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The Importance of Logistics Variables on Port Performance Analysis: A DEA Approach to Analyzing 57 Ports in the World Port Ranking

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Abstract - **Port performance is an important gateway to countries and business entities. This study aims to explore the importance of logistics variables towards port performance measurement. A standard method used to measure port performance is the analysis of its inputs and outputs based on port characteristics, such as length of berth, number of cranes, and depth. Indubitably, these approaches are among the most practical used by scholars to measure port performance. However, other external factors, such as logistical variables, need special attention, as they have been discussed in previous studies as having the capability to influence the measurement of a port's performance. As such, this study measures the technical efficiency of 57 ports, ranked among the most efficient ports globally, via a Data Envelopment Analysis (DEA) and uses sensitivity analysis to measure the impact logistics variables have on the measurement of performance. For robustness checking, the Robust Fixed Effects tool was applied to measure the impact of the logistics variables on port technical efficiency. The results show that logistics variables significantly impact the technical efficiency measurements of ports.**

Keywords – *DEA, logistics, port performance, ports, technical efficiency*

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I. Introduction

Global seaborne trade is doing well and expanding at a rate of 4 per cent, the fastest growth seen in five years. Global maritime trade has gathered momentum and raised sentiments in the shipping industry (UNCTAD, 2017). It is also reported that the total volumes have reached 10.7 billion tons, reflecting an additional 41 million tons, nearly half of which were made of dry bulk commodities. However, due to the Covid 19 pandemic, the value of the maritime industry has declined from 2.8 per cent in 2018 to 0.5 per cent in 2019 (Maritime, 2020). Some 80 per cent of this international trade is channeled through ports. Thus, ports play a crucial role in connecting many developing countries with port communities to international trade (De Langen, 2015). Current arising issue of supply disruption, causing other economic problems such as increasing prices and disrupted production is a strong enough evidence on the importance of transportation, and given that the high volume of trade is handled through ports, that makes port efficiency study highly relevance.

Ports are essential in logistics' supply chain systems and are at the forefront of national and regional trading. The performance of port and logistics systems are significant to the current business of trade. As of now, there are various port efficiency and logistics performance studies done in different contexts. Port efficiency is measured via various methods, indicators, and benchmarks, while, in logistics, the Logistics Performance Index (LPI), created by the World Bank, is the leading indicator used to evaluate the whole segment of logistics performance. The LPI is an indicator and benchmark used by investors to choose locations for various purposes (Lauri Ojala and Celebi, 2015). Exploring ports and logistics in a single study has not been attractive to many scholars because ports and logistics were considered to be separate issues. However, recently, due to constraints of revenue caused by cost increments in port operations, and a slow demand growth resulting from the pandemic, port operators are operating their ports more efficiently. Hence, external factors that might influence port efficiency, such as logistics inputs, must be considered to accelerate port performance in the market.

Various parties are involved in logistics' supply chain systems, including ports, shipping liners, warehouses, hinterlands, cargo movers, road transports, and up-to-last mile delivery. No doubt, ports are recognized as a primary component of the supply chain. Thus, the performance of the ports is critical. Currently, port performance is monitored through port efficiency measurements, which are significant for making decisions on investments, shipping, and other purposes. In logistics, time is a constraint, and delays incur additional transportation costs, thus reducing port efficiency. One of the standard methods used to measure efficiency is the Data Envelopment Analysis (DEA). Previous researchers have used it extensively to measure the efficiency of ports via the input and output approach. In this measurement method, input typically refers to the size and capacity of the ports, whereas output is the container's throughput, measured in TEUs (twenty-foot equivalent units). However, in reality, the efficiency of ports is not only influenced by the size and capacity of the ports' infrastructures, but also many things, such as the logistics performance and regulations. A good infrastructure is not enough if one's delivery systems are poor (Arvis et al., 2014). The delay of a customs inspection and slow documentation processing speeds are examples of poor logistics delivery systems that can influence a port's performance. Others studies also acknowledged the importance of policies by government, such as study by Parvin, et al. (2017) had analyzed the impacts of government decisions such as Brexit policy which influenced the economy of New Zealand. Government act also found very influential in facilitating the business rather than direct roles in the market Ramaiah (2018). Thus, current knowledge and methods of measuring port performance are incongruous with logistics' supply chain systems (Bichou, 2006).

Investors need to select ports based on the accuracy of their port's efficiency measurements and rankings. The wrong measurements, such as those that dismiss logistics performance, can seriously affect the efficiency measurements. Thus, it can be said that logistics performance plays a significant role in port efficiency measurement, and a serious study on these matters had to be conducted for the benefit of many parties. To date, there are minimal studies on logistics as an input of ports measured via DEA. Thus, this study developed a model of the DEA-L, where logistics performance was added as an input, on top of the conventional inputs, to measure the impact of logistics variables in a sensitivity analysis.

This paper is organized into several sections; the next section (Section 2.0) reviews the literature related to the efficiency of port measurements and the studies on logistics' effects on port performance. Section 3.0 explains the methods applied in this study, namely DEA, sensitivity analysis, and econometrics estimation. The section after discusses the results of the research, and the final section is the conclusion.

II. Literature Review

The efficiency measurement of ports is one of the preferred focuses of previous scholars in the transportation field. There are three approaches to port performance measurement, which are individual metrics and indices, economic impact studies, and frontier approaches (Bichou, 2006). Bichou (2006) explains that the first approach of individual metrics and indices is not suitable for measuring port performance, as it only provides snapshot measurements, such as for a single port. The second approach of using economic impact studies and general equilibrium is inconsistent with the structure of ports, since they rely on many constraints, such as perfect competition, a constant return to scale, and free labor movement between sectors. Therefore, this study will focus on the third approach, frontier analysis, as it is suitable for ports due to two main reasons: it accommodates multiple inputs and outputs, and there is no necessity to pre-define relative weight relationships. It also does not require an assumption about the technology, firms, or decision-making units (DMUs), benchmarked against an actual 'best' firm, and instead relies on a statistical measure. In the same vein, Lovell (1996) notes that there are three ways to analyze efficiency, known as the Deterministic Frontier Analysis (DFA), Stochastic Frontier Analysis (SFA), and Data Envelopment Analysis (DEA). DFA is defined by the maximum distance between inputs and outputs. Random error and characteristic deviations from the frontier are interpreted as inefficiency (Coelli, Prasada Rao, O'Donnell, and Battese, 2005). On the other hand, SFA is an alternate method to frontier estimation that assumes a given functional form for the relationship between inputs and outputs (Coelli et al., 2005). Finally, DEA is a nonparametric method used in operations research and economics to estimate production frontiers. It is used to empirically measure the productive efficiency of DMUs.

Traditionally, the input basis for the performance measurement of ports via DEA has been mainly based on port characteristics, such as port facilities, infrastructures, and capacities. As for the output, port throughput is usually the significant basis applied by scholars. However, the performance of ports might depend on other factors, such as the performance of logistics. Logistics performance has become more critical recently due to several reasons: the incremental cost of delivery, high competition among the ports, and an increment on the cost of importing goods worldwide. Ports have changed their strategy and integrated logistics as a part of their critical value-added services (Woo, Pettit, and Beresford, 2011). Logistics, in the context of performance issues, has become a subject of interest for many researchers.

On top of that, various discussion groups around the world have struggled to find the best solution to enable the highest efficiency in the logistics supply chain. The Logistics Performance Index (LPI), as introduced by the World Bank in 2014, is the best indicator of how important logistics performance is. Several researchers have utilized LPI data and evaluated it in various studies and approaches, including the DEA approach. Components of the LPI might be one of the most critical areas in logistics to explore, wherein six of them are indicators of customs, infrastructure, service quality, timeliness, international shipments, and tracking and tracing.

One study examined the ports in European countries and applied the LPI as variables (Markovits-Somogyi and Bokor, 2014), combining the methodology of the Data Envelopment Analysis – Pairwise Comparison (DEA-PC). This study investigated the logistics efficiency of 29 countries in Europe and used the length of motorways and railways, GDP, wages, and gross investment as its inputs, while the outputs were road transport performance, rail transport performance, and two more outputs from the LPI, which were quality and timeliness. This study offers critical insight into the significance of the LPI as a variable in twofold; firstly, through the integration of quality into DEA analysis, from the timeliness and quality aspects of the LPI being used as outputs of the DEA; and, secondly, through the use of logistics' competence and quality indicators offering evaluative data and benchmarks to which the results of the DEA and DEA-PC analysis could be measured against. Martí, Martín, and Puertas (2017) is another study that applied the LPI to the DEA method. This study used input and output data from the six elements of LPI scoring as its basis. The input were customs, infrastructure, and ease of arrangement shipments, which are considered regulatory policies, whereas the outputs were logistics quality and competence, tracking and tracing, and timeliness, which fall under service delivery performance. This study claims to be the first study to incorporate LPI data into the DEA-LPI model, and then compare its results with the actual LPI. The results were believed to be a more realistic efficiency measurement approach to logistics performance. One of the critical areas highlighted in the LPI is the quality of logistics systems, such as hinterland connectivity and end-to-end logistics systems. A study by Inoue (2018) found that neighboring ports in Japan might be more effective if they jointly enhanced their hinterland access to develop quality logistics systems.

Schøyen et al. (2018) is among the most recent studies done on DEA-related logistics performance at seaports. The research was conducted on 26 ports in 6 countries in Europe to clarify the efficiency of the ports in the continent. DEA, combined with data from various sources, especially LPI data, was used as the study's primary reference. Quay length, terminal areas, number of container-handling trucks, number of straddle carriers, number of yard gantry cranes, and rubber-tyre gantry were used as physical inputs for the DEA. Container throughput was used as the standard output, with an addition of three outputs from the LPI: the ease of arranging price shipments, the ability to track shipments, and timeliness. The purpose of the study was to examine the efficiency of small to medium sized northern European ports, to measure the impact of logistics service delivery outcomes on port efficiency measurements, and to explore the differences in efficiencies between direct calls, deep seaports, and ports with no direct calls. One of the study's most essential findings was the relevancy of input from logistics service deliveries (LPI) as an output to measuring the efficiency of ports, instead of the conventional approach used by previous researchers, which applied the port's throughput as its sole output. This study also found that the infrastructure variable components in the LPI have no significant impact on port efficiency.

Several studies have analyzed and discussed the importance of port performance in the field of logistics. Carbone and De Martino (2003) explained that port performance is determined by its internal strength (infrastructure and port facilities) and its position in the supply chain link. Thus, the deficiencies in port infrastructure are the reason for a port losing customers (Carbone and De Martino, 2003). Talley et al. (2014) concluded that previous studies on port performance consisted of two main topics: port technical efficiency in DEA studies and port effectiveness in performance-indicator studies. The former focuses on relative technical efficiency among the ports in the study, whereas the latter is the study of whether a port is effective in providing port services. In order to explore the effectiveness of port services, the overall port network related to the port service chain must be included in the performance evaluation, especially the quality of the services provided. Bichou (2006) explained that previous studies only focused on a port's quayside operation efficiency and ignored other components of the port service chain. A study by Talley et al. (2014) emphasized the quality of other services in the port network chain, including the speed of the process. Recent studies by Li, Jiang, and Liu (2022) expressed the importance of logistics coastal ports in determining the port performance in China, and Zhang, You, Haiyirete, and Zhang (2020) analyzed the logistics efficiency with the technology heterogeneity and carbon emission elements.

Time is a crucial component in logistics, and the World Bank has categorized it in its LPI as the component of timeliness. There have been several attempts by various scholars to show the importance of time in logistics. A discussion by Ducruet, Itoh, and Merk (2014) on the time efficiency of the world container ports might be one of the most focused discussions on time at port levels. One finding is that the time efficiency of individual ports depends on which country or region the port is located in, and the more significant ports, with more sophisticated and modern terminal handling capacity, have better time efficiency. Next, in the study by Wilmsmeier and Hoffmann (2008), it was proven that cargo delays during customs inspections impact freight rates. One per cent of a reduction in time implies a reduction of 0.051 per cent maritime cost.

Similarly, Nordås (2007) also recognized that minimizing wait times and providing seamless logistics chains are a challenge for logistics services providers. Djankov, McLiesh, and Ramalho (2006) found that a 10 per cent increase in overall transport time reduces the bilateral trade commerce by between 5 per cent and 8 per cent, depending on the sector and the country of destination. This author also concluded that customs and related procedures are the weakest links in the logistics chain and have a significant impact on dampening trade flows. In addition to that, Hummels (2001) revealed that increasing the shipping time to the United States by one day reduces the probability of exporting manufacturing to the country by 1.5 per cent.

III. Methodology

There are two original DEA models, namely the DEA-CCR and DEA-BCC, used in this study. Charnes, Cooper, and Rhodes introduced the former in 1978 as an extension to the Farrell (1957) idea of estimating technical efficiency concerning production. A DEA-CCR model assumes a constant return to scale. Thus, all production combinations can be scaled up and down proportionally. The DEA-CCR model can measure the technical efficiency of DMUs by constructing the ratio of the weighted sum of output to a weighted sum of input. Hence, the relative efficiency of DMUs is maximized, with the constraint that no DMU can have a relative efficiency score more significant than one.

On the other hand, as Banker, Charnes, and Cooper introduced in 1984, the DEA-BCC model allows for a variable return to scale. The DEA-CCR imposes constraint convexity in its model; alternately, the DEA-BCC relaxes these constraints by measuring efficiency in variables' return to scale. The result was that, where the DEA-CCR can only measure technical efficiency, the DEA-BCC can measure both technical and scale efficiency. Thus, the DEA-CCR and DEA-BCC defined different production possibilities and efficiency results (Wang, Cullinane, and Song, 2003). For this study, we applied the DEA-BCC model to complement the variables' return to scale. To apply DEA to this research, the DEAP software was used to process all the inputs and outputs.

To measure the efficiency of each port, first, we followed the DEA-CCR model of Charnes, Cooper, and Rhodes (1978), as expressed by: -

$$\theta^* = \min \theta$$

Subject to:

$$\sum_{j=1}^{n} x_{ij}\,\lambda_j \le \theta x_{i0} \quad i = 1,2,\dots,m$$

$$\sum_{j=1}^{n} y_{rj}\,\lambda_j \ge y_{r0} \quad r = 1,2,\dots,s$$

$$\lambda \ge 0 \qquad\qquad j = 1,2,\dots,n$$

Where θ^* is the relative efficiency of the DMU; y_{r0} and x_{i0} represent rth output and ith inputs, respectively; and the λ is the decision variables of the weights DMUj would place on DMU0. The above equation assumes n DMUs for efficiency analysis. Each of the DMUs uses m inputs to produce s outputs. Hence, $x_{ij} > 0$ is the amount of input i used by the DMUs j, and $y_{rj} > 0$ is the amount of output r produced by the DMUs. The θ^* shows that it is possible to obtain a unit value that is relatively efficient, or less than the unity value, representing inefficient DMUs. Finally, the DEA-BCC model derived from the original DEA-CC, with an additional convexity condition of $\sum_{j=1}^{n} \lambda_j$, was added into the model.

The DEA-BCC port technical efficiency result in the first stage consisted of all the port characteristics and logistics variables. Next, to evaluate the impact of the logistics variables, we omitted the logistics variables from the DEA-BCC model and deployed a second calculation of the DEA-BCC. Finally, we compared the results before and after the omission of logistics variables and verified the changes in a sensitivity analysis.

As for the robustness test, this research employed econometrics estimations to examine the relationship between the logistics variables and the technical efficiency of the port. After we run the Hausman test, it was suggested that FE model is preferred to RE model. Next, the Wooldridge test showed the model suffer from the heteroscedasticity, thus we used Robust Fixed Effects to estimate the results.

We employed the equation in 1.0 to measure the correlation between logistics variables and technical efficiency.

$$TE_{it} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \mu_{it} \qquad (1.0)$$

Where,
TE_{it} = technical efficiency
β_0 = Constant
β_1 = waiting time
β_2 = plsci
β_3 = cost export border
β_4 = time import documentation
β_5 = time import border
μ_{it}= error term

IV. Data

As the research intended to learn the impact logistics variables have, several inputs from two main contributors were elected. First, the port characteristics and, second, the logistics variables. As stated by the United Nations (1976) in section 2.3, the performance of port operations is an important indicator. Excellent operational performance can contribute to making a port's financial performance excellent. According to the UN, the most complicated port operation is the turn-around time of ships in port. An excellent indicator to monitor these effects by is the quantity of cargo worked per ship hour in port. The UN suggests that information be recorded on the activities of the port and ships that are related to the port's infrastructure and cargo load and are time-consuming. The UN suggests that port operational performance variables consist of two major components: the port's characteristics, such as the infrastructure, facilities, and equipments; and the time consumed in the undertaking of all port-related activities, measured in cargo worked per hour, for instance.

The data in Table 1.0 shows length of berth (LOB), depth of port (DOP), and total number of cranes (TQC) used as input for the DEA. The berth is a location at the port where ships or tankers berth to unload their containers. The LOB is measured in meters. The LOB provides extra benefits to the port operators due to their capacity to attract huge ships or tankers to berth at the port, thus influencing the berth length. The DOP was selected as an input due to the importance of a port's depth, as a port's ability to handle supertankers without limits is important to its operations. The TQC is the number of quay cranes used at the berth. Quay cranes move and relocate containers from ships or tankers to berths, or vice versa. There are many types and sizes of quay cranes available at ports; some come with the latest technology, high-end specifications, and special capabilities to deal with large or huge ships or tankers. Different quay cranes have different capabilities; thus, it influences the speed of the berthing process at port. TQC is measured by the number of cranes available at the port; the more quay cranes at port, the more significant the number of the containers manageable, and the faster the speed of operations.

Since the current study measures the importance of the logistics variables, the logistics aspects must be included in the measurement. Therefore, one prominent variable that determined how time-consuming the operations of the port was logistics performance, and the only data currently available on logistics performance is the Logistics Performance Index (LPI), which measures and indexes timeliness as one of its scoring components. Timeliness in the LPI refers to the frequency of shipments reaching their consignees within the scheduled or expected delivery times. However, LPI data changes from country-to-country and not port-to-port. Thus, the most relevant data about time and availability available, in terms of ports, is the Container Waiting Time (CWT), which measures ships' waiting times before they are granted access to the port's berth to unload their containers. CWT's data is information on how many days ships or tankers are made to wait to berth at the port. After departure from the original port, once the vessels approach the destination port's anchorage, an approval or grant from the port operators is a must before berthing. If the port is efficient, the waiting time is, at the minimum, a number of days, thus reducing the ship's operational cost and the amount of time wasted, as explained by Suárez-Alemán et al. (2014). In container management, time efficiency is critical to shipping liners. Above time, another criterion that affects the process is called trade facilitation, and it is vital to container management at ports. Therefore, in this research, a second logistics variable, namely the Port Liner Shipping Connectivity Index (PLSCI), was applied. There are two critical measures in the PLSCI, namely connectivity to maritime shipping and trade facilitation. The PLSCI reflects the strategies of container shipping lines seeking to maximise their revenue through market coverage. A good port with a high PLSCI index can create greater port competitiveness, thus influencing port efficiency (Figueiredo De Oliveira and Cariou, 2015).

Shipping connectivity is always associated with freight rates; the more significant the number of shipping lines, the lower the freight rates (Márquez-Ramos, Martínez-Zarzoso, Pérez-García, and Wilmsmeier, 2011). Four core components in the PLSCI are containership deployment, container carrying capacity, number of companies involved in shipping, and vessel size. These variables are indicators of how good or poor logistics performance is at the port. Both CWT and PLSCI were tested via sensitivity analysis from the DEA results to show the impact of the logistics variables on the model. The data in Table 2.0 represents the descriptive data of the CWT and PLSCI.

Table 1.0: Descriptive statistics of port characteristics for 57 ports (2019)

Number of ports	The Year of 2019	Length of berth (LOB)	Depth of Port (DOP)	Total Quay Cranes (TQC)
57	Mean	4201.053	15.675	51.544
	Minimum	555	9	9
	Maximum	13735	24	184
	Standard Deviation	3228.3194	2.5467	4201.053

Source: Author's calculations

Table 2.0: Descriptive statistics of logistics variables for 57 ports (2019)

Number of ports	Year		Minimum	Maximum	Mean	Standard Deviation
57	2019	TEU (Port Throughput)	1680751.00	43303000.00	7771014.95	8396652.04
		CWT (Container Waiting Time	52.27	14265.58	1127.01	2260.20
		PLSCI (Port Liner Shipping Connectivity)	1.51	134.32	53.81	27.98

Source: Author's calculations

As shown in Table 1.0, LOB, DOP, and TQC were selected as the ports' facility inputs, for representing port characteristics, whereas CWT and the PLSCI were selected for the logistics inputs of the DEA. The output of the DEA is the port throughput, as measured in number of containers, which were in TEUs.

The primary data for the inputs and outputs of both analyses of the DEA is as stipulated in Table 3.0. The data was outsourced from various sources, such as the Lloyd's List Maritime Intelligence Port Ranking 2020, Thomson and Reuters' EIKON, UNCTAD, International Association of Ports and Harbour (IAPH), the latest information from the online ports' communities (worldportsource.com and searates.com), port websites, and annual port reports.

As for the ports, 57 strategic ports around the world were selected for this research. The selected ports are the most strategic ports representing most of their individual regions, and all the ports possess similar operational standards as importer, exporter, and transshipment ports. Those ports are also listed in the One Hundred Ports Lloyd's List (2020) ranking, the most up-to-date list of the best performing ports in the world ranking.

Table 3.0: List of inputs, names, unit measurements, and sources (DEA)

Inputs/Output	Name	Unit Measurement	Source
Input	Length of berth (LOB)	The total length of berth in meters (m)	Lloyd's List, IAPH, worldportsource.com, searates.com and annual port report
Input	Depth of port (DOP)	Depth of port in meters (m)	Lloyd's List, IAPH, worldportsource.com, searates.com and annual port report
Input	Quay cranes (TQC)	Total number of quay cranes (unit)	Lloyd's List, IAPH, worldportsource.com, searates.com and annual port report
Input	Container Waiting Time (CWT)	Total number of waiting time (days)	Thomas and Reuters

Input	**Port Liner Shipping Connectivity Index (PLSCI)**	**Port Liner Shipping Connectivity Index**	**UNCTAD**
Output	Port Throughput (TEU)	Annual Container Throughput (TEU)	Lloyd's List

Source: Author's calculations

Table 4.0: List of variables, unit measurements, and sources

Variables	**Name**	**Unit Measurement**	**Source**
Dependent Variable	Technical Efficiency (TE)	DEA	Author's calculation
Independent Variable	Container Waiting Time (WT)	Index	Thomson and Reuters EIKON
Independent Variable	Logistics Time (LPITIME)	Index	World Bank
Independent Variable	Port Liner Shipping Connectivity Index (PLSCI)	Index	World Bank
Independent Variable	Cost of Export at Border (COSTEXPBORDER)	Index	World Bank
Independent Variable	Time Import Documentation (TIMIMDOC)	Index	World Bank
Independent Variable	Time Import at Border (TIMIMBORDER)	Index	World Bank

Source: Author's calculations

V. Results and Discussions

The DEA provides a mathematical programme to evaluate and estimate the best practices of frontier production and efficient DMUs. In this study, DMUs are the terminal containers that were evaluated to measure the best performance of terminal containers. The DEA approach finds the smallest enveloping set of inputs to outputs of all DMUs; hence the name Data Envelopment Analysis. This approach can be either input or output-oriented, where the former minimizes the inputs for a set of given outputs, and the latter maximizes the output for a set of given inputs (Kutin, Nguyen, and Vallée, 2017a). In many previous studies of port performance, the output-oriented approach was applied. Ports typically deal with massive investments into mega infrastructures (inputs); thus, minimizing inputs is not the best choice for port managers (Kutin et al., 2017a). Therefore, in port, port managers instead choose to increase the output of the port's throughput. Overall, the chosen orientation should select either inputs or outputs within the manager's control (Coelli et al., 2005). In this study, the output approach was applied.

First, this study employed the DEA-BCC based on a variable return to scale (VRS). Table 4.0 shows the results of the technical efficiency rates obtained using the DEA-BCC model. As shown in the table, out of 57 ports, 24 ports are shown to be technically efficient, with a score of 1. The efficient ports are in Antwerp, Bremerhaven, Busan, Colon, Genoa, Guayaquil, Ho Chi Minh, Khor Fakkan, Los Angeles, Manila, Manzanillo, Melbourne, Mundra, Ningbo-Zhoushan, Osaka, Port Said, Qingdao, Rizhao, Shanghai, Singapore, Southampton, St. Petersburg, Tianjin and Xiamen. These ports found to be more efficient than others port is based on several factors such as the efficient port infrastructures, and second, most of these ports are strategically located in the main containers ship routes.

On the other hand, 33 ports, or 58% of the total ports, operate inefficiently. These ports are in Algeciras, Ambarli, Balboa, Barcelona, Cartagena, Dalian, Durban, Felixstowe, Hong Kong, Houston, Incheon, Jakarta,

Jeddah, Kaohsiung, Karachi, Kobe, Laem Chabang, Lianyungang, Long Beach, Mersin, New York, Piraeus, Port Klang, Rotterdam, Salalah, Santos, Taichung, Tanger Med, Tanjung Pelepas, Tokyo, Valencia, Vancouver, and Yokohama. The least efficient port is the port of Mersin, with a DEA score of 0.162.
As shown in Figure 1.0, we concluded that 42% of the ports are efficient ports, and 21% of these ports are situated in Asia. One interesting finding is that China is the only country to have more than one efficient port, where six of the most efficient ports are located in China. China is recognized as one of the most efficient ports in the world, based on the volumes of TEUs and position in the world port ranking. China's ports mostly fully equipped with latest and advanced technology for containers management, makes them more advanced compared to others ports.

Table 5.0: DEA-BCC Results of 57 Ports

No	Port	Variable Return to Scale Technical Efficiency	Increasing /Decreasing Return to Scale	No	Port	Variable Return to Scale Technical Efficiency	Increasing /Decreasing Return to Scale
1	Antwerp	1	irs	30	Vancouver (Can)	0.75	irs
2	Bremerhaven	1	irs	31	New York	0.742	-
3	Busan	1	-	32	Laem Chabang	0.711	irs
4	Colon	1	irs	33	Hong Kong	0.705	-
5	Genoa	1	irs	34	Dalian	0.673	irs
6	Guayaquil	1	irs	35	Jakarta (Tanjung Priork)	0.665	irs
7	Ho Chi Minh City	1	-	36	Santos	0.625	irs
8	Khor Fakkan	1	irs	37	Salalah	0.623	irs
9	Los Angeles	1	-	38	Port Kelang	0.579	drs
10	Manila	1	irs	39	Karachi	0.577	irs
11	Manzanillo (Mex)	1	irs	40	Tanger Med	0.551	irs
12	Melbourne	1	irs	41	Yokohama	0.546	irs
13	Mundra	1	irs	42	Rotterdam	0.531	drs
14	Ningbo and Zhoushan	1	-	43	Inchon	0.528	irs
15	Osaka	1	irs	44	Tokyo	0.514	irs
16	Port Said	1	irs	45	Kaohsiung	0.494	irs
17	Qingdao	1	-	46	Jeddah	0.472	irs
18	Rizhao	1	irs	47	Houston	0.471	irs
19	Shanghai	1	-	48	Valencia	0.449	irs
20	Singapore	1	-	49	Felixstowe	0.429	irs
21	Southampton	1	irs	50	Balboa	0.421	irs
22	St Petersburg	1	irs	51	Algeciras	0.412	irs
23	Tianjin	1	-	52	Taichung	0.41	irs
24	Xiamen	1	-	53	Durban	0.374	irs
25	Tanjung Pelepas	0.962	drs	54	Barcelona	0.323	irs
26	Lianyungang	0.959	irs	55	Ambarli	0.288	irs
27	Piraeus	0.951	irs	56	Kobe	0.277	irs
28	Long Beach	0.772	irs	57	Mersin	0.162	irs
29	Cartagena	0.75	irs		Mean	0.749	

Source: Author's calculations

Next, we used sensitivity analysis to measure the impact of logistics variables on port performance. The DEA-BCC was ran in two stages. First, all the variables were set to consist of port characteristics and logistics variables, then, in the second stage, the logistics variables were deleted from the DEA-BCC measurement. The results in Table 6.0 explain the sensitivity analysis results, which details the differences in each port's performance after the two logistics variables were deleted from the DEA calculations. First, the analysis shows the change in DEA-BCC scores once the CWT and PLSCI were deleted from the DEA calculations. This analysis assumed that any change in score of more than 0.1 points was a significant change.

Thus, as stipulated in the table, the results found that 37 ports, or more than 66% of the total ports, faced significant change after the WT and PLSCI were deleted from the measurements of the DEA. These ports are the ports of Algeciras, Ambarli, Antwerp, Balboa, Bramen, Cartagena, Colon, Felixstowe, Guayaquil, Ho Chi Minh, Hong Kong, Houston, Incheon, Tanjung Priok, Jeddah, Kaohsiung, Karachi, Khor Fakkan, Kobe, Liam Chabang, Liangyungang, Long Brach, Los Angeles, Manila, Manzanillo, Melbourne, Mundra, New York, Port Klang, Rizhao, Rotterdam, Salalah, Santos, Southampton, St. Petersburg, Tanger Med, Tanjung Pelepas, Tianjin, and Vancouver. These results prove that both logistics variables (CWT and PLSCI) significantly impact port performance analysis.

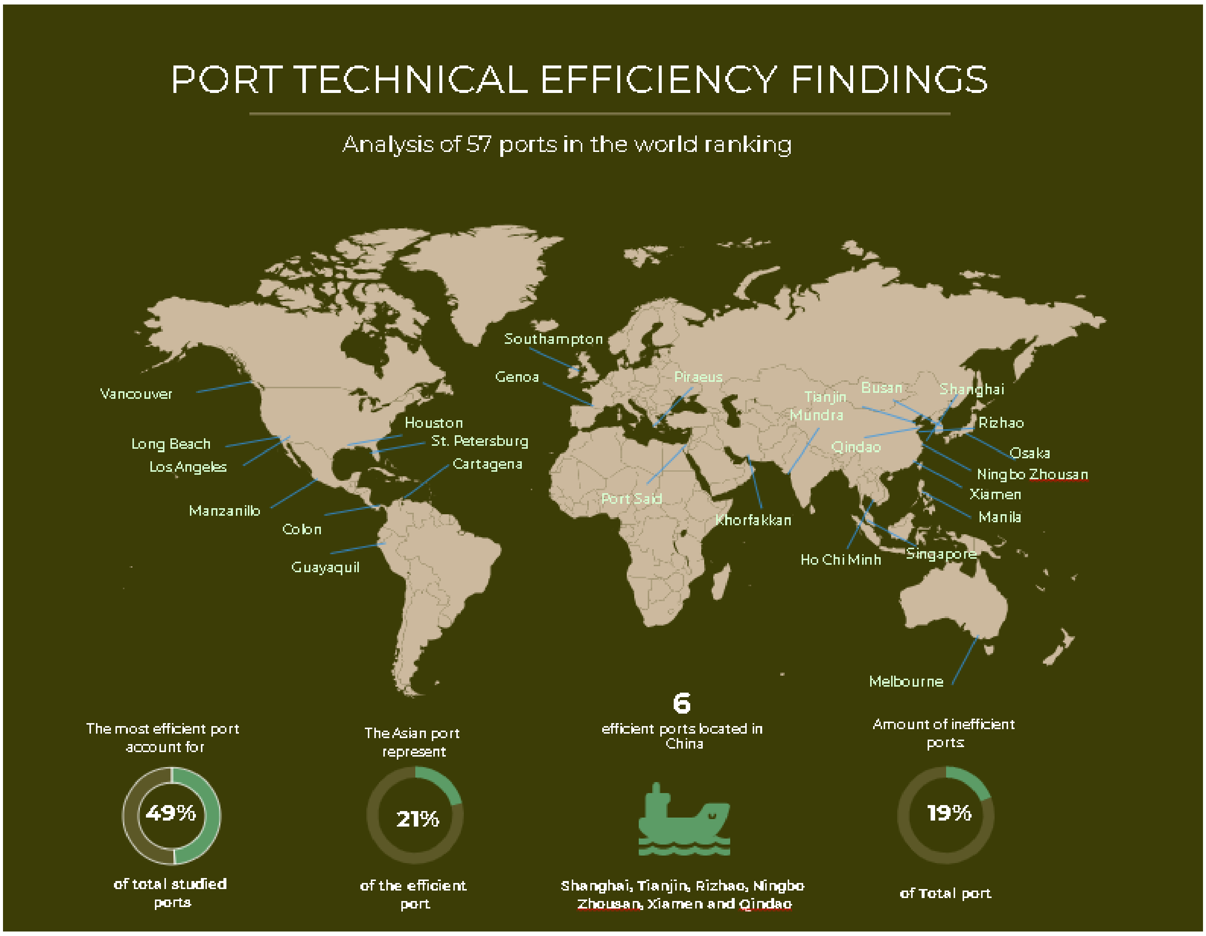

Figure 1.0: Analysis of Port Technical Efficiency

The below results lead to the conclusion that some ports depend very much on PLSCI and CWT as their inputs for port efficiency. The PLSCI is an essential factor for measuring time constraints on the transhipment of containers. The port with the higher shipping connectivity has a quicker transhipment process due to the number of days needed to deliver the containers being shorter. On top of that, CWT is another concern of port operators due to the importance of time factors that influence a port's performance. A port with a low CWT rate represents a more efficient port than one with a high CWT.

On average, the results of port performance based on VRS decreased in various categories, with changes being between 10 to 70 per cent. Eleven ports did not change in the first category after the logistics variables were deleted from the calculations, including Busan, Guayaquil, Ho Chi Minh, Manila, Ningbo-Zhoushan, Osaka Piraeus, Port Said, Shanghai, Singapore, and Xiamen. These are the ports with the highest DEA scores, where the value of each score is equal to one (1). These ports might be the most efficient, based on the DEA calculations. Thus, the logistics elements at these ports may be concluded to be excellent. Therefore, the omission of both logistics variables had no effect on their performances in the sensitivity analysis.

Next is the category of changes amounting to less than 20 per cent, in which there are ten ports: Qingdao, Antwerp, Hong Kong, Dalian, Kaohsiung, Durban, Tokyo, Santos, Valencia, and Yokohama. The next category, which is for changes between 20 to 40 per cent, has 11 ports: Barcelona, Rotterdam, Port Klang, Rizhao, Mundra, Genoa, Tanjung Priok, Tanger Med, Laem Chabang, Lianyungang, and Incheon. After that is the category of ports which saw more than 40 to 60 per cent of changes between their scores: Algeciras, Houston, Taichung, Kobe, Bramen, Mersin, Tianjin, St. Petersburg, Ambarli, Melbourne, and Balboa. Lastly are the ports which underwent 70 to 80 per cent score changes: Southampton, Jeddah, Felixstowe, Cartagena, Colon, Tanjung Pelepas, Long Beach, New York, Los Angeles, Manzanillo, Salalah, Vancouver, and Khorfakkan.

Table 6.0: Results of Sensitivity Analysis

No	Port	Variable Return to Scale Technical Efficiency (All Variables)	Variable Return to Scale Technical Efficiency (After Logistics Variable Deleted)	Differences	%	Increasing /Decreasing Return to Scale	Increasing /Decreasing Return to Scale (After Logistics Variables deleted)	Differences
1	Khor Fakkan	1	0.221	**0.779**	77.90	irs	irs	no change
2	Vancouver (Can)	0.75	0.187	**0.563**	75.07	irs	irs	no change
3	Salalah	0.623	0.178	**0.445**	71.43	irs	drs	decrease
4	Manzanillo (Mex)	1	0.293	**0.707**	70.70	irs	irs	no change
5	Los Angeles	1	0.298	**0.702**	70.20	-	irs	increase
6	New York	0.742	0.234	**0.508**	68.46	-	irs	increase
7	Long Beach	0.772	0.249	**0.523**	67.75	irs	irs	no change
8	Tanjung Pelepas	0.962	0.326	**0.636**	66.11	drs	drs	no change
9	Colon	1	0.37	**0.63**	63.00	irs	drs	decrease
10	Cartagena	0.75	0.285	**0.465**	62.00	irs	irs	no change
11	Felixstowe	0.429	0.165	**0.264**	61.54	irs	drs	decrease
12	Jeddah	0.472	0.184	**0.288**	61.02	irs	irs	no change
13	Southampton	1	0.394	**0.606**	60.60	irs	irs	no change
14	Balboa	0.421	0.171	**0.25**	59.38	irs	drs	decrease
15	Melbourne	1	0.407	**0.593**	59.30	irs	irs	no change
16	Ambarli	0.288	0.118	**0.17**	59.03	irs	irs	no change
17	Karachi	0.577	0.248	**0.329**	57.02	irs	irs	no change
18	St Petersburg	1	0.488	**0.512**	51.20	irs	irs	no change
19	Tianjin	1	0.495	**0.505**	50.50	-	drs	decrease
20	Mersin	0.162	0.084	0.078	48.15	irs	-	-
21	Bremerhaven	1	0.529	**0.471**	47.10	irs	irs	no change
22	Kobe	0.277	0.147	**0.13**	46.93	irs	irs	no change
23	Taichung	0.41	0.241	**0.169**	41.22	irs	irs	no change
24	Houston	0.471	0.278	**0.193**	40.98	irs	irs	no change
25	Algeciras	0.412	0.244	**0.168**	40.78	irs	drs	decrease
26	Inchon	0.528	0.321	**0.207**	39.20	irs	irs	no change
27	Lianyungang	0.959	0.589	**0.37**	38.58	irs	irs	no change
28	Laem Chabang	0.711	0.441	**0.27**	37.97	irs	drs	decrease
29	Tanger Med	0.551	0.356	**0.195**	35.39	irs	drs	decrease
30	Jakarta (Tanjung Prio	0.665	0.454	**0.211**	31.73	irs	irs	no change
31	Genoa	1	0.687	**0.313**	31.30	irs	irs	no change
32	Mundra	1	0.713	**0.287**	28.70	irs	irs	no change
33	Rizhao	1	0.751	**0.249**	24.90	irs	irs	no change
34	Port Kelang	0.579	0.448	**0.131**	22.63	drs	drs	no change
35	Rotterdam	0.531	0.411	**0.12**	22.60	drs	drs	no change
36	Barcelona	0.323	0.258	0.065	20.12	irs	irs	no change
37	Yokohama	0.546	0.437	**0.109**	19.96	irs	irs	no change
38	Valencia	0.449	0.367	0.082	18.26	irs	irs	no change
39	Santos	0.625	0.513	**0.112**	17.92	irs	irs	no change
40	Tokyo	0.514	0.435	0.079	15.37	irs	irs	no change
41	Durban	0.374	0.319	0.055	14.71	irs	irs	no change
42	Kaohsiung	0.494	0.429	0.065	13.16	irs	irs	no change
43	Dalian	0.673	0.6	0.073	10.85	irs	irs	no change
44	Hong Kong	0.705	0.637	0.068	9.65	-	irs	increase
45	Antwerp	1	0.938	0.062	6.20	irs	irs	no change
46	Qingdao	1	0.942	0.058	5.80	-	drs	decrease
47	Busan	1	1	0	0.00	-	-	-
48	Guayaquil	1	1	0	0.00	irs	irs	no change
49	Ho Chi Minh City	1	1	0	0.00	-	irs	increase
50	Manila	1	1	0	0.00	irs	irs	no change
51	Ningbo and Zhoushar	1	1	0	0.00	-	-	-
52	Osaka	1	1	0	0.00	irs	irs	no change
53	Piraeus	0.951	0.951	0	0.00	irs	irs	no change
54	Port Said	1	1	0	0.00	irs	irs	no change
55	Shanghai	1	1	0	0.00	-	-	-
56	Singapore	1	1	0	0.00	-	irs	increase
57	Xiamen	1	1	0	0.00	-	-	-
				37 bold				

Source: Author's calculations

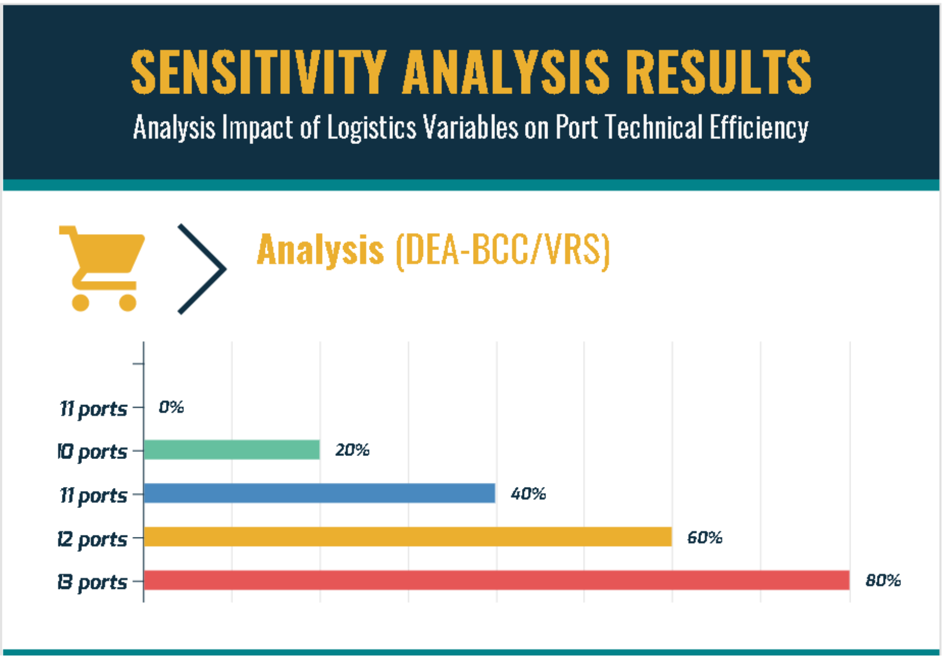

Figure 2.0: Sensitivity Analysis Results

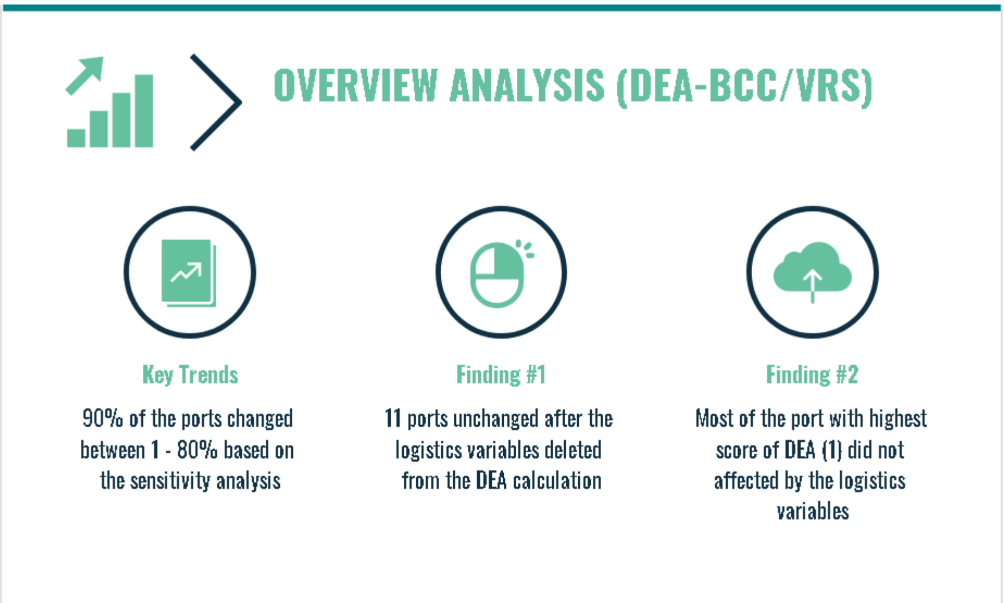

Figure 3.0: Findings of Sensitivity Analysis

The sensitivity analysis results acknowledge the importance of logistics variables as inputs in the DEA method of port technical efficiency measurement. This research also employed econometrics estimations in order to examine the relationship between the logistics variables and the technical efficiency of the ports. As a result, the logistics variable of Waiting Time (WT) was found to be significant, at 1%, with a coefficient of - 0.1086454, meaning that an increment of 1% of WT is able to reduce the technical efficiency of the ports by 0.10%. This result similar to what was found in study of four ports in Indonesia by Aqmarina and Achjar (2018), where the idle time are negatively correlated with the total traffic volume. On top of that, previous study of major port in India between 1992 to 2011, Rajasekar and Deo (2014) finalised that the idle time negatively correlated with port throughput.

As for the second logistics variables, the Port Liner Shipping Connectivity Index (PLSCI) showed a significance of 1% and negatively correlated with technical efficiency, where the coefficient was - 0.0095071. The PLSCI variable showed a contradictory result, as the 1% PLSCI increment is able to reduce 0.009% of a port's technical efficiency.

The study by Luttermann, Kotzab and Halaszovich (2020) is one of the most relevant studies on the impact of logistics on port performance, although it also explores exports, imports, and foreign direct investments. Their results prove that the LPI infrastructure and the LPI ease of arranging shipments have a significant relationship with exports, imports, and foreign direct investments. In 2011 Woo et al. (2011) reported that port performance is multi-faceted, where port performance should not be limited to internal processes and external processes, such as logistics, in the context of connectivity and value-added services.

VI. Conclusions

The DEA-BCC models exhibited a significant change after the sensitivity analysis and econometric estimation of Robust Fixed Effects tested the logistics variables' impact on port technical efficiency. Some ports are sensitive to logistics variables, while others are not. Thus, further study is needed to identify the cause of this sensitiveness, as agreed by Schøyen et al.(2018). Overall, logistics plays a significant role in determining the technical efficiency of a port. As supported by various scholars, logistics is regularly neglected an as input for the measurement of technical efficiency; thus, in terms of improving the technical efficiency of s port, all logistics issues must be included in the decisions made to enhance port performance. Undoubtedly, some logistics variables are on different dimensions and slightly different from port characteristics that generally involve port specifications, such as length of berth and number of cranes, which involve huge investments. Logistics might deal with different dimensions, such as correcting a human error, which delay the inspection process, and mismanagement of container movement that can be improvised from the management sector. Delays in container waiting time might be resolved if the proper system is in place during the container movement process from the ship to the berth. In this case, the issues of human error in handling the containers can be solved by applying ICT systems to accelerate the process.

Logistics variables such as CWT and PLSCI can be improved upon under specific facilitation programmes for ease of container movement, which can reduce the waiting time and improve shipping connectivity. These elements are the responsibility of the managers or parties controlling the port's operations, such as port operators and port authorities.

References

Aqmarina, A., & Achjar, N. (2018). Determinants of Port Performance - Case Study of 4 Main Ports in Indonesia (2005-2015). *Economics and Finance in Indonesia*, *63*(2), 176. https://doi.org/10.7454/efi.v63i2.574

Bichou, K. (2006). Chapter 24 Review of Port Performance Approaches and a Supply Chain Framework to Port Performance Benchmarking. *Research in Transportation Economics*, *17*(06), 567–598. https://doi.org/10.1016/S0739-8859(06)17024-9

Carbone, V., & De Martino, M. (2003). The changing role of ports in supply-chain management: An empirical analysis. *Maritime Policy and Management*, *30*(4), 305–320. https://doi.org/10.1080/0308883032000145618

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, *2*(6), 429–444. https://doi.org/10.1016/0377-2217(78)90138-8

Coelli, T. J., Prasada Rao, D. S., O'Donnell, C. J., & Battese, G. E. (2005). *An introduction to efficiency and productivity analysis*. *An Introduction to Efficiency and Productivity Analysis*. https://doi.org/10.1007/b136381

De Langen, P. W. (2015). Port Management 3. *United Nations Conference on Trade and Development*, *15*(9), 46. https://doi.org/10.1057/9781137475770

Djankov, S., McLiesh, C., & Ramalho, R. M. (2006). Regulation and Growth. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.893321

Ducruet, C., Itoh, H., & Merk, O. (2014). Time Efficiency at World Container Ports. *International Transport Forum*, (2014–08), 30. Retrieved from www.internationaltransportforum.org/jtrc/DiscussionPapers/jtrcpapers.html%5Cnwww.internationaltransportforum.org/jtrc/DiscussionPapers/jtrcpapers.html%5Cnwww.internationaltransportforum.org/jtrc/DiscussionPapers/jtrcpapers.html

Farrell, M. J. (1957). The Measurement of Productive Efficiency. *Journal of the Royal Statistical Society. Series A (General)*, *120*(3), 253–290. Retrieved from http://goo.gl/AFhm2N

Figueiredo De Oliveira, G., & Cariou, P. (2015). The impact of competition on container port (in)efficiency. *Transportation Research Part A: Policy and Practice*, *78*, 124–133. https://doi.org/10.1016/j.tra.2015.04.034

Hummels, D. (2001). Time as trade barrier. *GTAP Working Paper 1152. Purdue University*, (July).

Inoue, S. (2018). Realities and challenges of port alliance in Japan — Ports of Kobe and Osaka. *Research in Transportation Business and Management*, *26*(September 2017), 45–55. https://doi.org/10.1016/j.rtbm.2018.02.004

Jean-François Arvis, Daniel Saslavsky, Lauri Ojala, Ben Shepherd, Christina Busch, & Anasuya Raj. (2014). Connecting to Compete 2014 Trade Logistics in the Global Economy: The Logistics Performance Index, 72. Retrieved from https://openknowledge.worldbank.org/bitstream/handle/10986/20399/904190WP0LPI0R00Box385316B00PUBLIC0.pdf?sequence=1&isAllowed=y

Lauri Ojala, & Celebi, D. (2015). The World Bank ' s Logistics Performance Index (LPI) and drivers of logistics performance. *International Transport Forum*, (February).

Li, H., Jiang, L., & Liu, J. (2022). Research on the Evaluation of Logistics Efficiency in Chinese Coastal Ports Based on the Four-Stage DEA Model.

Lovell, C. A. K. (1996). Applying Efficiency Measurement Techniques to the Measurement of Productivity Change Author (s): Source : Journal of Productivity Analysis , Vol . 7 , No . 2 / 3 , Special Issue : Efficiency and Frontier Analysis : Proceedings of a Research Workshop on, *7*(2), 329–340.

Luttermann, S., Kotzab, H., & Halaszovich, T. (2020). The impact of logistics performance on exports, imports and foreign direct investment. *World Review of Intermodal Transportation Research*, *9*(1), 47–62. https://doi.org/10.1504/WRITR.2020.106444

Markovits-Somogyi, R., & Bokor, Z. (2014). Assessing the logistics efficiency of European countries by using the DEA-PC methodology. *Transport*. https://doi.org/10.3846/16484142.2014.928787

Márquez-Ramos, L., Martínez-Zarzoso, I., Pérez-García, E., & Wilmsmeier, G. (2011). "Special Issue on Latin-American Research" Maritime Networks, Services Structure and Maritime Trade. *Networks and Spatial Economics*, *11*(3), 555–576. https://doi.org/10.1007/s11067-010-9128-5

Martí, L., Martín, J. C., & Puertas, R. (2017). A DEA-logistics performance index. *Journal of Applied Economics*, *20*(1), 169–192. https://doi.org/10.1016/S1514-0326(17)30008-9

Nordås, H. K. (2007). Time as a trade barrier. *OECD Economic Studies*, *2006*(1), 137–167. https://doi.org/10.1787/eco_studies-v2006-art4-en

Parvin, S., Subramaniam, G., Sadman, N. A., & Baptist, S. (2017). Brexit and Its Impact on New Zealand Economy : A Conceptual Analysis, *2*(2), 37–42.

Rajasekar, T., & Deo, M. (2014). Determinants of Port Performance ¨C Evidence from Major Ports in India ¨C A Panel Approach. *International Journal of Econometrics and Financial Management*, *2*(5), 206–213. https://doi.org/10.12691/ijefm-2-5-5

Ramaiah, A. K. (2018). The Competition Neutrality in Malaysia : Challenges and Policy Options, *3*(2), 45–54.

Schøyen, H., Bjorbæk, C. T., Steger-Jensen, K., Bouhmala, N., Burki, U., Jensen, T. E., & Berg, Ø. (2018). Measuring the contribution of logistics service delivery performance outcomes and deep-sea container liner connectivity on port efficiency. *Research in Transportation Business and Management*, *28*, 66–76. https://doi.org/10.1016/j.rtbm.2018.03.002

Schøyen, Halvor, Bjorbæk, C. T., Steger-Jensen, K., Bouhmala, N., Burki, U., Jensen, T. E., & Berg, Ø. (2018). Measuring the contribution of logistics service delivery performance outcomes and deep-sea container liner connectivity on port efficiency. *Research in Transportation Business and Management*, *28*(February 2017), 66–76. https://doi.org/10.1016/j.rtbm.2018.03.002

Suárez-Alemán, A., Trujillo, L., & Cullinane, K. P. B. (2014). Time at ports in short sea shipping: When timing is crucial. *Maritime Economics and Logistics*, *16*(4), 399–417. https://doi.org/10.1057/mel.2014.5

Talley, W. K., Ng, M. W., & Marsillac, E. (2014). Port service chains and port performance evaluation. *Transportation Research Part E: Logistics and Transportation Review*, *69*, 236–247. https://doi.org/10.1016/j.tre.2014.05.008

UN - United Nations. (1976). UN Port Performance Indicators (1976). Retrieved from http://unctad.org/en/PublicationsLibrary/tdbc4d131sup1rev1_en.pdf

UNCTAD. (2017). *Review of Maritime Transport 2017*. https://doi.org/10.18356/a9b345e7-en

UNCTAD. (2020). *Review of Maritime Transport 2020* (Vol. 53). https://doi.org/10.18356/9789210052719

Wang, T., Cullinane, K., & Song, D. (2003). Container port production efficiency: a comparative study of DEA and FDH approaches. *Jornal of the Eastern Asia Society for Transportation Studies*, *5*(1), 698–701.

Wilmsmeier, G., & Hoffmann, J. (2008). Liner shipping connectivity and port infrastructure as determinants of freight rates in the Caribbean. *Maritime Economics and Logistics*, *10*(1–2), 130–151. https://doi.org/10.1057/palgrave.mel.9100195

Woo, S. H., Pettit, S., & Beresford, A. K. C. (2011). Port evolution and performance in changing logistics environments. *Maritime Economics and Logistics*, *13*(3), 250–277. https://doi.org/10.1057/mel.2011.12

Zhang, H., You, J., Haiyirete, X., & Zhang, T. (2020). Measuring Logistics Efficiency in China Considering Technology Heterogeneity and Carbon Emission through a Meta-Frontier Model, 1–18. https://doi.org/10.3390/su12198157