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Relative Efficiencies of ASEAN Container Ports based on Data Envelopment Analysis

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ABSTRACT

Ports play a critical role in the economies of many countries in the ASEAN region. Efficient ports facilitate a country's imports and exports, and the "relative efficiency" of a port is evaluated based on its efficiency compared to others in its group. This study analyzes the relative efficiencies of 50 ASEAN container ports and terminals. These ports are categorized according to their container handling system and location (those located in a riverbank connected to the sea are called "inland seaports" and those by the seaside are called "seaports"). The traditional output-oriented data envelopment analysis method is applied, and measures of super-efficiency constant returns to scale are estimated in order to compare the units situated on the efficiency frontier. The findings may support port managers in the ASEAN region to make decisions on whether to increase container traffic. In addition, policymakers may consider the evaluation results in deciding whether to improve the trans-ASEAN transport network and ASEAN trade competitiveness.

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1. Introduction

Ports' efficiency has become increasingly important topic. As connecting links between different transport modes in the global logistics chain, container terminals are vital to the efficiency of the whole chain. Beyond its pivotal role in the global trade network, the efficiency of container ports and terminals is also a key issue for operators due to intensifying port and terminal competition worldwide.

Because of their position in the logistics chain, the level of port efficiency greatly affects a country's productivity and competitiveness (Wu and Goh, 2010). Port markets used to be perceived as monopolistic due to the exclusive and immovable geographic locations of the ports and the unavoidable concentration of port traffic. However, the rapid development of international container and intermodal transportation has

drastically changed the market structure from that of a monopoly to that of fierce competition in many parts of the world (Cullinane and Wang, 2007). Along with these trends, the economy is becoming more regional (Rex et al., 2015; UNCTAD, 2015). A recent example is the establishment of the ASEAN Economic Community (AEC) in 2015. The AEC offers opportunities in the form of a market of US\$2.6 trillion and over 622 million people. As of 2014, the AEC was collectively the third largest economy in Asia and the seventh largest in the world and accounted for 14% of world container throughput. As ASEAN has designated 47 main ports in the trans-ASEAN transport network, these ports face a number of challenges in providing more efficient shipping network services given the varying levels of port infrastructure development (ASEAN, 2011).

Thus, it is necessary to analyze the efficiency and productivity of these ports in order to pursue the realization of the ASEAN Single Shipping Market (ASSM).

This study evaluates the relative efficiency of 50 ASEAN container ports and terminals. The objective of the research is to highlight the most efficient ports in the sample according to their type (inland or sea) and their container yard equipment. Such categorization is necessary because, to apply the data envelopment analysis (DEA) method, we need to compare homogenous units. The traditional DEA output-oriented models are applied to determine the target values of the outputs for each port. The important contributions of this study include providing a benchmarking analysis based on the DEA method and assisting decision makers in their ports' development operations and the improvement of the trans-ASEAN transport network

2. Literature Review

Production optimization has been analyzed by many researchers. Debreu (1951) establishes the first measure of productive efficiency with his concept of the coefficient of resource utilization. Farrell (1957) proposes a similar method of measuring efficiency by including multiple inputs and outputs. The so-called input-based Farrell efficiency can be defined as the maximum proportional contraction of all inputs that allows the production of the same amount of output. In the opposite case, the output-oriented Farrell efficiency measures the proportional expansion of all outputs with a given amount of inputs. There are two types of efficiency: allocative (cost) and technical. The former represents the optimal combination of inputs and outputs under the assumption that the producer wants to minimize costs, whereas the latter is associated with the effectiveness with which a given set of inputs is used to produce an output. The main drawback of the Farrell efficiency is the attribution of weights to the inputs and outputs. To overcome this problem, Charnes, Cooper, and Rhodes (CCR) (1978) define an optimization method based on mathematical programming. They created the DEA method with constant returns to scale (CRS), or the so-called DEA-CCR. This method allows the measurement of the relative efficiency of decision-making units (DMUs) without attributing any predetermined weights or conducting any time series analyses. This method is extended by Banker, Charnes, and Cooper (BCC) (1984) to include variable returns to scale (VRS) and is also known as DEA-BCC. Since then, the DEA method has been extended in multiple ways, incorporating, for example, dummy or categorical variables, discretionary and non-discretionary variables, nonparametric Malmquist indices, etc. This study applies the traditional DEA method to determine the most efficient ports in the ASEAN region. As DEA is suited for the comparison of homogenous units such as container ports, a common feature of port benchmarking studies is the use of operational data due to the difficulty of obtaining a port's costs and prices (Bichou, 2013). Thus, this study focuses on technical efficiency measurements.

Table 1 provides an overview of DEA use in the literature to evaluate the relative efficiencies of container terminals and ports. In this list, the sample size generally varies between 10 and 70 DMUs, and Bichou (2013) is the only study that analyzes a considerable number of terminals, i.e., 420. The most commonly applied DEA methods are the traditional ones, DEA-CCR and DEA-BCC. In the literature, the selected inputs are usually the terminal area, the quay length, the number of container berths, the number of quay cranes, and the number of employees. In order to compare homogenous units using similar technologies, some authors include other specific indicators regarding the port's infrastructure, such

as the number of tugs, the number of straddle carriers, the number of reach stackers, etc. The most suitable indicator to evaluate the ports' production is the annual container throughput in TEUs, as the main purpose of any container terminal is to handle as many containers as possible. Another potential output indicator is the number of ship calls. Two studies use non-conventional indicators as inputs or outputs. Hai-bo and He-zhong (2009) evaluate the allocative efficiencies of 13 port companies in China by taking into account net permanent assets and total employees as production factors and the main business revenues as output. The study conducted by Guimaraes et al. (2014) evaluates the environmental performances of 15 Brazilian container terminals using total energy consumption, the consumption of non-renewable energy, sewage emissions, office supply consumption, CO₂ emissions, and water consumption as inputs and container throughput as an output.

By using DEA-BCC, DEA-CCR, and panel data, the empirical results of Bichou (2013) show that most of the container terminals clearly utilize a VRS production technology. Similarly, Hung et al. (2010) conclude that the overall technical inefficiencies of Asian container ports are primarily due to pure technical inefficiencies rather than scale inefficiencies. Only 26% of Asian container ports are regarded as efficient. This result also suggests that port managers should focus first on improving their management practices to meet the market requirements of container ports, and then container ports can be subject to improvements in their scale efficiencies. Cullinane and Wang (2007) conduct a rather arbitrary dichotomous classification of the sample between large and small ports on the basis of a cut-off throughput of 1 million TEUs per annum. Their findings suggest an association between large ports and decreasing returns to scale and between small ports and increasing returns to scale. In Tongzon (2001), the underutilization of labor is highlighted as a primary source of inefficiency for 11 of 12 ports in the sample. Wanke (2013) shows, based on a two-stage network DEA model to calculate the physical infrastructure and shipment consolidation efficiency levels, that just 7 out of 27 (25.9%) ports achieved 100% efficiency in the first stage of physical infrastructure efficiency. The results of DEA-CCR for 19 container terminals in the Middle East show that 84.21% of the terminals are inefficient (Almawshaki and Shah, 2014). Li, Luan and Pian (2013) assess the efficiency of coastal container terminals in China via a three-stage DEA model. The overall coastal container terminal efficiency is relatively low because of scale inefficiency, and there is a vast regional difference in terminal efficiency across different port groups. In addition, there is serious input excess in coastal container terminals in China of approximately 35%. Finally, in the assessment of terminal efficiency, the environment and statistical noise both affect the efficiency value (Li, Luan and Pian, 2013).

The main conclusions of the literature review are as follows: a) there is a need to find appropriate criteria to categorize container terminals; b) the sample sizes in these studies range from 11 to 420 container terminals; c) the output most commonly used by researchers is the annual container throughput; d) for a small sample with homogenous ports, it is appropriate to apply only DEA-CCR; and e) for a larger sample with ports of different sizes, both DEA-CCR and DEA-BCC should be applied.

Table 1
Non-parametric method in analyzing the relative efficiency of container ports and terminals

Authors	Model	Sample and region	Inputs	Outputs
Almawshaki and Shah (2015)	DEA-CCR	19 container terminals in the Middle East	Terminal Area; Quay length; Quay cranes; Yard equipment; Maximum Draft	Container throughput
Bichou (2012)	DEA-CCR; DEA-BCC; Panel data	420 container terminals	Terminal area; Max draft; Quay length Quay crane Index; Yard stacking index Gates	Container throughput
Bray et al. (2014)	Fuzzy DEA	16 container ports	Number of cranes; Container berths; Number of tugs; Terminal area; Delay time; Number of port authority employees	Container throughput; Shiprate; Shipcalls; Crane; productivity
Cullinane and Wang (2007)	DEA-CCR; DEA-BCC;	57 container ports	Terminal Area; Quay cranes; Yard cranes Straddle Carriers	Container throughput
Cullinane et al. (2006)	DEA-CCR; DEA-BCC	30 container ports	Terminal length; Terminal area; Quay cranes Yard gantry cranes; Straddle carriers	Container throughput
Garmendia and Schwartz (2015)	DEA-CCR DEA-BCC	63 container ports in Latin America and the Caribbean	Quay length; Terminal area; Mobile cranes with more than 14 t. capacity STS gantry cranes	Container throughput
Gonzales and Trujillo (2007)	Parametric and DEA	10 Spanish ports	Length of berths; Port area; Number of employees	Containers Liquid bulk Other cargo Passengers
Guimaraes et al. (2014)	DEA-CCR; DEA-BCC.	15 Brazilian container terminals	Total Energy; Non-renewable energy Sewage emission; Office supplies consumption; Total emissions and Water consumption per worker	Container Throughput
Hai-bo and He-zhong (2009)	SFA	13 port companies in China	Net permanent asset; Total employees	Main business revenue
Hung et al. (2010)	DEA-CCR; DEA-BCC; DEA with bootstrap method	31 container ports in Asia-Pacific	Terminal area; STS container gantry cranes (No); Berths (No); Total quay length	Container throughput
Jiang and Li (2009)	DEA-CCR; DEA-BCC.	12 container ports in Asia	Import/Export by customs; GDP by region Berth Length; Crane number	Container throughput
Li et al. (2013)	DEA; SFA	42 Coastal ports on China	Terminal length Handling equipment (bridge, mobile and beam cranes) Number of employees	Container throughput
Lim, Bae and Lee (2011)	Additive non-oriented DEARAM	26 Asian container terminals	Quay length; Total area; Gantry Cranes	Container Throughput
Lozano, Villa and Canca (2010)	Centralised DEA using a non-radial Russell measure of technical efficiency.	50 Spanish container ports	Land and stacking area; Total quay length Total number of cranes; Number of tugs	Total port traffic Container Throughput Ship calls
Sanchez and Millan (2012)	Malmquist index	46 ports in Spain	Number of employees; Intermediate consumption; Capital	Liquid bulk Solid bulk Containerized general cargo Non-containerized general cargo

Sharma and Yu (2010)	DT based context-dependent DE	70 container terminals	Quay cranes; Transfer cranes; Straddle carriers Reach stackers; Quay length Terminal area	Container throughput
Tongzong (2001)	DEA-CCR; Additive DEA	4 Australian and 12 other international container ports	Number of cranes; Number of container berths Number of tugs; Terminal Area; Delay time Labor (units)	Container throughput Number of shipcalls
Wanke (2013)	Network-DEA centralized efficiency	27 Brazilian ports	Number of berths; Warehousing area Yard area; Container frequency (shipments)	Container throughput
Wilmsmeier and al. (2013)	Malmquist index	40 ports in Central and South America	Terminal area; Ship-to-shore crane capacity equivalent; Number of employees	Container throughput
Wu and Goh (2009)	DEA-CCR; DEA-BCC; DEA Window Analysis.	21 major international container ports	Terminal area; Total quay length No. of pieces of equipment	Container throughput

Source: Authors collected

3. Methodology: Conceptual Framework and Measures

DEA provides a mathematical programming method of estimating the best practice production frontier and evaluating the efficiencies of different Decision Making Units (DMUs). In this study, DMUs are container ports. This approach finds the smallest set enveloping the input-output observations for all DMUs, hence the name “data envelopment analysis,” and, therefore, DEA models can be input and output oriented. The former minimizes the inputs for a given set of outputs, whereas the latter maximizes the outputs for a given set of inputs. In this study, the output-oriented DEA-BCC and DEA-CCR models have been applied. Only output-oriented models are selected because port managers are more interested in how they can increase the container throughput rather to decrease their inputs. In addition, inputs such depth at berth, number of berth, and container yard size are very costly to reduce. In these cases, it is hard to provide any recommendations about the reduction of inputs due to the fact that DEA has no predetermined weights on inputs and outputs. Since there is only one output (container throughput) in applied DEA output-oriented models, precise results regarding the relative efficiencies of ports and their capacities to increase their productivity can be provided.

When K is the number of DMUs, firm “k” uses a combination of m inputs denoted as $x_k = (x_{1k}, \dots, x_{mk}) \in R_+^m$ to produce n outputs $y_k = (y_{1k}, \dots, y_{nk}) \in R_+^n$

Let $\lambda_k = (\lambda_1, \dots, \lambda_K) \in R_+^K$ be non-negative vector which forms the linear combination of the K firms. Finally we have the technology set or production possibilities set:

$$T = \{(x, y) \in R_+^m \times R_+^n \mid x \text{ can produce } y\}$$

The reference technology (benchmark) set is T^* , which is constructed according to the minimum extrapolation principle. It is the smallest set of that contains the data (x^k, y^k) , $k = 1, \dots, K$, and satisfy certain technological assumptions.

Following Bogetoft and Otto (2011), the output-oriented DEA model can be presented mathematically as follows:

$$F^0 = F((x^0, y^0); T^* = F \in R_+^m \mid (x^0, Fy^0) \in T^*$$

F^0 is the output efficiency score of DMU “0”. F^0 is obtained by the resolution of the following maximization problem.

$$\begin{aligned} \text{Max } F \text{ w.r.t. } (F, \lambda^1, \dots, \lambda^K) \quad \text{s.t.} \quad & x^0 \geq \sum_{j=1}^K \lambda^j x^j \quad (1) \\ & Fy^0 \leq \sum_{j=1}^K \lambda^j y^j \quad (2) \end{aligned}$$

Constraint (1) implies that the inputs of DMU “0” must be greater than

or equal to the sum of the weights (λ) multiplied by the inputs of the other DMUs in the sample, and constraint (2) indicates that the output efficiency score of DMU “0” multiplied by its real output must be less than or equal to the sum of the weights attributed to all other DMUs multiplied by their outputs.

In the DEA model, the efficiency score is computed under the assumption of different economies of scale. Each assumption involves adding one of the following constraints:

- $\forall \lambda^k \geq 0$, if the efficiency score represent the operation of the DMU under constant returns to scale (CRS).
- $\forall \lambda^k \geq 0$ and $\sum_{j=1}^K \lambda^j = 1$, if the efficiency score is computed under the assumption of variable returns to scale (VRS).
- $\forall \lambda^k \geq 0$ and $\sum_{j=1}^K \lambda^j \leq 1$, if the efficiency score is calculated under the assumption of decreasing returns to scale (DRS).
- $\forall \lambda^k \geq 0$ and $\sum_{j=1}^K \lambda^j \geq 1$, if the efficiency score depicts how the DMU operate under increasing returns to scale (IRS)

When $F^0=1$, the DMU “0” is efficient and it is a benchmark for at least one inefficient DMU. The F^0 scores of inefficient DMUs are smaller than one. For each of these DMUs, we can find the target output value (the output that the DMU could produce with its current set of inputs if it achieves efficiency) by dividing the original output by the efficiency score, n^0 / F^0 . By estimating the scores of a given unit under CRS and VRS, the scale efficiency (SE) can be computed, with $SE = F_{CRS} / F_{VRS}$. A DMU with an SE score closer or equal to one has an optimum scale of production. The source of its inefficiency is related to the management of the organization. If a DMU has an SE score considerably smaller than one, it means that the observed DMU operates on an inefficient scale, and, according to the efficiency scores under DRS and IRS, it should either increase or decrease its size. However, if many of them reach the score of one, we cannot distinguish between them. Therefore, the concept of super-efficiency has been introduced. Super-efficiency measures are constructed by excluding the evaluated firm and checking how the efficiency frontier would change. Thus, the reference technology set could be written as $T^*(\gamma | -k)$, where γ refers to the different assumptions of DEA. We compute the optimal solution by excluding DMU “k”.

$$F^{sup} = F((x^k, y^k); T(y | -k))$$

The super-efficiency measures on the input and output sides are not restricted to either greater than or less than one. On the output side, $F^{sup k}$ (the super-efficiency score of firm k) is less than one when the DMU has reduced all of its outputs by a factor of $F^{sup or k}$ without being dominated by another firm (Bogetoft and Otto, 2011). However, in some cases, the Farell-based super-efficiency may not provide feasible solutions ($F^{sup k} = -\infty$). The presence of infinite super-efficiencies simply means that there are no other units against which to gauge firm k with the given data and the imposed technological regularities. Such DMUs can be defined as hyper-efficient (Bogetoft and Otto, 2011). Such infeasible solutions appear frequently in the cases of DEA-VRS models.

In this study, the efficiency CRS and VRS scores have been computed by using *Win4Deap2*¹ software. The CRS super-efficiency measures were calculated with R² software and its *Benchmarking*³ package.

4. Analysis and Findings

4.1. Data

The container seaports can be categorized into two main types: “inland seaports” and “seaports.” The former normally has a smaller capacity, is located on a riverbank connected to the sea, and handles small container vessels (less than 2,000 TEUs), whereas the latter has a larger capacity, is located on the seashore, and serves much larger container ships, up to Triple E class ships of 16,000 TEUs.

Another way to categorize the container ports is according to their handling systems (Carlo et al., 2014), which include “quay side crane” handling systems and “yard” handling systems. The former is the so-called “ship-to-shore crane” or “quay crane,” which handles containers from the ship to temporary buffer areas and vice versa. This type includes the Panamax gantry crane, the Post-Panamax gantry crane, and the Super Post-Panamax gantry crane, which serve Panamax container ships, Post-Panamax container ships and Super Post-Panamax container ships, respectively. The second type of handling system works in container yards only and includes yard gantry systems, such as rail-mounted gantry systems (RMGs) and rubber-tired gantry systems (RTGs); straddle carrier system (SCs); and forklift truck systems (FTs), including reach stackers and front loaders. Yard gantry systems are used for large terminals, whereas the latter systems are used for smaller terminals. Most popular is the mixed system, in which two or even three types of handling systems are used at the same time. In addition, containers are transferred from temporary buffer areas to yards by container-trucks, transtainers, or straddle carriers, depending on the terminal operation. In this study, note that SC systems are also counted as yard gantry systems for further analysis.

In the sample, all container terminals use a mixed system of handling containers in the storage yard, combining forklifts with RTGs and/or RMGs. Only one terminal, North (Port Klang) has an SC system. Most of the ASEAN terminals use forklifts with RTGs. In the sample, four inland seaports and 22 seaports have such equipment. Only four terminals (all of them inland) have RMGs and FTs. Another four ports use RMGs, RTGs, and FTs.

Due to the small number of container terminals handled by only SC and RMG systems, it is impossible to create additional categories according to the type of yard equipment, but it should be emphasized that more than one category of handling system is used for container terminals nowadays. Therefore, this study categorizes the port and its terminal, with its current yard handling system, into six groups:

- Category 1: Inland seaports and seaports with yard gantry systems and SCs;
- Category 2: Inland seaports and seaports with RTGs and FTs;
- Category 3: Seaports/terminals with yard gantry systems and FTs;
- Category 4: Seaports/terminals with RTGs and FTs;
- Category 5: Inland seaports, regardless of their yard handling equipment;
- Category 6: Inland seaports with yard gantry systems (including SCs).

Table 2
Container yard handling systems

Port Type	Number	Container yard handling systems					
		RTG + FTs	RMG+ FTs	RMG + RTG + FTs	FTs	SC + RTG + FTs	RTG
Inland seaport	17	7	4	1	5	0	0
Seaport	33	22	0	3	5	1	1
Total	50	30	4	4	10	1	1

Source: Authors' collection

¹ <http://www.sigmdel.ca/aed-dea/install2-en.html>

² <https://www.r-project.org/>

³ <https://cran.r-project.org/web/packages/Benchmarking/Benchmarking.pdf>

Table 3
Inputs used for the DEA analysis for each category of port and its terminals

	Sample size	Max depth at berth (m)	Size of the container yard (m2)	Length of the quays (m)	No of quay cranes	No. of RTGs	No of yard cranes (RMG+SC+RTG)	No of FTs	No. of trucks
Category 1	37	X	X	X	X		X	X	X
Category 2	29	X	X	X	X	X		X	X
Category 3	25	X	X	X	X		X	X	X
Category 4	22	X	X	X	X	X		X	
Category 5	16	X	X	X	X				
Category 6	12			X			X		

Source: Authors' collection

The first category includes the largest number of ports, including all inland seaports and seaports with yard cranes (any type) and quay cranes. This category takes into account seven input indicators. All types of yard cranes (RTG, RMG, and SC) are summed up into one input indicator (number of yard cranes in the container yard). In the second category, inland and sea container ports and terminals with RTG and FT systems are compared. In the third category, only seaports with yard cranes are included, and in the fourth category, seaports with RTG and FT handling systems are included. Inland seaports and terminals, regardless of their handling equipment in the container yard, are grouped in the fifth category. Finally, the last category compares inland seaports with yard gantry systems, which includes SCs.

The maximum number of inputs that can be used with respect to the number of DMUs is given by the rule of thumb: $\# DMUs > 3(m + n)$.

Hence, for categories four, five, and six, some inputs must be eliminated from the analysis due to the small number of DMUs in the sample. Inputs were excluded based on their level of correlation with the other inputs.

We collected the data from various sources, such as port websites, reports, articles, Google Earth, and other sources, with serious concern for the availability and reliability of the data. Unfortunately, there is no database that contains the equipment and infrastructure of the ports. Considering the fact that the industry is facing huge issues in terms of oversupply and efficiency, such a database could be very useful for decision makers.

4.2. Results

Fifty container terminals and ports were categorized into six groups. Some terminals appear in more than one group. For all of the groups, we have used as an output the annual container throughput measured in number of TEUs in 2014. In this section, we describe the main results of the output DEA-CCR and DEA-BCC models applied in the survey.

• Category 1

The first group includes all inland and sea container ports and terminals with yard cranes or SCs in the storage area. Ports that have only forklift systems in the container yard were not included in this category. Fig.1 shows by how the ports in the first category should increase their output (container throughputs) to become efficient. In order for the results to be visible on the graph, we limit the displayed upper boundary percentage to 200% for all ports that have to increase their output by more than 200% to become efficient. The ports are ranked from left to right according to their super-efficiency measures. As we can see, the most efficient port is Tan Cang-Cai Mep (a terminal belonging to Saigon New Port, Vietnam), followed by West (Port Klang) (Malaysia) and Tanjung Perak (Indonesia). There is only one inland seaport that appears to be efficient, Đinh Vu (Vietnam). The most inefficient ports are Ben Nghe (Vietnam), Panjang Port (Indonesia), Bông Sen - Lotus Port (Vietnam), Quy Nhon (Vietnam), Jambi Port (Indonesia), and Cai Lan ICT (Vietnam). These inefficient ports must increase their container throughput by more than 200% in order to be on the efficiency frontier. It is also observed that these ports have an annual container throughput of around 100,000 TEUs. On average, the ports in the sample score well in terms of scale efficiency (0.802). The source of inefficiency is related to their small size, because most of them are operated under increasing returns to scale. There are only four ports that are experiencing decreasing returns to scale (DRS), namely, Belewan ICT (Malaysia), North (Port Klang) (Malaysia), Saigon New Port (Vietnam), and Hai Phong Port (Vietnam). The size of these ports has a negative effect on their performance.

The average score of all ports in terms of CRS efficiency is relatively low at 0.676. This result is probably due to the fact that both inland seaports and seaports are included, and there are some outliers (very efficient ports) that cause the others to appear very inefficient. This hypothesis is confirmed by the relatively high VRS score (0.852).

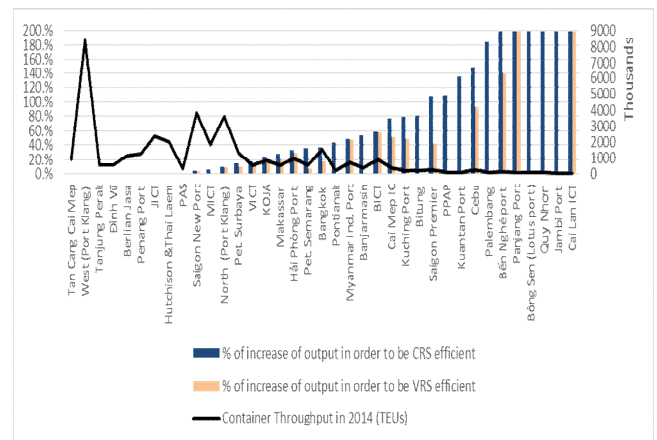


Fig. 1. Target values and actual container throughput of inland seaports and seaports with yard cranes (RTG, RMG and SC)

Note: The container terminals and ports are ranked from the most to the least efficient (from left to right), according to their CRS super efficiency measures

Table 4
Ports' benchmark times in DEA-CCR and DEA-BCS models (Category 1)

Ports/Terminals	Country	CRS peer	VRS peer
Bitung	Indonesia	0	1
Pontianak	Indonesia	0	10
Jambi Port	Indonesia	0	2
Jakarta International Container Terminal	Indonesia	2	2
Tanjung Perak Port	Indonesia	20	10
Berlian Jasa Terminal	Indonesia	3	2
Kuantan Port	Malaysia	0	1
Penang Port	Malaysia	1	1
West Port Container Terminal (Port Klang)	Malaysia	15	12
Phnom Penh Autonomous Port	Cambodia	0	1
Sihanoukville Autonomous Port	Cambodia	0	10
Hutchison Ports Thailand (1. Thai Laemchabang Terminal Co., Ltd. (TLT))	Thailand	1	1
Đình Vũ	Vietnam	17	7
Tan Cang-Cai Mep International Terminal	Vietnam	17	12

In 2014, the ports in the first category had a total container throughput of 38 million TEUs. If they had operated efficiently under the CRS assumption (producing their CRS efficiency targets), they would have been able to increase the container throughput by 20.17% (7.7 million TEUs). On the other hand, if all ports were VRS efficient, they would have handled 10.83% more containers (4.1 million TEUs).

Regarding the number of times that a port is a benchmark for another unit, Table 4 shows that under the CRS assumption, Tanjung Perak, Đình Vũ, Tan Cang-Cai Mep, and West (Port Klang) are peers for other ports. However, under VRS, the port of Pontianak becomes a peer for a considerable number of terminals.

In this category, most of the ports are Indonesia and Vietnam ones. On average, the ports in these two countries have similar scale efficiencies (0.77), but Indonesian ports reach better CRS and VRS scores. Malaysia and Thailand have the most efficient ports, but it is not possible to make any general conclusions because there are very few ports from these countries in the sample. As expected, seaports have better efficiency scores than inland seaports. The former operate on a better scale. However, in terms of VRS efficiency, the performances of both types of ports are almost identical.

Table 5
Average CRS, VRS and SC scores per country (Category 1)

Country	Number of ports	CRS Average	VRS average	Scale average
Indonesia	14	0.68	0.89	0.77
Vietnam	11	0.59	0.77	0.77
Malaysia	3	0.97	0.97	1.00
Cambodia	2	0.74	1.00	0.74
Thailand	2	0.86	0.92	0.93
Myanmar	1	0.67	0.68	1.00
Philippines	2	0.67	0.75	0.86
Total seaport	25	0.74	0.85	0.86
Total inland seaports	12	0.55	0.86	0.67

• Category 2

Among the 29 inland seaports and seaports operated by RTGs and FTs in container yards, eight are working efficiently. According to super-efficiency measures, the best performance is achieved by West (Port Klang), which also has the largest volume of container throughput in 2014, i.e., 16.3 million TEUs. Although Sihanoukville Autonomous Port (PAS) has only 330,000 TEUs, it also appears to be efficient. The Vietnamese inland seaport Đình Vũ is again a benchmark. The most inefficient ports are Bến Nghé, Panjang, Quy Nhơn, and Cai Lan ICT. Belewan ICT and Hai Phong are the only ports operating under decreasing returns to scale. In 2014, the total container throughput of these ports was 28.6 million TEUs. If all of them were operating on the efficiency frontier, they would have attracted 21.36% more of container volume for their throughput (6.1 million additional TEUs). Regarding the efficiency under VRS, the total loss in terms of transported containers is 8.82%. Most of the ports have a good scale, and on average, the scale efficiency is 0.798.

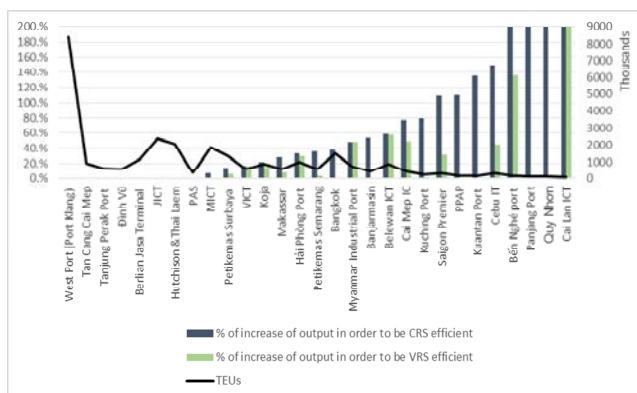


Fig. 2. Target values and actual container throughput of inland seaports and sea ports with RTGs and FTs (Category 2)

Table 6 depicts how many times a port appears to be a benchmark in the DEA-CCR and DEA-BCC models. Under the assumption of CRS, Tan Cang-Cai Mep is a benchmark 15 times, Đình Vũ is a benchmark 14 times, and West (Port Klang) and Tanjung Perak are benchmarks 13 times. In the DEA-BCC model, few ports differ from the others. The first is Kuantan Port (peer to four ports), followed by Phnom Penh Autonomous Port (PPAP) (peer to seven ports). These ports are not CRS efficient. However, when they are compared to similar ports, they appear to be efficient, which means that there are some factors (i.e., structural differences) that do not allow them to be CRS efficient.

Regarding the average scores at a country level (Table 7), it is observed that Indonesia has higher scores than Vietnam, and is very good scale efficiencies, with an average of 0.83. In general, seaports perform better than inland seaports, although the difference is small (0.06 points). This result means that, by excluding the five inland seaports that use only a forklift system, the overall performance of the other inland seaports increased.

Table 6
Port's benchmark times in DEA-CCR and DEA-BCC models (Category 2)

Port	Type	Country	CRS peer	VRS peer
Jakarta International Container Terminal	Seaport	Indonesia	2	3
Tanjung Perak Port	Seaport	Indonesia	13	12
Berlian Jasa Terminal	Seaport	Indonesia	3	2

Kuantan Port	Seaport	Malaysia	0	4
West Port Container Terminal (Port Klang)	Seaport	Malaysia	13	8
Phnom Penh Autonomous Port	Inland seaport	Cambodia	0	7
Sihanoukville Autonomous Port	Seaport	Cambodia	0	10
Thai Laemchabang Terminal Co., Ltd. And Hutchison Laemchabang Terminal Limited	Seaport	Thailand	1	1
Đinh Vũ	Inland seaport	Vietnam	14	3
Quy Nhơn	Seaport	Vietnam	0	1
Tan Cang-Cai Mep International Terminal	Seaport	Vietnam	15	6

Table 7
Average CRS, VRS and SC scores by country (Category 2)

Country	Number of ports	CRS Average	VRS average	Scale average
Indonesia	10	0.77	0.93	0.83
Vietnam	8	0.58	0.73	0.81
Malaysia	3	0.71	1.00	0.71
Cambodia	2	0.74	1.00	0.74
Thailand	2	0.86	1.00	0.86
Myanmar	1	0.67	0.68	1.00
Philippines	2	0.67	0.84	0.76
Total seaports	22	0.72	0.88	0.82
Total inland seaports	7	0.61	0.83	0.74

• **Category 3**

The third category includes 25 ASEAN sea container port/terminals that operate yard gantry handling systems. Recall that RTGs, RMGs, and SCs are counted as yard gantry systems. The port of Tan Cang-Cai Mep (Vietnam) appears to be the most efficient according to CRS super-efficiency measures, followed by West (Port Klang) (Malaysia) and Tanjung Perak (Indonesia). Cebu, Panjang Port, Quy Nhon, and Cai Lan ICT again appear to be inefficient. The ports in the sample handled 30 million TEUs of container throughput in 2014. If they operated efficiently, they would have transported 4.7 million additional containers, or 15.36% more. In the case of VRS efficiency, they would have increased their total throughput by 6.67% (around 2 million additional TEUs).

Tanjung Perak is a peer 14 times (Table 8), followed by West (Port Klang) and Tan Cang-Cai Mep, in the case of the DEA-CCR output model. In terms of VRS efficiency, we see that, despite the fact that Bitung is not CRS efficient, it is VRS efficient and is a benchmark for two other ports. On the other hand, regarding CRS efficiency measures, PAS is a peer for none of the ports, but under VRS assumption, it is a benchmark for seven units.

Among the countries with more than two seaports with RTGs and forklift systems in the sample, Malaysia has the highest average CRS score, followed by Indonesia and Vietnam (Table 9). In terms of scale efficiency, Malaysian ports have the best performance.

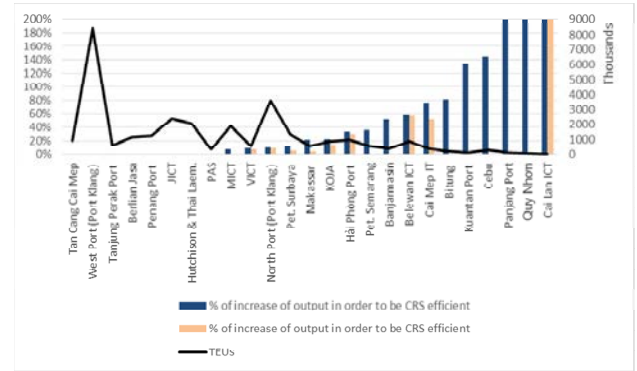


Fig. 3. Target values and actual container throughput of seaports with yard gantry systems and FTs (Category 3)

Table 8
Ports' benchmark times in DEA-CCR and DEA-BCC models (Category 3)

Port	Country	CRS peer	VRS peer
Bitung	Indonesia	0	2
JICT	Indonesia	2	1
Tanjung Perak Port	Indonesia	14	7
Berlian Jasa	Indonesia	1	1
Penang Port	Malaysia	1	1
West Port (Port Klang)	Malaysia	13	8
PAS	Cambodia	0	7
Hutchison & Thai Laem.	Thailand	1	1
Tan Cang Cai Mep	Vietnam	11	6

Table 9
Average CRS, VRS and SC scores by country (Category 3)

Country	Number of ports	CRS Average	VRS average	Scale average
Indonesia	11	0.76	0.94	0.81
Vietnam	6	0.59	0.75	0.78
Malaysia	4	0.83	0.98	0.85
Cambodia	1	1.00	1.00	1.00
Thailand	1	1.00	1.00	1.00
Philippines	2	0.67	0.96	0.70

• **Category 4**

Category 4 includes 22 ASEAN seaports/terminals that have RTG and FT handling systems in the yards. Because a small number of ports use such systems, we excluded one input. The most correlated input was found to be the number of trucks. Therefore, the following inputs were used for the DEA models: depth at berth (meters), container yard size (m²), length of quays (meters), number of quay cranes, number of RTGs, and number of FTs. Figure 6 shows that the most efficient port in terms of CRS super-efficiency measures is West (Port Klang) (Malaysia), followed by Tan Cang-Cai Mep (Vietnam), Tanjung Perak (Indonesia), Berlian Jasa (Indonesia), JICT (Indonesia), and PAS (Cambodia). The least efficient terminals, which must increase their output by more than 100% to become CRS efficient, are Cebu (Philippines), Kuantan (Malaysia), Panjang Port (Indonesia), Quy Nhon (Vietnam), and Cai Lan ICT (Vietnam). Notice that all of these CRS inefficient ports, excluding Cai Lan ICT, are VRS

efficient. This result means that these ports are somehow different from each other's (i.e., they have a significant difference in the distribution of the inputs). All ports except Hai Phong are operating under increasing returns to scale. By removing both the input "trucks" and the seaports that are not using RTG and FT systems, Belewan ICT will operate under increasing returns to scale (IRS).

West (Port Klang) appears as a benchmark for 14 ports in the DEA-CCR model. In addition, as we have already seen, this port is the most efficient in terms of CRS super-efficiency measures. Tanjung Perak is also a benchmark many times (nine times), whereas JICT and Berlian Jasa have a very interesting result in that the former is not a benchmark for any of the units in the sample and the latter is a benchmark for only one. These two terminals probably have significant structural differences from the others.

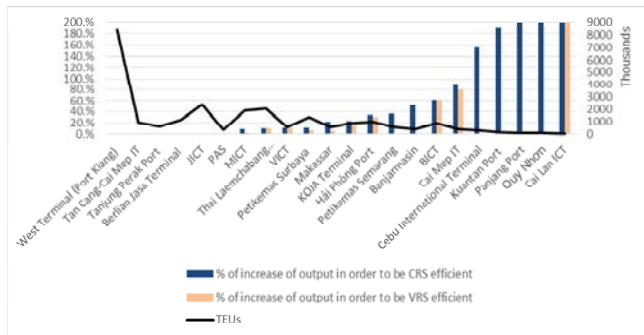


Fig. 4. Target values and actual container throughput of seaports with RTGs and FTs (Category 4)

Table 10
Ports' benchmark times in DEA-CCR and DEA-BCC models (Category 4)

Port	Type	Country	Peer CRS	Peer VRS
JICT	Seaport	Indonesia	4	0
Tanjung Perak Port	Seaport	Indonesia	9	10
Berlian Jasa Terminal	Seaport	Indonesia	1	1
West Container Terminal (Port Klang)	Seaport	Malaysia	14	11
PAS	Seaport	Cambodia	3	10
Tan Cang-Cai Mep International Terminal	Seaport	Vietnam	5	4

Table 11
Average CRS, VRS and SC scores by country (Category 4)

	Number of ports	CRS Average	VRS average	Scale average
Indonesia	10	0.779	0.937	0.840
Vietnam	6	0.572	0.724	0.805
Malaysia	2	0.672	1.000	0.672
Cambodia	1	1.000	1.000	1.000
Thailand	1	0.903	0.906	0.997
Philippines	2	0.654	0.989	0.664

In the sample, most of the ports are Indonesian and Vietnamese ones. According to Table 11, Indonesian ports reach higher CRS and VRS efficiency scores. Regarding scale measurements, the difference between the two groups is not significant.

• Category 5

In this category, all inland seaports have been included regardless of their handling equipment in the container yard. According to the rule of thumb, since there are only 16 container terminals in this category, four inputs have been selected. The least correlated inputs have been chosen, that is, maximum depth at berth (m), container yard size (m²), length of quays (m), and number of quay cranes. Figure 7 depicts the necessary percentage increase of output for each of the ports to reach its target values and the actual container throughput in 2014. Seven ports are efficient, and, according to the CRS super-efficiency measure, the most efficient inland seaport is Binh Duong, followed by Bangkok, PTSC Đĩnh Vũ, Saigon New Port, and Đĩnh Vũ. The most inefficient ones are Bến Nghé Port, Bông Sen (Lotus Port), and Jambi Port. The total container throughput in 2014 of all ports in the sample was almost 8.8 million TEUs. If all of them were laying on the CRS efficiency frontier, they would have increased their productivity by 20%. In the case of VRS efficiency, these ports would have been able to handle 18.68% more container volume.

It should be highlighted that, by removing some input indicators, the efficiency of the port of Đĩnh Vũ is reduced. In the first and second categories, this port was the only efficient inland seaport. In this group of inland seaports, Đĩnh Vũ appears as efficient, even though in terms of super-efficiency, it is ranked 5th.

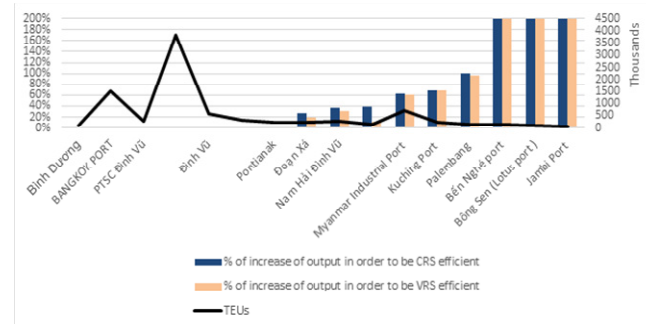


Fig. 5. Target values and actual container throughput of inland seaports regardless of yard crane system (with FTs and/or yard cranes) (Category 5)

Table 12 shows that the ports of Bangkok and Đĩnh Vũ were benchmarks six times, followed by the port of Binh Duong (four times). Regarding VRS efficiency, the port of PTSC Đĩnh Vũ is still a benchmark for six other ports. Vietnamese terminals have very good efficiency scores and are the most numerous in this category (nine ports). Contrary to the results of the previous group, Vietnamese inland seaports seem to be more efficient than Indonesian inland seaports.

Table 12
Ports' benchmark times in DEA-CCR and DEA-BCC models (Category 5)

Ports/terminals	Country	CRS peer	VRS peer
Pontianak	Indonesia	1	5
Bangkok Port	Thailand	6	5
Saigon Premier Container Terminal	Vietnam	3	3
Đĩnh Vũ	Vietnam	6	4
PTSC Đĩnh Vũ	Vietnam	3	6
Binh Duong	Vietnam	4	5
Saigon New Port	Vietnam	1	2

Table 12 shows that the ports of Bangkok and Đĩnh Vĩ is 6 times the benchmark, followed by the port of Binh Dương (4 times). Regarding VRS efficiency, the port of PTSC Đĩnh Vĩ is still a benchmark for 6 ports. Vietnamese terminals have very good efficiency scores, they are also the most numerous in this category (9 ports). Contrary to the results of the previous group, inland Vietnamese ports seem to be more efficient than the Indonesian ports.

Table 13
Average CRS, VRS and SC scores per country (Category 5)

Country	Number of ports	CRS Average	VRS average	Scale average
Indonesia	3	0.57	0.58	0.96
Vietnam	9	0.78	0.79	0.99
Malaysia	1	0.59	0.59	1.00
Cambodia	1	0.72	0.90	0.80
Thailand	1	1.00	1.00	1.00
Myanmar	1	0.61	0.62	0.98

• Category 6

Since there are 12 inland seaports with cranes in the container yard, only two inputs were included. Therefore, eight DEA output-oriented CCR models are selected. Table 14 gives the ranking of the ports according to the use of different combinations of the seven inputs. Saigon New Port is efficient seven times, and Đĩnh Vĩ is a benchmark five times. The terminals of Pontianak (Indonesia), Bangkok (Thailand), and Saigon Premier are also efficient in some of the DEA models. In 2014, the total container throughput of the ports in the sample was 7.95 million TEUs. On average, if all of the ports were operating efficiently, they should have been able to increase their container throughput by around 64.5%. However, it should be emphasized that, for each DEA model, only two indicators are taken, and therefore, in order to have more reliable results, the sample size must be increased. In addition, this high percentage may be due to the presence of outlier(s) or super-efficient port(s) that make the other ones appear very inefficient.

Most inland seaports operated by yard gantry systems in the sample are in Vietnam, but there are no additional conclusions to be made due to the small size of the sample and the small number of inputs used for the different DEA models (Table 14).

Table 14
Ranking of inland seaports with cranes in the storage yard according to DEA-CCR output-oriented models with two inputs

Port	Country	TEUs	Number of time the port appears efficient	Depth & CY size	Depth & length	Depth & quay cranes	CY size & length	CY size & forklifts	Length & h & yard cranes	Length & h & forklifts	Length & h & trucks
Palenbang	Indonesia	137,685	0	8	6	10	7	7	6	6	6
Pontianak	Indonesia	227,130	2	1	4	6	1	2	4	5	4
Jambi Port	Indonesia	29,379	0	9	12	12	8	8	12	12	12
Kuching Port	Malaysia	227,600	0	10	9	5	10	10	9	8	9
Myanmar Industrial	Myanmar	728,000	0	7	7	7	9	9	7	9	10
PPAP	Cambodia	133,666	0	6	8	8	4	4	8	7	8

Bangkok Port	Thailand	1,356,106	2	1	3	3	3	3	3	4	3
Saigon Premier	Vietnam	301,382	4	1	5	4	1	1	5	1	5
Đĩnh Vĩ	Vietnam	574,635	5	5	2	1	5	5	1	1	1
Saigon New Port	Vietnam	3,827,115	7	1	1	1	6	6	1	1	1
Bến Nghé Port	Vietnam	148,306	0	12	11	9	12	12	11	10	7
Bông Sen (Lotus) Port	Vietnam	84,900	0	11	10	11	11	11	10	11	11
Total		7,755,904									
Average CRS target value		13,087,662									
Average % increase of output in order to be CRS efficient		64.5%									

4.2. Findings

The overall results show that ASEAN seaports perform better than ASEAN inland seaports. We consider six categories of ports. The first one includes inland and sea terminals with yard cranes (we count all cranes regardless of the type of handling system) and has an average CRS score of 0.676 (Table 15) for all ports in this category. The second category contains all ports using RTGs and FTs as yard handling equipment. It has higher CRS scores (0.696), which means that, on average, the terminals using RTG and FT systems are more efficient than those using other systems, such as SC or RMG. The third and the fourth categories excludes all inland seaports, and their average CRS, VRS, and scale scores increase as a result (Table 15). It indicates that the seaports are more efficient than the inland seaports. When three seaports not operated by RTG and FT handling systems, specifically North (Port Klang), Penang, and Bitung, are removed, and when the number of trucks is no longer used as an input, the average efficiency scores decrease. In the fifth category, all inland seaports in the sample are compared, and the conclusion is that their efficiency scores are relatively high. By excluding and including ports based on their handling systems, we are able to have some idea about which type of cranes is appropriate. It is interesting to observe that the average scores increases when we include in the sample only ports operating with RTG system. However, regarding the third and fourth categories we have the opposite results. Another important finding is that the average score increases when we have only seaports in the sample rather than inland seaports and seaports.

Comparing the first four categories, we find that the same seaports always have the highest relative efficiency: Tan Cang-Cai Mep, West (Port Klang), Tanjung Perak, Berlian Jasa, Penang Port, JICT, TLT, and PAS. Đĩnh Vĩ is the only inland seaport that has a score of one in the first two categories. Saigon Premier is another inland seaport that is very close to the efficiency frontier in the first category. Some seaports are also close to the efficiency frontier, such as MICT, North (Port Klang), Pet. Surabaya, KOJA Terminal, and Makassar.

The last two categories only compare inland seaports, and it appears that, in addition to Đĩnh Vĩ and Saigon Premier, three other ports, Bangkok Port, Binh Dương, and Pontianak, are also benchmarks.

In all categories, most of the ports operate under increasing returns to scale, which means that these ports should increase their inputs in order to become more efficient. Very few are experiencing decreasing returns to scale. Thus, with respect to the DEA models applied in this study, it can be concluded that the reason for the inefficiency of most of ASEAN ports is their small size.

Table 15
Average efficiency scores per category

Categories	Average CRS	Average VRS	Average Scale
Category 1 (Inland seaport and seaports with yard cranes)	0.676	0.852	0.802
Category 2 (Inland seaport and seaports with RTGs & FTs)	0.696	0.872	0.798
Category 3 (Seaports with yard cranes)	0.741	0.908	0.818
Category 4 (Seaports with RTGs and FTs)	0.717	0.891	0.814
Category 5 (Inland seaports)	0.728	0.748	0.971
Category 6 (Inland seaports with yard cranes)	0.522	0.699	0.770

5. Conclusions

The relative efficiency DEA analyses conducted in this study imply that ASEAN ports have relatively good scale efficiencies and that most of them could handle even more container volume. There is still a need to analyze in more detail what makes seaports or inland seaports efficient. Not surprisingly, this study has identified a significant difference between the performances of inland seaports and seaports.

For future research, more data on port connectivity should be collected, and more ASEAN ports should be included in the sample in order to conduct a complementary analysis at the country level of the relation between the trade performances of the ASEAN states and the performances of their container ports. Additional inputs and ports from other regions, such as China, Europe, Africa, and America, should also be included.

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