities are spatially concentrated in particular regions, with agglomeration forces such as economies of scale, transport costs, and market size playing a key role. The theory shows how the reduction of transport costs and labour mobility can lead to uneven development, with initially favourable locations becoming increasingly attractive and the periphery falling behind. A balance is sought between forces favouring concentration (e.g. proximity of buyers and suppliers) and forces favouring dispersion (e.g. higher cost of living and competition). The theory has important applications in regional policy and in understanding urban and industrial clusters. Although the New Economic Geography provides valuable insights into the spatial concentration of economic activity and the role of infrastructure in regional development, it is not directly applicable as a theoretical basis for this study. The present analysis focuses on quantifying the impact of selected input factors on seaport production and not on modelling spatial agglomeration or location decisions.

The balanced theory of port competitiveness provides insights into a model that jointly considers the influence of customers and investors on seaport competitiveness (Hales et al., 2016). The theory comprises ten key factors: five that influence volume-related competitiveness (e.g. location, service, port fees) and five that influence investment-related competitiveness (e.g. reputation, finance, institutional framework). The focus is on the balance of these aspects, as an excessive focus on one aspect can have a negative impact on the others. The aim is to help seaports make better strategic decisions in a global environment. Although the balanced theory of port competitiveness provides useful insights into seaport management behaviour, it is not a suitable theoretical framework for analysing the determinants of seaport production at the level of EU regions due to its micro-focus and dependence on qualitative assessments. Firstly, the theory focuses on the micro level of individual seaport management, whereas the present study focuses on the macro level. Secondly, the theory uses subjective indicators derived from the perception of stakeholders (e.g. seaport managers), while the present study uses a quantitative analysis with objective, regional indicators.

Cluster theory (Porter, 1998) provides a conceptual framework for understanding the geographic concentration of interconnected companies, institutions, and infrastructures that together increase regional productivity and innovation. Clusters provide easier access to skilled labour, knowledge, innovation, and shared infrastructure, which increases efficiency and productivity. They also promote entrepreneurship, faster diffusion of technologies, and increase the ability of regions to attract investment. Cluster theory has important applications in regional development and industrial strategies, as it assumes that success depends not only on individual companies but also on the quality of the local economic ecosystem. In the context of seaports, this theory has been applied to analyse the role of seaports within broader industrial or logistics clusters. However, due to its qualitative orientation and emphasis on institutional and relational dynamics, cluster theory is not directly applicable to this research. The empirical focus of this research is on the quantifiable effects of economic, human capital, and infrastructural inputs on seaport production, for which a production function approach is more appropriate.

Considering that the production function theory explains the relationship between the inputs used in production and the resulting output, it provides the most suitable framework for determining the factors influencing seaport production. Moreover, it represents how resources, such as labour, capital, land, and technology, combine to produce goods or services (Cobb & Douglas, 1928). The Cobb-Douglas production function has been extensively used to study seaport operations and their economic effects. Researchers have used this theory to estimate the role of seaports in economic growth (Jouili, 2016), measure seaport production overcapacity (Li et al., 2019), and evaluate the influence of port cities on seaport production (Cheung & Yip, 2011). The advantages of the Cobb-Douglas production function are visible through its capacity to manage multiple inputs, address market imperfections, and facilitate computations (Bhanumurthy, 2002). It presumes a certain level of interchangeability between inputs, which makes it an effective tool for analysing the interactions between various inputs influencing seaport production and assessing how a change in one input impacts overall seaport production, when other inputs remain constant or experience a decrease. Since the Cobb-Douglas production function allows for multiple inputs in the production process, it is suitable for determining the factors that influence seaport production, and it can be expanded to encompass a variety of factors, including economic, human capital, and infrastructural factors.

2.2. Empirical review

A considerable amount of research has been devoted to examining the impact of seaports on economic growth; the emerging benefits are a reduction in transportation costs (Crescenzi & Rodríguez-Pose, 2012), an increase in GDP (Ayesu et al., 2023; Bottasso et al., 2014; Fratila et al., 2021; Mudronja et al., 2020; Özer et al., 2021; Shan et al., 2014), more employment (Ayesu & Boateng, 2024; Bottasso et al., 2013; Ferrari et al., 2010; Hidalgo-Gallego & Núñez-Sánchez, 2023; Seo & Park, 2017), the boosting of private investments and the promotion of trade (Ayesu et al., 2022; Bottasso et al., 2014; Mlambo, 2021), the attraction of other port-related activities (Ferrari et al., 2010) and the improvement of logistics (Notteboom & Winkelmans, 2001). Empirical studies researching the regional factors that influence the production and growth of seaports are seldom, to the best of our knowledge.

Cheung and Yip (2011) researched how port cities impact seaport production, considering port cities as production organizations, city factors as inputs (economic, demographic, and infrastructural), and seaport production as output. They found that economic factors are the largest contributors to seaport growth, but the effects of infrastructural and demographic factors remain unclear, possibly due to the variables used. The classification of city factors into economic, demographic, and infrastructural categories offers a clear study framework. However, limited results for infrastructure and demographics may be due to the variables used (e.g. fixed asset investment for infrastructure, population, and employment for demographics). Focusing on port cities rather than larger entities such as port regions may also narrow the research's scope, missing broader interdependencies and spillover effects that are more apparent in regional analysis.

Caldas et al. (2024) found that higher GDP *per capita* negatively affects seaport performance, while lower GDP correlates with better performance. Munim and Schramm (2018) similarly found that seaport infrastructure enhances trade and economic growth in developing countries but has less impact as countries become wealthier. This paper challenges the above conclusions and assumes GDP *per capita* positively impacts seaport operations for developing regions and wealthier regions since GDP *per capita* reflects a region's general economic well-being, leading to increased trade activity and demand for seaport services.

UNCTAD (2023) highlights that digital solutions and interoperability significantly impact seaport performance. Technologies like data exchange and AI improve efficiency, benefiting global supply chains and streamlining government regulatory processes, leading to enhanced trade efficiency. Agatić and Kolanović (2020) found that digital technologies enhance seaport services by improving reliability, flexibility, security, digital-based infrastructure and superstructure, and digital skills, making them more competitive. Similarly, Adabere et al. (2021) showed that information technology (IT) positively affects seaport operations, improving efficiency, flexibility, and customer satisfaction. Tijan et al. (2022) noted that seaport competitiveness depends on infrastructure quality, connectivity, service standards, cost reduction, and the possibilities of business process digitalization. Building on the above, since seaports operate in highly competitive markets, they require continuous development through innovation and digital solutions. Development of new ideas and technologies should be supported by quality human capital (Bronzini & Piselli, 2006), considering an educated workforce is the backbone of research and development (R&D) that drives innovations, adaptability to innovations, and addresses complex challenges. This formed the foundation for selecting the human capital variables in the research.

To determine the impact on seaport performance, various authors used different variables such as logistic performance index, import volume index, GDP, Gross national income (GNI) (Mahpour et al., 2023), number of berths, enterprise total assets, total imports and exports (Xing, 2021). Furthermore, the authors used logistics facilities, ferry connections, the number and capacity of terminals, the population of the port city (Bocheński et al., 2021), total quay cranes, terminal area, quay length, operational expenses (Caldas et al., 2024), quality of seaport infrastructure, seaport traffic, GDP *per capita* (Munim & Schramm, 2018). However, the empirical literature does not provide a comprehensive look at regional drivers of seaport production. Additionally, since recent seaport production policies emphasize the adoption of innovations and digital technology, this variable is absent from the mentioned studies, leaving the analysis incomplete.

The theoretical and empirical literature reviewed demonstrates that seaports play an important role in economic growth, increasing employment, and enhancing trade. However, no empirical research has been conducted specifically within the framework of EU port regions to examine regional factors influencing seaport production. Consequently, this study provides the first empirical evidence of the impact of economic, human capital, and infrastructural determinants of seaport production in EU port regions in the existing literature. Assessing the influence of regional factors on seaport performance is essential for understanding how these factors affect efficiency. Those insights support informed decision-making and help create specific policies promoting sustainable and efficient seaport operations.

3. METHODOLOGY

This section describes the methods used to achieve the aim of the research. Namely, it provides the specification of the empirical model, describes the used data and variables, and defines the estimation technique.

3.1. Model specification

The economic model used in this paper examines the impact of economic, human capital, and infrastructural factors on seaport production and has the following format:

$$SEAPORT\ PRODUCTION = f\ (ECONOMIC,\ HUMAN\ CAPITAL,\ INFRASTRUCTURAL) \quad (1)$$

where seaport production = freight; economic = GDP *per capita*; human capital = population, employment, education, and innovation capacity; infrastructural = gross fixed capital formation and motorways.

Freight traffic was selected to represent seaport production and is a commonly recognized measure of seaport performance and operational efficiency in the literature (Bottasso et al., 2013; Cheung & Yip, 2011; Ferrari et al., 2010; Mudronja et al., 2020; Park & Seo, 2016; Shan et al., 2014). Indicators such as seaport profit, the annual number of vessels, and passenger count can assess seaport activity, but they are either unavailable on the regional level or unsuitable for this study.

Since GDP *per capita* is one of the most commonly used indicators of economic performance that helps estimate a region's standard of living, this variable was chosen to represent economic factors. This aligns with the existing literature (Ayesu et al., 2023; Bilbao-Osorio & Rodríguez-Pose, 2004; Bottasso et al., 2014; Crescenzi & Rodríguez-Pose, 2012; Fratila et al., 2021; Jouili, 2016; Mudronja, 2020; Özer et al., 2021; Park & Seo, 2016; Shan et al., 2014).

The variables population, employment, education, and innovation capacity were selected as proxies for human capital factors. Population influences market size, labour force, and demand for goods and services (Rodríguez-Pose & Crescenzi, 2008). A larger population provides more workers for port-related industries like logistics and shipping. Employment levels also affect labour market efficiency, as seaports commonly operate as significant employers, both directly and indirectly through port-related industries. The population is frequently used in research as a foundational variable related to socioeconomic and human capital factors (Bonnefond, 2014; Ferrari et al., 2010; Hong et al., 2011; Vlahinić Lenz et al., 2018). A stable employment rate indicates that the port region is capable of sustaining its logistics and supply chain operations, which are essential for seaport production. Education also plays a key role, as higher levels lead to a more skilled, innovative workforce, driving economic growth and technological advancements (Crescenzi & Rodríguez-Pose, 2012; Mudronja et al., 2020). Authors using the same proxy for education are the following: Crescenzi (2005), Crescenzi and Rodríguez-Pose (2012), Ferrari et al. (2010), and Hong et al. (2011). Innovation capacity is used as a proxy for the transformation of human capital into innovation potential, particularly relevant in the seaport context, where a highly skilled workforce is essential for adopting and operating technologies such as IoT, robotics, self-driving vehicles, blockchain, and other advanced technologies. Innovation capacity is important for long-term growth, especially in industries that rely on technology and innovation, such as the maritime industry (Andrews &

Criscuolo, 2013; Koilo, 2021; Rodríguez-Pose & Crescenzi, 2008). It is essential to keep the seaport and its related industries competitive globally. In empirical studies, R&D is often used as a proxy for measuring innovative and absorptive capabilities (Bilbao-Osorio & Rodríguez-Pose, 2004; Crescenzi, 2005; Crescenzi & Rodríguez-Pose, 2012). Together, these variables capture the human capital structure of a port region, offering a comprehensive perspective on the size and quality of the workforce, its economic participation, and its potential for future growth through education and innovation.

Gross fixed capital formation was chosen to represent infrastructural factors as it measures resident producers' net acquisitions of fixed assets, including machinery, equipment, vehicles, buildings, dwellings, and other types of structures (Eurostat, 2024). A higher level of gross fixed capital formation in a port region suggests ongoing investment in facilities like seaports, seaport technology, and warehouses, vital for efficient freight handling. Lastly, the length of motorways was chosen as another proxy for infrastructural factors, as it reflects the transportation network connecting seaports to their hinterland. A longer, well-maintained motorway network enhances seaport accessibility and enables faster, more cost-efficient freight movement (Arvis et al., 2018).

Based on the economic model, a panel analysis model was proposed to show the extent to which each of the factors mentioned influences seaports. The econometric model is expressed as follows:

$$Freight_{it} = \beta_0 + \beta_1 GDPpc_{it} + \beta_2 Pop_{it} + \beta_3 Empl_{it} + \beta_4 Educ_{it} + \beta_5 RD_{it} + \beta_6 Capital_{it} + \beta_7 Motorw_{it} + \lambda_t + a_i + u_{it} \quad (2)$$

$Freight_{it}$ = the value of freight traffic in the seaports for region *i* and time *t*,
$GDPpc_{it}$ = the value of the gross domestic product *per capita* for region *i* and time *t*,
Pop_{it} = the percentage share in the total population change for region *i* and time *t*,
$Empl_{it}$ = the percentage share of employed persons in the total workforce for region *i* and time *t*,
$Educ_{it}$ = the indicator of persons who have completed tertiary education for region *i* and time *t*,
RD_{it} = the value of investment in R&D for region *i* and time *t*,
$Capital_{it}$ = the gross fixed capital formation for region *i* and time *t*,
$Motorw_{it}$ = the length of the motorways for region *i* and time *t*,
λ_t = the unobservable time effects,
a_i = the unobservable time-invariant individual effects,
u_{it} = the relation error,
$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$, and β_7 = the coefficients.

GDP *per capita* is expected to have a positive impact on seaport production since it reflects the region's economic strength and trade activity. The expectation is in line with the maritime economics literature (Caldas et al., 2024; Cheung & Yip, 2011; Mahpour et al., 2023; Munim & Schramm, 2018).

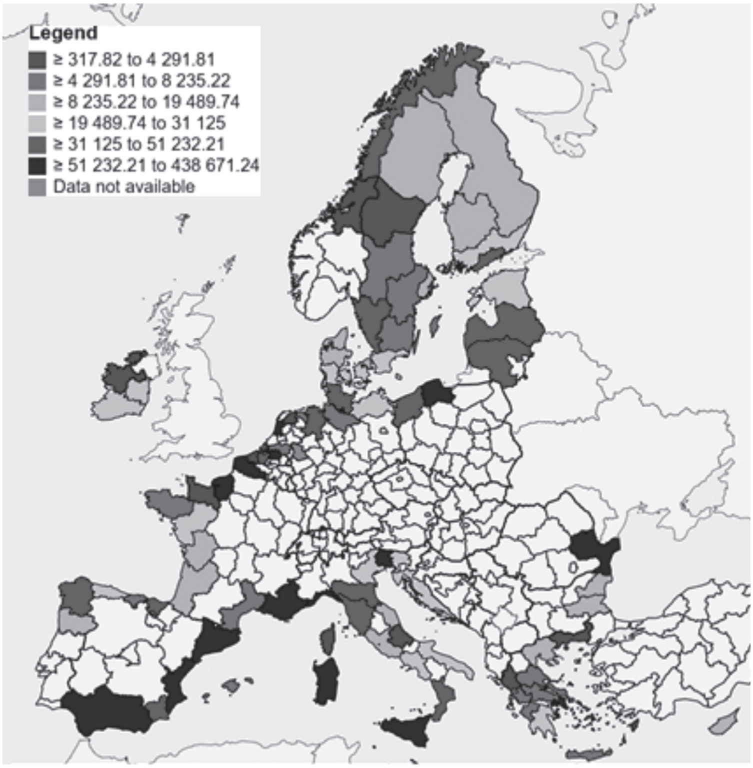
Population is expected to positively impact seaport production, considering a denser population typically drives higher demand for goods, economic activity, and employment, leading to increased seaport traffic (Ayesu & Boateng, 2024; Bonnefond, 2014; Ferrari et al., 2010; Park & Seo, 2016). The employment rate's coefficient is expected to be positive, as a higher rate indicates greater economic activity and consumption, amplifying seaport production. Education is expected to positively impact seaport production since skilled workers enhance efficiency and support modern technologies. An educated population drives innovation and success in both the region and its seaports (Crescenzi & Rodríguez-Pose, 2012; Mudronja et al., 2020; Thai et al., 2016). Innovation capacity is expected to have a positive impact on seaport production since it enables the development of new technologies and innovative methods to optimize operations (Mudronja et al., 2019).

The gross fixed capital formation coefficient is expected to be positive, considering investments in fixed capital modernize seaport infrastructure and increase capacity, attracting more customers and improving service (Munim & Schramm, 2018). The length of the motorways is expected to positively impact seaport production, given that motorways provide a key infrastructural connection between the hinterland and seaports. A well-developed network facilitates the transport of goods, increasing port traffic and enhancing trade (Arvis et al., 2018).

3.2. Data, variables, and descriptive statistics

The sample of this research consists of panel data for 86 EU port regions from 2009 to 2019. This period was chosen because data from 2009 to 2019 are complete and consistent. Furthermore, the end of 2019 serves as a pre-COVID benchmark, offering insights into how seaports operated during a stable period before the pandemic's disruptions. This could be valuable for comparing seaport performance before and after the pandemic in future studies. The port regions have the classification level NUTS 2 (Nomenclature of Spatial Units for Statistics), which is a hierarchical system for subdividing the economic territory of the EU and the United Kingdom for official statistics. The research covered the regions of the following countries: Belgium, Bulgaria, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Croatia, Italy, Cyprus, Latvia, Lithuania, Malta, the Netherlands, Poland, Romania, Slovenia, Finland, and Sweden. Norway is not part of the EU but was included in the research as data were found in the database. Figure 1 shows the regions included in the research, with different colours indicating the volume of freight traffic in thousand tonnes.

Figure 1. The regions of the European Union included in the research



Source: Adapted from (European Commission, 2024b)

All data used in this research were taken from the Eurostat Database (Eurostat Database, 2022). The list of variables used is shown in Table 1.

Table 1. List and explanation of the variables

Dependent Variable	**Description**	**Formulation**
Freight	Freight traffic in seaports	1,000 tons
Independent Variables	**Description**	**Formulation**
	Economic factor	
GDPpc	Gross domestic product *per capita*	Expressed in purchasing power standards (PPS) in EUR
	Human capital factors	
Pop	Population	% of total population change per 1,000 persons
Empl	Employment rate	% of employed in the total workforce

Educ	Education	% population between 25 – 64 who completed tertiary education
RD	Innovation capacity	Intramural R&D expenditure as a % of GDP
	Infrastructural factors	
Capital	Gross fixed capital formation	Resident producers´ acquisitions, less disposals, of fixed tangible or intangible assets in millions of EUR
Motorw	Motorways	Kilometer

Source: Author's compilation

Prior to model testing, a descriptive statistical analysis was performed, and the presence of correlation was tested. The descriptive statistics for the variables included in the model are presented in Table 2.

Table 2. Descriptive statistics of the variables

Variable	Number of Observations	Mean	Standard Deviation	Minimum	Maximum
Freight	1,142	31,095.97	49,402.66	292	451,847
GDPpc	1,144	25,838.02	9,021.466	8,700	74,900
Pop	1,127	2.289885	7.153956	-21.9	54.8
Empl	1,144	63.1903	9.566955	28.1	80.1
Educ	1,129	28.27724	9.167671	8.3	53.7
RD	951	1.455578	1.064689	0.06	5.3
Capital	1,144	10,849.25	10,130.59	216.4	93,417.88
Motorw	890	326.2022	358.0408	0	2,626

Source: Author's calculation

Freight traffic shows the largest standard deviation (49,402.66), which was to be expected since different seaports have different levels of development and differing levels of attractiveness for freight transport. The minimum value is 292, while the maximum is 451,847, indicating significant differences between the various port regions. GDP *per capita* also varies significantly (9,021.466), reflecting differences in development across EU member states, which are transferred to their port regions. It ranges from 8,700 to 74,900, underscoring notable disparities.

Education has a mean value of 28.27 and a standard deviation of 9.17, suggesting considerable differences in the level of education. The minimum is 8.3 and the maximum is 53.7, indicating that some regions have a high level of education while others follow at a slower pace. The innovation capacity variable has the lowest mean value (1.46) and the lowest standard deviation (1.06), which indicates that investments in R&D in the analysed regions are modest but relatively stable. The highest value of 5.3 indicates that some regions have a stronger focus on innovation, while others allocate fewer resources to R&D.

There is notable variation in gross fixed capital formation and motorway length due to differing infrastructure investments in EU port regions. The variable capital has a mean value of 10,849.25 and a high standard deviation of 10,130.59, which indicates great inequality between the regions. The minimum value (216.4) is drastically lower than the maximum value (93,417.88), meaning some regions have significantly more capital than others. The variable motorways has a mean value of 326.2, but a relatively high standard deviation of 358.04, which means that there are notable disparities in the length of motorways between the regions. The maximum value (2,626) suggests that some regions have a very well-developed transportation infrastructure, while others have no motorways (minimum = 0).

Overall, substantial differences can be observed in all variables, which indicates uneven development between the regions. Extreme values for some variables (e.g. freight traffic, capital, motorways) indicate regions with exceptionally high or low resources. The high standard deviation for capital and motorways points out that infrastructure and economic resources are unevenly distributed. Although there is moderately high employment, investment in R&D is relatively low. Before testing the model, the correlation between the variables was tested. The correlation coefficients are shown in Table 3.

Table 3. Correlation coefficients

	Freight	GDPpc	Pop	Empl	Educ	RD	Capital	Motorw
Freight	1.0000							
GDPpc	0.1988	1.0000						
Pop	-0.0388	0.4056	1.0000					
Empl	-0.0241	0.6371	0.2163	1.0000				
Educ	0.0506	0.5605	0.2644	0.5820	1.0000			
RD	0.0771	0.6384	0.3193	0.5651	0.6246	1.0000		
Capital	0.3816	0.4816	0.2362	0.1339	0.1931	0.3785	1.0000	
Motorw	0.3006	-0.0822	-0.0460	-0.2505	-0.0021	-0.0177	0.5661	1.0000

Source: Author's calculation

A threshold for the presence of a correlation is a positive or negative correlation that is greater than 0.80 (Lovrić, 2005). There are no coefficients that exceed the defined threshold, which is an indicator of the absence of multicollinearity.

3.3. *Estimation technique*

The standard approach in panel data analysis consists of three different estimators: Pooled Ordinary Least Squares (POLS), Fixed Effects (FE), and Random Effects (RE). The selection of these estimators is based on previous empirical research using POLS and FE to determine the effects of port city factors on seaport production (Cheung & Yip, 2011). The POLS estimator is a simple approach that treats all data as a single set, regardless of the panel structure. This means that data from all units (e.g. regions) and all time periods are combined and treated as one large data set. The POLS estimator assumes homoscedasticity and the absence of correlation between the errors. Since it does not account for individual effects, it can lead to biased estimates if unobserved heterogeneity is present. In the presence of heteroscedasticity or correlated errors, the standard errors are imprecise, which can lead to incorrect conclusions about statistical significance. Also, if individual effects are correlated with the regressors, the POLS estimates may be biased and inconsistent (Wooldridge, 2015). For seaports, it can provide efficient, unbiased estimates if they are similar in production and lack significant individual-specific unobserved heterogeneity. However, if unobserved port-specific factors exist and are related to the independent variables, it can result in biased estimates.

The FE estimator accounts for individual-specific characteristics that remain constant over time and treats them as fixed parameters, controlling for unobserved heterogeneity and focusing on time-varying variables. This estimator eliminates all time-invariant characteristics by transforming the data, which is usually done by centering around the mean of each unit. The FE estimator is used when there is a correlation between the individual effects and the explanatory variables (Wooldridge, 2015). This is important for seaport production, where factors like geographical location and long-term contracts affect efficiency. The FE estimator uses variation within each seaport over time to estimate the relationships, making it well-suited for analysing how changes in operational factors such as changes in the workforce or technology influence production within each seaport. The limitation of using the FE estimator is that it does not allow for the estimation of time-invariant variables, such as distance to major markets or water depth, because it eliminates all cross-sectional variations (Wooldridge, 2015). Another limitation is that the FE estimator uses only the variation within each seaport over time and it does not consider variations between seaports such as differences in capacity, size, etc.

The RE estimator assumes that the individual effects are randomly distributed and uncorrelated with the explanatory variables. This means that the specific effects for each unit are random and independent of the regressors. The RE estimator uses the within- and between-unit variation to estimate the effect and is appropriate when analysing the influence of time-invariant variables. However, if the assumption of uncorrelated individual effects with the independent variables is violated, it may lead to biased estimates, making the FE estimator a better choice (Wooldridge, 2015).

An F-test confirmed the suitability of the FE estimator over the POLS estimator. The Hausman test further indicated that the FE estimator is more appropriate than the RE estimator, rejecting the H_0 hypothesis. The FE estimator helps address endogeneity by controlling for time-invariant, unobserved variables that may correlate with the independent variables. Specifically, it estimates the model using deviations from the individual's time-mean, removing any unobserved effects that do not vary over time, and eliminating the part of the error term that is correlated with the independent variables (Wooldridge, 2015).

4. RESULTS AND DISCUSSION

This section presents the impact of economic, human capital, and infrastructural factors on seaport production using the FE estimator. Regardless of the selected FE estimator, the results of all three estimators are given in Table 4, as estimating the model using all three approaches allows for robustness checks. The consistency of results across the methods refers to more precision in results. Data were analysed using statistical software Stata.

Table 4. Results of the model testing

	POLS	**FE**	**RE**
VARIABLES	Freight	Freight	Freight
GDPpc	1.417***	0.476**	0.483***
	(0.286)	(0.185)	(0.181)
Pop	-903.3***	2.663	-0.478
	(207.8)	(45.49)	(45.77)
Empl	-617.4***	156.5	143.7
	(230.5)	(131.4)	(130.7)
Educ	136.0	300.6*	262.7*
	(214.6)	(156.1)	(152.4)
RD	-3,186*	4,414***	4,245***
	(1,809)	(967.7)	(956.5)
Capital	1.075***	-0.349**	-0.291**
	(0.256)	(0.137)	(0.134)
Motorw	16.31***	41.23***	41.38***
	(5.379)	(8.534)	(7.251)
Constant	24,305*	-16,469*	-13,943

	(12,834)	(9,270)	(10,276)
Time effects included	Yes	Yes	Yes
Observations	727	727	727
Number of regions	86	86	86
Standard errors in parentheses			
*** $p<0.01$, ** $p<0.05$, * $p<0.1$			

Source: Author's calculation

The Cobb-Douglas production function is used to describe how different production factors contribute to total seaport output. In this research, port regions are treated as production entities, with seaport production as the output. Economic, human capital, and infrastructural factors are considered inputs. In essence, seaport metrics (freight traffic) represent output, driven by regional production factors. Regional factors influence seaports and promote their development in a reciprocal relationship, with seaport production being the cumulative outcome of these regional factors.

Economic factors contribute significantly to seaport production; if the region's economic situation improves, the seaports will operate more successfully, which is in line with expectations. Higher GDP *per capita* may be accompanied by higher consumption of the population, and, at the same time, higher production of goods and services, which may subsequently lead to greater import and export of goods via the seaports. Furthermore, more prosperous areas are more prone to innovation and technological progress (Rodríguez-Navarro & Brito, 2022), which can be implemented in the operations of seaports and increase their efficiency. Improved economic activity often leads to better infrastructure (Miyamoto et al., 2020), such as modernized terminals and increased seaport capacity. Higher GDP *per capita* can also lead to stricter environmental standards, prompting investment in green technologies, as seen in many EU countries that are already influenced by policies such as the European Green Deal (European Commission, 2024). Although stricter policies might seem harmful to the economy, OECD data shows they have minimal impact on employment, investment, and productivity (OECD, 2021). The more prosperous regions in the EU will presumably see their seaports thrive, while less developed areas may lag in infrastructure and competitiveness. This could lead to a disparity in the capacity and efficiency of seaports across the EU, where Western and Northern European countries like the Netherlands or Germany have more advanced and competitive seaports compared to less developed Southern or Eastern European countries such as Croatia or Greece. To address this, the EU will likely need to focus on regional cohesion policies to ensure that less developed regions can keep pace, using targeted funding and support for green technologies and innovation, with programs like the Cohesion Fund playing a key role.

Human capital factors, particularly education and innovation capacity, significantly impact seaport production. Higher levels of tertiary education improve seaport efficiency, as skilled workers enhance productivity, handle complex processes, and adopt advanced technologies (Doms et al., 1997; Kampelmann et al., 2018). Educated workers are also adept at using ICT for logistics, security, and freight tracking, have a greater awareness of environmental protection in seaports, and are more willing to use environmentally friendly technologies and promote sustainable development. This suggests that EU regions with stronger educational systems will gain a better competitive advantage. Seaports in countries such as the Netherlands, Germany, and Denmark, with well-educated workforces, are likely to experience greater productivity and more effective technology adoption, helping them stay competitive in the market. Education fosters innovation, leading to new technologies that improve seaport operations. Therefore, innovation capacity, which is statistically significant and has a positive impact on seaport production, was included in the research.

Investing in R&D fosters new technologies that improve seaport efficiency, productivity, and safety by optimizing processes like inventory and logistics, ultimately reducing costs. It enhances environmental protection through eco-friendly technologies, such as alternative energy sources and emission-reducing innovations (Geerlings & Wiegmans, 2018). Technological progress helps preserve the environment while maintaining strong economic performance (Napolitano et al., 2022). In addition, it leads to more tertiary education, reduces low-skilled workers, and raises their wages (Prettner & Strulik, 2020). In the dynamic seaport industry, adopting new technologies is key to staying competitive. Moreover, a combination of education and innovation capacity is essential, as R&D alone is ineffective without skilled human capital to apply innovations (Mudronja et al., 2019). Disparities in education and innovation capacity could increase the gap between more developed and less developed regions. Seaports in economically and educationally stronger regions, such as Western and Northern Europe, are likely to progress faster than those in Southern or Eastern Europe unless additional measures are taken to support education and innovation capacity in these regions.

The research results show that population change is not a statistically significant variable, except in the POLS estimator, but with a negative sign. Population growth can have a complex impact on seaports. Potential benefits are reflected in increased demand for the transportation of goods, but if seaports do not have sufficient infrastructure and labour capacity, there may be reduced efficiency and business congestion. Although the employment rate was expected to positively impact seaport production as a sign of economic activity and consumption, it did not prove significant. There are several possible economic explanations for this phenomenon. High employment can lead to a skilled labour shortage; therefore, attracting and retaining workers in seaports requires an increase in wages, which consequently increases the seaports' business costs and may reduce their competitiveness. Additionally, high employment promotes inflation, increasing overall costs, including seaport resources.

According to the results obtained, infrastructural factors have a statistically significant influence on seaport production, with motorway length positively influencing operations. Road connectivity is essential as it facilitates the movement of goods to and from seaports. Improved connectivity promotes trade, increases seaport traffic, lowers costs, and enables faster delivery, improving seaport competitiveness by attracting more business and increasing volumes (Cohen & Monaco, 2008; Crescenzi & Rodríguez-Pose, 2012; Parikesit et al., 2019). EU regions that invest in improving road connections between seaports and hinterland will promote trade and stimulate economic growth. This is particularly important for regions with major seaports like Rotterdam, Antwerp, and Hamburg, which significantly rely on efficient transport networks, and for seaports aiming to increase their freight traffic in the future.

Gross fixed capital formation is a significant variable, but it does not have the expected sign in the FE and the RE model. The reason for this may lie in the insufficient focus of fixed capital investments on the modernization and maintenance of seaport infrastructure, as the variable used includes all fixed capital investments in the region, not only those related to the seaports, which could not be assessed due to a lack of data.

These results emphasize the significance of accounting for economic, human capital, and infrastructural factors when evaluating seaport performance and identifying potential areas for enhancement. Identifying key influences helps seaport managers allocate resources wisely and ensure long-term sustainability. By focusing on these factors, seaports and regions can prioritize investments in technology, infrastructure, human capital, and operational improvements. Recognizing these factors enables seaports to anticipate future demands and investments in technology and infrastructure as well as to align with regulatory standards and to improve customer satisfaction. Efficient seaports are more likely to attract more customers and freight which consequently leads to more revenue, greater employment, and a positive impact on regional economic growth.

The findings of this research are in line with EU policies on seaport production. The research results indicate that innovation and technological advancements are important drivers of seaport production which is also encouraged by the Horizon Europe funding program for research and innovation. One of the areas supported by Horizon Europe is the advancement of smart ports by utilizing technologies like the IoT, big data analytics, and AI. These innovations help seaports enhance efficiency, optimize resource management, and adapt to freight demands, leading to increased production (ESPO & De Langen, 2024; European Commission, 2017). The research confirms a positive link between infrastructure and seaport operations, aligning with the Connecting Europe Facility (CEF) goals. Through this funding instrument, the EU supports the expansion and modernization of transport networks, including seaports, aiming to improve connectivity, efficiency, and capacity to handle larger freight volumes (European Commission, 2024a). The EU's Trans-European Transport

Network (TEN-T) policy seeks to build a comprehensive and efficient transport network across Europe, including seaports, to promote economic growth and foster greater integration within the EU (European Commission, 2024d). In conclusion, the research findings align with key EU policies on seaport production, emphasizing the role of innovation and infrastructure in driving efficiency and capacity.

5. CONCLUSION

This paper contributes to the examination of key determinants influencing seaport production, seeking to enhance seaport efficiency and increase freight turnover. The increased seaport production is proven to have many benefits for their regional and national economies, such as economic growth, trade development, increased employment, and attraction and improvement of other port-related activities; therefore, it is valuable to examine what factors affect the operations of seaports. The paper examined the impact of regional economic, human capital, and infrastructural factors on seaport production in the EU within the framework of the Cobb-Douglas production function. The estimation is based on panel data from 86 EU port regions for the period 2009–2019 employing the POLS, FE, and RE estimators.

The empirical results show that there is an influence of economic factors on seaport production, as better economic activity increases the consumption and production of goods and services, leading to more seaport traffic. However, at the same time, there might arise the need for a better intermodal transport system that might impose additional investments. Education and innovation capacity, as human capital factors, also positively impact seaport production. Considering the maritime industry is dynamic and subject to frequent change, to remain competitive in the market, seaports must regularly respond to innovations, new technologies, and new knowledge. Innovations such as automated cranes, IoT, blockchain technology, AI, machine learning, and PCS are among the new advancements in the maritime industry that seaports will have to adapt to. Alongside innovation, it is essential to have a well-educated workforce, as they are better prepared to adapt to new technologies. Seaports can encourage education through collaboration with universities, establishing innovation hubs, and offering internships. Finally, the research results show that infrastructural factors affect seaport production, especially motorways, which are important for the transportation of freight to and from seaports. Better road connectivity can boost trade, reduce costs, and enable faster delivery of freight, which increases seaport production.

Given these findings, the economic factors highlight the need for policies that promote sustainable economic growth, increase domestic consumption, and expand international trade flows. Strengthening these dimensions of economic activity contributes directly to higher demand for goods and services, which in turn increases the volume of imports and exports through the seaports. In addition, the implications for policymakers are to promote digitalization and innovative technologies in seaport operations since enhancement in automation and greater adoption of smart port technologies such as IoT, AI, big data analytics, PCS, etc. can improve seaport efficiency. Furthermore, policymakers should aim for policies that strengthen workforce development, focusing on upskilling seaport workers in new technologies. Collaboration with educational institutions and the establishment of innovation hubs, that would provide knowledge exchange and collaborative research to help overcome business challenges, should be supported. Lastly, policymakers should enhance programs that improve multimodal transport connections between seaports and other transportation modes, considering that improved integration between seaports and hinterland transport networks will enhance the movement of goods, aligning with the objectives of the TEN-T.

Although these findings offer valuable insights, it is essential to recognize the limitations of this study. The research employed the EU regional data, which are less diverse and available compared to data at the aggregate level. The only indicator of seaport production available on the regional level was freight traffic. To provide more detailed insights into seaport production, having data on seaport profits or seaport investments would have been advantageous. For that reason, future research should implement other metrics to gain more comprehensive insights and assist in the development of more efficient policies. Additional recommendations for future research include incorporating other factors influencing seaport production, such as environmental factors, government performance, trade openness, and safety. Finally, the proposed model can be tested on different data samples that are not exclusive to the EU, which would provide insight into the drivers of seaport performance in different areas, and the obtained results could be compared with the ones from this study.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author.

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BIBLIOGRAPHY

Adabere, S., Owusu Kwateng, K., Dzidzah, E., & Kamewor, F. T. (2021). Information technologies and seaport operational efficiency. *Marine Economics and Management, 4*(2), 77–96. https://doi.org/10.1108/maem-03-2021-0001

Agatić, A., & Kolanović, I. (2020). Improving the seaport service quality by implementing digital technologies. *Pomorstvo, 34*(1), 93–101. https://doi.org/10.31217/p.34.1.11

Andrews, D., & Criscuolo, C. (2013). Knowledge-Based Capital, Innovation and Resource Allocation. In *OECD Economics Department Working Papers* (Issue 1046). https://doi.org/10.1787/9789264193307-5-en

Arvis, J. F., Vesin, V., Carruthers, R. C., Ducruet, C., & De Langen, P. W. (2018). *Maritime Networks, Port Efficiency, and Hinterland Connectivity in the Mediterranean*. World Bank Group. http://documents.worldbank.org/curated/en/508771540319329808/Maritime-Networks-Port-Efficiency-and-Hinterland-Connectivity-in-the-Mediterranean

Ayesu, E. K., & Boateng, K. A. B. (2024). Estimating the impact of container port throughput on employment: an analysis for African countries with seaports. *Journal of Shipping and Trade, 9*(8), 1–19. https://doi.org/10.1186/s41072-024-00166-z

Ayesu, E. K., Sakyi, D., & Baidoo, S. T. (2022). The effects of seaport efficiency on trade performance in Africa. *Maritime Policy & Management, 51*(3), 420–441. https://doi.org/10.1080/03088839.2022.2135178

Ayesu, E. K., Sakyi, D., & Darku, A. B. (2023). Seaport efficiency, port throughput, and economic growth in Africa. *Maritime Economics & Logistics, 25*, 479–498. https://doi.org/10.1057/s41278-022-00252-8

Bhanumurthy, K. V. (2002). Arguing a Case for the Cobb-Douglas. *Review of Commerce Studies, 20–21*(1), 75–91.

Bilbao-Osorio, B., & Rodríguez-Pose, A. (2004). From R&D to Innovation and Economic Growth in the EU. *Growth and Change, 35*(4), 434–455. https://doi.org/10.1111/j.1468-2257.2004.00256.x

Bocheński, T., Palmowski, T., & Studzieniecki, T. (2021). The Development of Major Seaports in the Context of National Maritime Policy. The Case Study of Poland. *Sustainability, 13*(22), 1–20. https://doi.org/10.3390/su132212883

Bonnefond, C. (2014). Growth dynamics and conditional convergence among Chinese provinces: A panel data investigation using system GMM estimator. *Journal of Economic Development, 39*(4), 1–25. https://doi.org/10.35866/caujed.2014.39.4.001

Bottasso, A., Conti, M., Ferrari, C., Merk, O., & Tei, A. (2013). The impact of port throughput on local employment: Evidence from a panel of European regions. *Transport Policy, 27*, 32–38. https://doi.org/10.1016/j.tranpol.2012.12.001

Bottasso, A., Conti, M., Ferrari, C., & Tei, A. (2014). Ports and regional development: A spatial analysis on a panel of European regions. *Transportation Research Part A: Policy and Practice, 65*, 44–55. https://doi.org/10.1016/j.tra.2014.04.006

Bronzini, R., & Piselli, P. (2006). *Determinants of Long-Run Regional Productivity: The Role of R&D, Human Capital and Public Infrastructure*. SSNR Bank of Italy Economic Research Paper, 597. https://doi.org/10.2139/ssrn.935010

Caldas, P., Pedro, M. I., & Marques, R. C. (2024). An Assessment of Container Seaport Efficiency Determinants. *Sustainability, 16*(11), 1–38. https://doi.org/10.3390/su16114427

Cheung, S. M. S., & Yip, T. L. (2011). Port City Factors and Port Production: Analysis of Chinese Ports. *Transportation Journal, 50*(2), 162–175. https://doi.org/10.5325/transportationj.50.2.0162

Cobb, C. W., & Douglas, P. H. (1928). A Theory of Production. *The American Economic Review, 18*(1), 139–165.

Cohen, J., & Monaco, K. (2008). Ports and Highways Infrastructure: An Analysis of Intra- and Interstate Spillovers. *International Regional Science Review, 31*(3), 257–274. https://doi.org/10.1177/0160017608318946

Crescenzi, R. (2005). Innovation and regional growth in the enlarged Europe: The role of local innovative capabilities, peripherality, and education. *Growth and Change, 36*(4), 471–507. https://doi.org/10.1111/j.1468-2257.2005.00291.x

Crescenzi, R., & Rodríguez-Pose, A. (2012). Infrastructure and regional growth in the European Union. *Papers in Regional Science, 91*(3), 487–513. https://doi.org/10.1111/j.1435-5957.2012.00439.x

de Langen, P. W. (2004). The Performance of Port Clusters. *Journal of International Logistics and Trade, 2*(1), 47–56. https://doi.org/10.24006/jilt.2004.2.1.47

Doms, M., Dunne, T., & Troske, K. R. (1997). Workers, Wages, and Technology. *The Quarterly Journal of Economics, 112*(1), 253–290. https://doi.org/10.1162/003355397555181

Ducruet, C., Notteboom, T. E., & de Langen, P. W. (2009). Revisiting Inter-Port Relationships under the New Economic Geography Research Framework. In T. E. Notteboom, C. Ducruet, & P. W. de Langen (Eds.), *Ports in Proximity, Competition and Coordination among Adjacent Seaports* (pp. 11–27). Ashgate Publishing Company.

ESPO. (2023). *ESPO at 30: Ports looking into the future*. Available at: https://www.espo.be/publications/espo-at-30-ports-looking-into-the-future

ESPO, & De Langen, P. (2024). *The Investment Pipeline and Challenges of European Sea Ports Organisation*. Available at: https://www.espo.be/publications/espo-port-investments-study-2024-europes-ports-hav

European Commission. (2017). *Towards clean, competitive and connected mobility: the contribution of Transport Research and Innovation to the Mobility package*. Available at: https://transport.ec.europa.eu/system/files/2017-06/swd20170223-transportresearchandinnovationtomobilitypackage.pdf

European Commission. (2024a). *Connecting Europe Facility*. Available at: https://cinea.ec.europa.eu/programmes/connecting-europe-facility_en

European Commission. (2024b). *Maritime transport of freight by NUTS 2 region - map*. Eurostat. https://ec.europa.eu/eurostat/databrowser/view/TRAN_R_MAGO_NM__custom_13341324/default/map?lang=en

European Commission. (2024c). *The European Green Deal*. Available at: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

European Commission. (2024d). *Trans-European Transport Network (TEN-T)*. Available at: https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t_en

European Sea Ports Organisation (ESPO). (2023). *ESPO Environmental Report 2023*. Available at: https://www.espo.be/publications/espo-environmental-report-2023

Eurostat. (2024). *Gross fixed capital formation (investments)*. Available at: https://ec.europa.eu/eurostat/databrowser/view/tec00011/default/table?lang=en

Eurostat Database. (2022). *No Title*. Available at: https://ec.europa.eu/eurostat/data/database

Ferrari, C., Percoco, M., & Tedeschi, A. (2010). Ports and local development: Evidence from Italy. *International Journal of Transport Economics, 37*(1), 9–30. http://www.jstor.org/stable/42747893

Fratila, A., Gavril, I. A., Nita, S. C., & Hrebenciuc, A. (2021). The Importance of Maritime Transport for Economic Growth in the European Union: A Panel Data Analysis. *Sustainability, 13*(14), 1–23. https://doi.org/10.3390/su13147961

Geerlings, H., & Wiegmans, B. (2018). Technological Innovations. In H. Geerlings, B. Kuipers, & R. Zuidwijk (Eds.), *Ports and Networks, Strategies , Operations and Perspectives* (pp. 332–347). Taylor & Francis Group.

Hales, D., Lee Lam, J. S., & Chang, Y.-T. (2016). The Balanced Theory of Port Competitiveness. *Transportation Journal, 55*(2), 168–189. https://doi.org/10.5325/transportationj.55.2.0168

Hidalgo-Gallego, S., & Núñez-Sánchez, R. (2023). The effect of port activity on urban employment: An analysis for the Spanish functional urban areas. *Journal of Transport Geography, 108*, 103570. https://doi.org/10.1016/j.jtrangeo.2023.103570

Hong, J., Chu, Z., & Wang, Q. (2011). Transport infrastructure and regional economic growth: Evidence from China. *Transportation, 38*(5), 737–752. https://doi.org/10.1007/s11116-011-9349-6

Huang, Z., Yang, Y., & Zhang, F. (2022). Configuration Analysis of Factors Influencing Port Competitiveness of Hinterland Cities under TOE Framework: Evidence from China. *Journal of Marine Science and Engineering, 10*(1558), 1–15. https://doi.org/10.3390/jmse10101558

Jouili, T. A. (2016). The Role of Seaports in the Process of Economic Growth. *Developing Country Studies, 6*(2), 64–69.

Kampelmann, S., Rycx, F., Saks, Y., & Tojerow, I. (2018). Does education raise productivity and wages equally? The moderating role of age and gender. *IZA Journal of Labor Economics, 7*(1), 1–37. https://doi.org/10.1186/s40172-017-0061-4

Koilo, V. (2021). Evaluation of R&D activities in the maritime industry: Managing sustainability transitions through business model. *Problems and Perspectives in Management, 19*(3), 230–246. https://doi.org/10.21511/ppm.19(3).2021.20

Krugman, P. (1991). Increasing Returns and Economic Geography. *Journal of Political Economy, 99*(3), 483–499.

Li, Y., Ge, X., Hang, Y., & Liu, X. (2019). Measuring Seaport Enterprise Production Overcapacity: A Cobb-Douglas Product Function Based Study. *Journal of Coastal Research, 94*, 422–428. https://doi.org/10.2112/SI94-084.1

Lovrić, L. (2005). *Uvod u ekonometriju*. Ekonomski fakultet Sveučilišta u Rijeci.

Mahpour, A., Farzin, I., Baghestani, A., Ashouri, S., Javadi, Z., & Asgari, L. (2023). Modeling the impact of logistic performance, economic features, and demographic factors of countries on the seaborne trade. *Asian Journal of Shipping and Logistics, 39*(2), 60–66. https://doi.org/10.1016/j.ajsl.2023.02.003

Miyamoto, H., Baum, A., Gueorguiev, N., Honda, J., & Walker, S. (2020). Growth Impact of Public Investment and the Role of Infrastructure Governance. In G. Schwartz, M. Fouad, T. S. Hansen, & G. Verdier (Eds.), *Well Spent, How Strong Infrastructure Governance Can End Waste in Public Investment* (pp. 15–29). International Monetary Fund. https://doi.org/10.5089/9781513511818.071.ch002

Mlambo, C. (2021). The Impact of Port Performance on Trade: The Case of Selected African States. *Economies, 9*(4), 1–18. https://doi.org/10.3390/economies9040135

Mudronja, G. (2020). Inovacije i tehnološki napredak u poslovanju morskih luka i njihov utjecaj na gospodarstvo. In K. Skala (Ed.), *MIPRO 2020 43rd International Convention Proceedings* (pp. 1737–1742). Croatian Society for Information, Communication and Electronic Technology – MIPRO.

Mudronja, G., Jugović, A., & Škalamera-Alilović, D. (2019). Research and Development and Economic Growth: EU Port Regions. *Zbornik Radova Ekonomskog Fakulteta u Rijeci, 37*(2), 587–602. https://doi.org/10.18045/zbefri.2019.2.587

Mudronja, G., Jugović, A., & Škalamera-Alilović, D. (2020). Seaports and Economic Growth: Panel Data Analysis of EU Port Regions. *Journal of Marine Science and Engineering, 8*(12), 1–17. https://doi.org/10.3390/jmse8121017

Munim, Z. H., & Schramm, H.-J. (2018). The impacts of port infrastructure and logistics performance on economic growth: the mediating role of seaborne trade. *Journal of Shipping and Trade, 3*(1), 1–19. https://doi.org/10.1186/s41072-018-0027-0

Napolitano, L., Sbardella, A., Consoli, D., Barbieri, N., & Perruchas, F. (2022). Green innovation and income inequality: A complex system analysis. *Structural Change and Economic Dynamics,* 63, 224–240. https://doi.org/10.1016/j.strueco.2022.09.007

Notteboom, T. E., & Winkelmans, W. (2001). Structural changes in logistics: how will port authorities face the challenge? *Maritime Policy & Management, 28*(1), 71–89. https://doi.org/10.1080/03088830119197

OECD. (2021). *Assessing the Economic Impacts of Environmental Policies: Evidence from a Decade of OECD Research*. OECD Publishing. https://doi.org/10.1787/bf2fb156-en

Özer, M., Canbay, Ş., & Kırca, M. (2021). The impact of container transport on economic growth in Turkey: An ARDL bounds testing approach. *Research in Transportation Economics, 88*. https://doi.org/10.1016/j.retrec.2020.101002

Parikesit, D., Basalim, S., & Wibowo, W. W. (2019). The Critical Importance of Land Transport when Considering Port Development, The Case of Three Indonesian Ports. In C. Duffield, F. K. P. Hui, & S. Wilson (Eds.), *Infrastructure Investment in Indonesia*: *A Focus on Ports* (pp. 281–326). Open Book Publishers. https://doi.org/10.11647/OBP.0189.11

Park, J. S., & Seo, Y. J. (2016). The impact of seaports on the regional economies in South Korea: Panel evidence from the augmented Solow model. *Transportation Research Part E: Logistics and Transportation Review, 85*, 107–119. https://doi.org/10.1016/j.tre.2015.11.009

Porter, M. E. (1998). Clusters and the New Economics of Competition. *Harvard Business Review, 76*(6), 77–90.

Prettner, K., & Strulik, H. (2020). Innovation, automation, and inequality: Policy challenges in the race against the machine. *Journal of Monetary Economics, 116*, 249–265. https://doi.org/10.1016/j.jmoneco.2019.10.012

Rodríguez-Navarro, A., & Brito, R. (2022). The link between countries' economic and scientific wealth has a complex dependence on technological activity and research policy. *Scientometrics, 127*(5), 2871–2896. https://doi.org/10.1007/s11192-022-04313-w

Rodríguez-Pose, A., & Crescenzi, R. (2008). Research and development, spillovers, innovation systems, and the genesis of regional growth in Europe. *Regional Studies, 42*(1), 51–67. https://doi.org/10.1080/00343400701654186

Seo, Y. J., & Park, J. S. (2017). The role of seaports in regional employment: evidence from South Korea. *Regional Studies, 52*(1), 80–92. https://doi.org/10.1080/00343404.2016.1262014

Shan, J., Yu, M., & Lee, C. Y. (2014). An empirical investigation of the seaport's economic impact: Evidence from major ports in China. *Transportation Research Part E: Logistics and Transportation Review, 69*, 41–53. https://doi.org/10.1016/j.tre.2014.05.010

Thai, V. V., Yeo, G.-T., & Pak, J.-Y. (2016). Comparative analysis of port competency requirements in Vietnam and Korea. *Maritime Policy & Management, 43*(5), 614–629. https://doi.org/10.1080/03088839.2015.1106017

Tijan, E., Jović, M., Žgaljić, D., & Aksentijević, S. (2022). Factors Affecting Container Seaport Competitiveness: Case Study on Port of Rijeka. *Journal of Marine Science and Engineering, 10*(1346), 1–17. https://doi.org/10.3390/jmse10101346

UNCTAD. (2022). *Why ports are at the heart of sustainable development*. Available at: https://unctad.org/news/why-ports-are-heart-sustainable-development

UNCTAD. (2023). *Review of Maritime Transport 2023*. Available at: https://unctad.org/publication/review-maritime-transport-2023

Wooldridge, J. M. (2015). *Introductory Econometrics: A Modern Approach*. Cengage Learning.

Xing, J. (2021). Research on port competitiveness and port and city synergy in China's Bohai Rim. *ICIC Express Letters, 15*(11), 1203–1210. https://doi.org/10.24507/icicel.15.11.1203