The Asian Journal of Shipping and Logistics 36 (2020) 157–168

Contents lists available at ScienceDirect

The Asian Journal of Shipping and Logistics

journal homepage: www.elsevier.com/locate/ajsl

Original Article

# Does higher technical efficiency induce a higher service level? A paradox association in the context of port operations

Ziaul Haque Munim

*Faculty of Technology, Natural and Maritime Sciences, University of South-Eastern Norway and School of Business and Law, University of Agder, Norway*

ARTICLE INFO

*Article history:*
Received 8 August 2019
Received in revised form 11 February 2020
Accepted 12 February 2020

*Keywords:*
Data envelopment analysis
Bootstrap DEA
Port congestion
Benchmarking
Mixed methods
Data triangulation

ABSTRACT

Researchers and practitioners are benchmarking technical efficiency of ports and exploring the drivers of high efficiency. Paradoxically, this study argues that high technical efficiency (TE = 1) is not always essential, but an optimal level needs to be achieved while balancing the port service level. This study applies data envelopment analysis (DEA) and free disposal hull (FDH) methods to perform efficiency rankings of 38 container terminals from 17 different ports in 12 Asian countries. Four terminals are technically efficient (TE = 1) in all frontier approaches, thereof one Bangladeshi, one Chinese, one Indian and one Vietnamese. Furthermore, this study presents a case study combining qualitative and quantitative data analysis to investigate the characteristics of a port hosting high technically efficient container terminals. The finding suggests that ports with growing throughput, not investing actively in infrastructure and equipment, become high technically efficient over time, but the higher their technical efficiency, the lower their service level.



## 1. Introduction

The containerisation of ports has significantly improved overall port efficiency, as did efficient container handling and dedicated containerships. Because the operational function of ports is no longer limited to ordinary cargo handling, ports now compete to attract cargo, which has fostered competition among neighbouring ports. In addition, "the derived demand for maritime transport has evolved from a demand for the possession of goods to an integrated demand for the possession of goods that have been added value, timely, reliably and cost-efficiently" (Panayides, 2006, p. 3). The competitive environment requires individual terminals and ports to remain efficient in order to sustain in the market (Heaver, 2002; Notteboom & Winkelmans, 2001; Robinson, 2002). Thus, benchmarking the performance of individual port terminals can provide the 'best-in-class' terminal operations as well as necessary measures to improve the overall competitiveness of terminals and ports. Meanwhile, the emergence of increasingly internationalised production patterns linking national economies across the globe made the monitoring of port's performance even tougher.

Excessive port capacity is a growing concern in the port industry. According to the WTO (2016), for the first time since 1990, global trade volume has dropped below GDP growth. Meanwhile, many countries are heavily investing in building new ports or expanding existing port terminals, based on the previous forecast of world trade growth, which is often based on the association of trade to GDP growth ratio. As this association seems to have weakened recently, particularly for developed countries (Munim & Schramm, 2018), the investment decisions in expanding port capacity may require re-evaluation, and it is crucial to investigate whether nations are overinvesting in seaports. On the other hand, port infrastructure is vital for the economies of developing countries (Munim & Schramm, 2018), and they might not be investing enough into it. To this end, this study first scrutinises the technical efficiency of 38 Asian container terminals. Second, with the help of an in-depth case study, this study explores the association between technical efficiency and port service level of high technically efficient port/terminals. Nowadays, ports typically have multiple container terminals and major strategic decisions such as the selection of port governance models (Munim, Saeed, and Larsen (2019) and capacity expansion (Wiegmans, Ubbels, Rietveld, & Nijkamp, 2002) are made on the terminal level rather than the port level. Therefore, the findings of this study will be helpful for the respective port managers and authorities to evaluate their container terminals compared to competing ones. At the same time, this study questions blind applications of the frontier approaches

*E-mail address:* Ziaul.h.munim@usn.no
Peer review under responsibility of the Korean Association of Shipping and Logistics, Inc.

https://doi.org/10.1016/j.ajsl.2020.02.001
2092-5212 

to port efficiency benchmarking without taking the port service level into account.

The remainder of this paper is structured as follows. Section 2 presents a review of the literature related to port efficiency benchmarking with an overview of different models applied in the field. The data and methodology are presented in Section 3. Section 4 presents the findings, including efficiency rankings and bootstrap DEA application. An in-depth case study of a port hosting high technically efficient terminals is explored in Section 5. Finally, Section 6 concludes with the contribution to literature, policy implications and future research directions.

## 2. Literature review

The academic literature on port efficiency benchmarking has been enriched with new techniques and tools over the last three decades. Roll and Hayuth (1993), Cullinane, Song, and Gray (2002), Cullinane and Song (2003), Estache, de la Fe, and Trujillo (2004), Bichou and Gray (2004) and many others have evaluated port performance from different perspectives using different methods. Bichou (2006) mentioned three broad categories of port performance benchmarking: individual metrics and indices, economic impact studies and frontier approaches. In the frontier concept, the efficiency range is denoted by the upper and lower limit of a boundary. Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) are the two most frequently used frontier approaches in port efficiency research. The use of the Free Disposal Hull (FDH) method is also evident.

Since the inception by Charnes, Cooper, and Rhodes (1978), DEA has been applied in many contexts. Port efficiency studies that have applied DEA include Roll and Hayuth (1993), Barros and Athanassiou (2004), Wang and Cullinane (2006), Barros (2006), Hung, Lu, and Wang (2010) and Tongzon (2001), among others. The notable applications of SFA studies include Cullinane et al. (2002), Cullinane and Song (2003), Notteboom, Coeck, and Van Den Broeck (2000) and Tongzon and Heng (2005). In addition to these, Cheon (2009) extend the DEA model into tiered DEA model to shape port efficiency from different types of global terminal operators (GTOs) perspective. Hung et al. (2010) is most likely the first study to apply the bootstrap DEA to measure the operating performance of 31 ports in the Asia-Pacific region. To incorporate time in the DEA method while analysing the efficiency of container port or terminal, Cullinane, Song, Ji, and Wang (2004) apply the DEA Windows analysis.

Some studies compare two different frontier approaches to efficiency benchmarking. For example, Cullinane, Wang, Song, and Ji (2006) compare the DEA and SFA while benchmarking the technical efficiency of container ports, and find that DEA models are relatively robust compared with distributional assumptions under SFA. Wang, Cullinane, and Song (2003) and Cullinane, Song, and Wang (2005) compare the DEA and FDH model to measure container port production efficiency but find that these two models lead to different conclusions. Wang et al. (2003) criticise FDH for poor managerial implications, but De Borger, Kerstens, Moesen, and Vanneste (1994) argue that FDH has better managerial implications because it estimates the efficiency based on observed production unit rather than a hypothetical frontier.

A few non-conventional approaches are also evident in port efficiency benchmarking literature. González and Trujillo (2008) apply a translog distance function to analyse reforms and infrastructure efficiency in Spanish container ports. Haralambides, Hussain, Barros, and Peypoch (2010) introduce the Luenberger Indicator to benchmark port efficiency. Blonigen and Wilson (2008) examine the effect of port efficiency on trade using the gravity model in the USA context. Cheon, Dowall, and Song (2009) use the Malmquist Total Factor Productivity Index to analyse the typology of long-term port efficiency improvement for world container ports. They find that scale efficiency was one of the major factors that shape port efficiency, although it is affected by the external economic environment. However, some of the impactful studies such as Hung et al. (2010), Wang and Cullinane (2006) and Haralambides et al. (2010) report that most ports worldwide are experiencing significant inefficiency. Therefore, there exists substantial room for improvement in port efficiency studies in terms of methodology, theoretical underpinnings and implications for port management practice.

## 3. Data and methodology

This study analyses data of 38 Asian container terminals from ports in Bangladesh, China, Hong Kong, India, Indonesia, Japan, Korea, Pakistan, Philippine, Sri Lanka, Thailand and Vietnam. The primary source of the data is the Containerisation International Yearbook (CIY, Containerisational International, 2012). The sample of 38 terminals is selected based on complete data availability on the terminal level and throughput of 400,000 TEUs or more on the average of 2009 and 2010 container throughput (to make the sample identical to some extent). For each of the container terminals, data is collected on container throughput, number of berths, berth length, maximum water depth at the terminal, total terminal area, number of yard gantry cranes, and the total number of gantries (ship-shore and quay). Due to unavailability in CIY, container throughput data of eight terminals (Dalian Container Terminal, Gateway Terminal India, JNP Container Terminal, Nhava Sheva International Container Terminal, Jakarta International Container Terminal, Korea Express Busan Container Terminal, GT Container Terminal, Cat Lai Terminal) are updated from other sources.[1] In the case of Chittagong Port, due to unavailability of terminal level data in CIY, relevant data of their container terminals are collected from the Port Authority. Table 1 presents descriptive statistics.

Application of multiple methods in a study enhances the validity of findings (Ha & Yang, 2017). Such applications are evident in port benchmarking studies (for example, Cullinane et al., 2006; Wang et al., 2003). Hence, DEA and FDH are used in this study to benchmark the container terminal's technical efficiency and compare results. A container terminal is technically efficient if it produces the maximum throughput utilising the minimum quantity of inputs such as equipment, infrastructure and technology, when compared

[1] *Dalian Container Terminal:* TEU 2010 estimated (3412368) from CIY port level TEU in 2010 using 2009 market share of the terminal; *Gateway Terminal India, JNP Container Terminal, Nhava Sheva International Container Terminal:* TEU 2010 estimated (1801840, 685441, 1574719 respectively) from Indian Port Association (IPA) port level TEU in 2010 (http://ipa.nic.in/index1.cshtml?lsid=159, accessed on November, 2016) using 2009 market share of the respective terminals. TEU 2009 of JNP Container Terminal (666879) was calculated by deducting combined CIY 2009 TEU of Gateway Terminal India and Nhava Sheva International Container Terminal from IPA port level 2009 TEU; *Jakarta International Container Terminal:* TEU 2009 (1445912) from a master thesis available at https://thesis.eur.nl/pub/33021/Syafaaruddin-D.S.-Evaluation-of-container-terminal-efficiency-performance-in-Indonesia-Future-Investment.pdf, accessed on November, 2006; *Korea Express Busan Container Terminal:* TEU 2010 (2682598) from Port of Busan Container Statistics 2010 available at http://www.busanpa.com/eng/Board.do?mCode=MN0043, accessed on November, 2016; *GT Container Terminal:* TEU 2010 (1970254) updated from terminal website, available at https://saigonnewport.com.vn/en/about/pages/throughput-market-share.aspx, accessed on November 2016; *Cat Lai Terminal:* TEU 2010 (2850000) updated from terminal website, available at https://saigonnewport.com.vn/en/about/pages/throughput-market-share.aspx, accessed November 2016.

**Table 1**
Descriptive statics of terminal data.

| | Obs | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| Container throughput 2009 (TEUs) | 38 | 1,621,333 | 1,648,211 | 385,521 | 8,961,785 |
| Container throughput 2010 (TEUs) | 38 | 1,862,017 | 1,963,093 | 348,713 | 10,568,100 |
| Container throughput avg. (TEUs) | 38 | 1,741,675 | 1,792,508 | 406,345 | 9,764,943 |
| Berth (n) | 38 | 4.24 | 2.50 | 1 | 10 |
| Berth length (sq. m) | 38 | 1174.53 | 709.81 | 300 | 3200 |
| Depth (m) | 38 | 13.79 | 2.26 | 8.55 | 17.80 |
| Terminal area (sq. m) | 38 | 718,353.10 | 1,108,676 | 75,400 | 6,747,319 |
| Yard gantry (n) | 38 | 30.79 | 24.19 | 0 | 101 |
| Ship-shore and/or quay gantry (n) | 38 | 11.24 | 8.52 | 0 | 36 |

Obs: number of observations, SD: standard deviation.

to a reference container terminal. Technical efficiency of a container terminal can be expressed as:

$$\text{Technical efficiency} = \frac{\text{Actual productivity}}{\text{Reference productivity (estimated frontier)}}$$

The application of DEA and FDH as a methodology for benchmarking studies is widely accepted across disciplines. Both of the methods are non-parametric frontier approaches and are based on a linear programming framework. In DEA, a virtual frontier that defines the best in class is estimated based on inputs and outputs of decision-making units (DMUs, in this case, container terminals). Other DMUs are then compared with the best in class to estimate the technical efficiency. In FDH, a DMU is efficient if there is no other DMU that produces the same or more output but employs less input. FDH does not estimate a hypothetical frontier but is more related to observing real input–output relationship. Thus, frontier models require input and output to be identified. To reduce the impact of abnormal fluctuation in port throughput over time, similar to Cheon, Dowall, and Song (2010), this study uses the average of container throughput of 2009 and 2010 as the output. The inputs are number of berths, berth length, maximum water depth at the terminal, total terminal area, number of yard gantry cranes, and the total number of gantry cranes. All the inputs and output are selected based on a critical review of inputs and outputs used in the previous studies including Hung et al. (2010), Yuen, Zhang, and Cheung (2013), and De Oliveira and Cariou (2015).

To measure efficiency, DEA can be applied in an input-oriented and an output-oriented assumption. Input-oriented DEA measures the potential proportionate reduction in input quantity without changing the output quantity. On the other hand, output-oriented DEA explores the potential proportionate expansion in output quantity without changing the input quantity. This study applies input-oriented DEA to find areas of improvement in port resource utilisation. Two important concepts in DEA are constant return to scale (CRS) and variable return to scale (VRS). Charnes et al. (1978) introduced the input-oriented constant-return-to-scale model (DEA-CCR), and Banker, Charnes, and Cooper (1984) introduced the variable-return-to-scale model (DEA-BCC). An input-oriented DEA-CCR, DEA-BCC and FDH can be written as the following series of linear programming envelopment problem with different constraints.

$$\min_{\phi,\delta} \phi \tag{1}$$

$$\text{s.t.} \quad \phi x_s - X\delta \geq 0 \tag{2}$$

$$Y\delta \geq y_s \tag{3}$$

$$\delta \geq 0 \quad \text{(DEA-CCR)} \tag{4}$$

$$e\delta = 1 \quad \text{(DEA-BCC)} \tag{5}$$

$$\delta_s \in \{0, 1\} \quad \text{(FDH)} \tag{6}$$

where $s = 1, \ldots, S$ denotes the number of container terminals that use $x'_s = (x_{s1}, x_{s2}, \ldots, x_{sm}) \in R^m_+$ inputs to produce $y'_s = (y_{s1}, y_{s2}, \ldots, y_{sn}) \in R^n_+$ outputs (the superscript [′] represents transpose of the matrix). The s-th columns of data matrices $X$ and $Y$ are formed by column vectors $x_s$ and $y_s$, respectively. Non-negative vector $\delta' = (\delta_1, \delta_2 \ldots \delta_s) \in R^S_+$ forms the linear combinations of the S container terminals. Finally, let the suitably dimensioned vector of unity values be $e' = (1, 1, \ldots, 1)$.

From computational perspective DEA and FDH are similar. Similar to Cullinane et al. (2005), Eqs. (1) to (4), (1) to (3) plus (5), and (1) to (3) plus (6) are solved to estimate efficiency results of DEA-CCR, DEA-BCC and FDH models, respectively. The results of DEA-BCC model denote pure technical efficiency (PTE). DEA-CCR model denotes the overall technical efficiency, which consists of two components: scale efficiency and pure technical efficiency. While comparing scores from both DEA-CCR and DEA-BCC model, if a DMU has a different efficiency score that means that the particular DMU has scale inefficiency. Scale efficiency of the $s$-th observed container terminals can be obtained by:

$$SE_s = \frac{CCR_s}{BCC_s} \tag{7}$$

This study uses the '*Benchmarking*' package of the *R* software for analysis purpose. Further details on the methodologies can be found in De Borger et al. (1994) and Banker et al. (1984).

## 4. Analysis and results

### 4.1. Technical efficiency benchmarking

Considering the perspective of terminal managers, the efficiency technology in this study is defined as a minimisation of the terminal inputs linear programming model. Table 2 presents the technical efficiency scores of all container terminals considered in this study for input-oriented DEA-CCR, DEA-BCC and FDH as well as scale efficiencies. For the DEA models, overall technical efficiency (CCR, mean = 0.527) can be decomposed into pure technical efficiency (BCC, mean = 0.869) and scale efficiency (Scale, mean = 0.596). The mean efficiency score of the average of DEA-CCR, DEA-BCC and FDH is 0.791. In contrast to Hung et al. (2010), this study finds that the overall terminal inefficiencies are due to scale inefficiencies rather than pure technical inefficiencies. Therefore, container terminals have room for improvements by adjusting their scales, except the scale efficient terminals (Scale = 1). On this note, a valid strategy for terminals with low scale efficiency would be to consider cooperating with other terminals with high technical efficiency in close proximity.

Apart from that, a number of points emerge from Table 2. First, considering the scale efficiency score, four out of 38 Asian container terminals in the sample are scale-efficient (10.53%). Second, despite a rather high average pure technical efficiency (BCC, mean = 0.869), 52.63% of the terminals still fall below the average score. On the other hand, based on the efficiency score derived using the FDH method, 86.84% of the terminals are efficient. However, as Wang

**Table 2**
Technical efficiency of 38 Asian container terminals[a]

| No. | Container terminal | Port | Country | DEA-CCR | DEA-BCC | FDH | AVG | Scale |
|---|---|---|---|---|---|---|---|---|
| 1 | Dalian Container Terminal | Port of Dalian Authority | China | 0.533 | 0.798 | 1.000 | 0.777 | 0.668 |
| 2 | Dalian Port Container Terminal | Port of Dalian Authority | China | 0.463 | 0.622 | 1.000 | 0.695 | 0.744 |
| 3 | Nansha Terminal | Gaungzhou Port Group Co. Ltd | China | 0.620 | 0.923 | 1.000 | 0.847 | 0.672 |
| 4 | Nansha Terminal Phase 2 | Gaungzhou Port Group Co. Ltd | China | 0.450 | 0.712 | 1.000 | 0.720 | 0.632 |
| 5 | Xingang Terminal | Gaungzhou Port Group Co. Ltd | China | 0.453 | 0.839 | 1.000 | 0.764 | 0.540 |
| 6 | Xinsha Terminal | Gaungzhou Port Group Co. Ltd | China | 0.357 | 0.838 | 1.000 | 0.732 | 0.426 |
| 7 | Kwai Tsing Container Port Terminals 1/2/5 & 9 (south) | Hong Kong Port Development Council | Hong Kong | 0.616 | 0.858 | 1.000 | 0.824 | 0.718 |
| 8 | Cosco-HIT Terminals (Hong Kong) Ltd | Hong Kong Port Development Council | Hong Kong | 0.593 | 0.871 | 1.000 | 0.822 | 0.681 |
| 9 | Qianwan Container Terminal | Qingdao Port (group) Co Ltd | China | **1.000** | **1.000** | **1.000** | **1.000** | **1.000** |
| 10 | Shanghai Container Terminals Ltd | Shanghai Port | China | 0.765 | 1.000 | 1.000 | 0.922 | 0.765 |
| 11 | Shanghai Pudong International Container Terminals | Shanghai Port | China | 0.743 | 1.000 | 1.000 | 0.914 | 0.743 |
| 12 | Gateway Terminal India | Jawaharlal Nehru Port | India | 0.728 | 1.000 | 1.000 | 0.909 | 0.728 |
| 13 | JNP Container Terminal | Jawaharlal Nehru Port | India | 0.259 | 0.829 | 1.000 | 0.696 | 0.312 |
| 14 | Nhava Sheva International Container Terminal | Jawaharlal Nehru Port | India | 0.663 | 1.000 | 1.000 | 0.888 | 0.663 |
| 15 | PT Container Terminal | Tanjung Perak Port | Indonesia | 0.336 | 0.858 | 1.000 | 0.731 | 0.392 |
| 16 | Jakarta International Container Terminal | Tanjung Priok Port | Indonesia | 0.252 | 0.677 | 0.750 | 0.559 | 0.372 |
| 17 | Nabeta Pier Terminal | Nagoya Port Authority | Japan | 0.320 | 0.860 | 1.000 | 0.727 | 0.372 |
| 18 | Jasungdae Container Terminal | Busan Port | South Korea | 0.246 | 0.693 | 0.912 | 0.617 | 0.355 |
| 19 | Korea Express Busan Container Terminal | Busan Port | South Korea | 0.728 | 0.810 | 1.000 | 0.846 | 0.898 |
| 20 | Pusan New Port Terminal | Busan Port | South Korea | 0.670 | 0.707 | 1.000 | 0.792 | 0.947 |
| 21 | U-am Container Terminal | Busan Port | South Korea | 0.249 | 1.000 | 1.000 | 0.750 | 0.249 |
| 22 | Gwangyang International Container Terminal | Gwangyang Port | South Korea | 0.351 | 0.830 | 0.933 | 0.705 | 0.423 |
| 23 | Korea International Terminals | Gwangyang Port | South Korea | 0.372 | 0.705 | 1.000 | 0.692 | 0.528 |
| 24 | Karachi International Container Terminal | Karachi Port | Pakistan | 0.351 | 0.851 | 1.000 | 0.734 | 0.413 |
| 25 | Pakistan International Container Terminal | Karachi Port | Pakistan | 0.329 | 0.887 | 1.000 | 0.739 | 0.371 |
| 26 | Manila International Container Terminal | Manila Port | Philippines | 0.716 | 1.000 | 1.000 | 0.905 | 0.716 |
| 27 | GT Container Terminal | Colombo Port | Sri Lanka | 0.641 | 0.863 | 1.000 | 0.835 | 0.743 |
| 28 | EGCT Terminal B2 | Laem Chabang Port | Thailand | 0.523 | 1.000 | 1.000 | 0.841 | 0.523 |
| 29 | ESCO Terminal B3 | Laem Chabang Port | Thailand | 0.490 | 1.000 | 1.000 | 0.830 | 0.490 |
| 30 | HLT Terminal C1/C2 | Laem Chabang Port | Thailand | 0.178 | 0.578 | 0.781 | 0.512 | 0.309 |
| 31 | LCB1 Terminal B1 & A0 | Laem Chabang Port | Thailand | 0.570 | 0.929 | 1.000 | 0.833 | 0.614 |
| 32 | LCIT Terminal B5 & C3 | Laem Chabang Port | Thailand | 0.410 | 0.812 | 1.000 | 0.741 | 0.505 |
| 33 | TIPS Terminal B4 | Laem Chabang Port | Thailand | 0.523 | 1.000 | 1.000 | 0.841 | 0.523 |
| 34 | TLT Terminal A2/A3 | Laem Chabang Port | Thailand | 0.168 | 0.687 | 0.750 | 0.535 | 0.244 |
| 35 | Cat Lai Terminal | Ho Chi Minh | Vietnam | **1.000** | **1.000** | **1.000** | **1.000** | **1.000** |
| 36 | CCT-Chittagong Container Terminal | Chittagong Port Authority | Bangladesh | 0.366 | 1.000 | 1.000 | 0.789 | 0.366 |
| 37 | GCB – Jetty 6,9,10,11,12,13 | Chittagong Port Authority | Bangladesh | **1.000** | **1.000** | **1.000** | **1.000** | **1.000** |
| 38 | Mundra International Container Terminal | Mundra Port | India | **1.000** | **1.000** | **1.000** | **1.000** | **1.000** |
| Average | | | | **0.527** | **0.869** | **0.977** | **0.791** | **0.596** |

Bold indicates technically efficient container terminal.

[a] For robustness check of the efficiency ranking, technical efficiency of 30 container terminals excluding the eight with updated data (see footnote 1) were estimated using DEA-CCR, DEA-BCC and FDH (available upon request). As expected, efficiency scores change slightly, but ranking remains the same with average DEA-CCR, DEA-BCC and FDH estimate of 0.514, 0.871, and 0.980, respectively.

et al. (2003) mentioned, an FDH-efficient terminal is not necessarily better than its counterparts with lower technical efficiency and may not identify the potential for improvement as they are already efficient in FDH. Finally, in line with Barros (2006), all the efficient terminals in DEA-CCR are also efficient in DEA-BCC, indicating that scale efficiency represents the ultimate technical efficiency score.

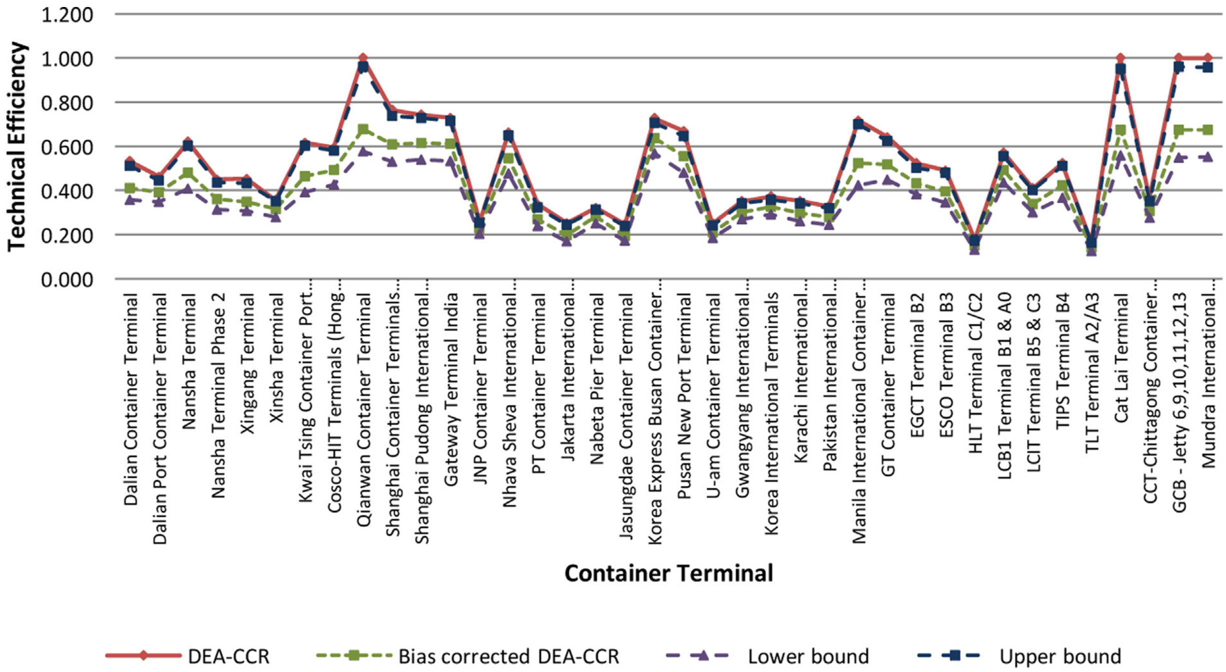
### 4.2. Bootstrap DEA

Being a deterministic method, DEA does not explicitly consider random error and overall deviation from the technology frontier, which means that DEA estimates may be affected by sampling variations. However, only a few technical efficiency benchmarking studies in the port industry have taken this into account (for example, Hung et al., 2010; Nguyen, Nguyen, Chang, Chin, and Tongzon, 2016). Simar and Wilson (1998) suggest employing bootstrapping in any DEA application as a standard practice to enhance the reliability of the estimates. Bootstrapping is a computer-based statistical method for checking the accuracy of statistical estimates. The basic idea of bootstrapping is to replicate the sample by mimicking the data generation process to repeatedly estimate parameters, which in this case is estimating the efficiency of container terminals. For detail procedure of bootstrap DEA, see Simar and Wilson (1998). The result of the bias-corrected bootstrap of container terminal technical efficiency with 3000 bootstrap replicates at 95% confidence interval is shown in Fig. 1.

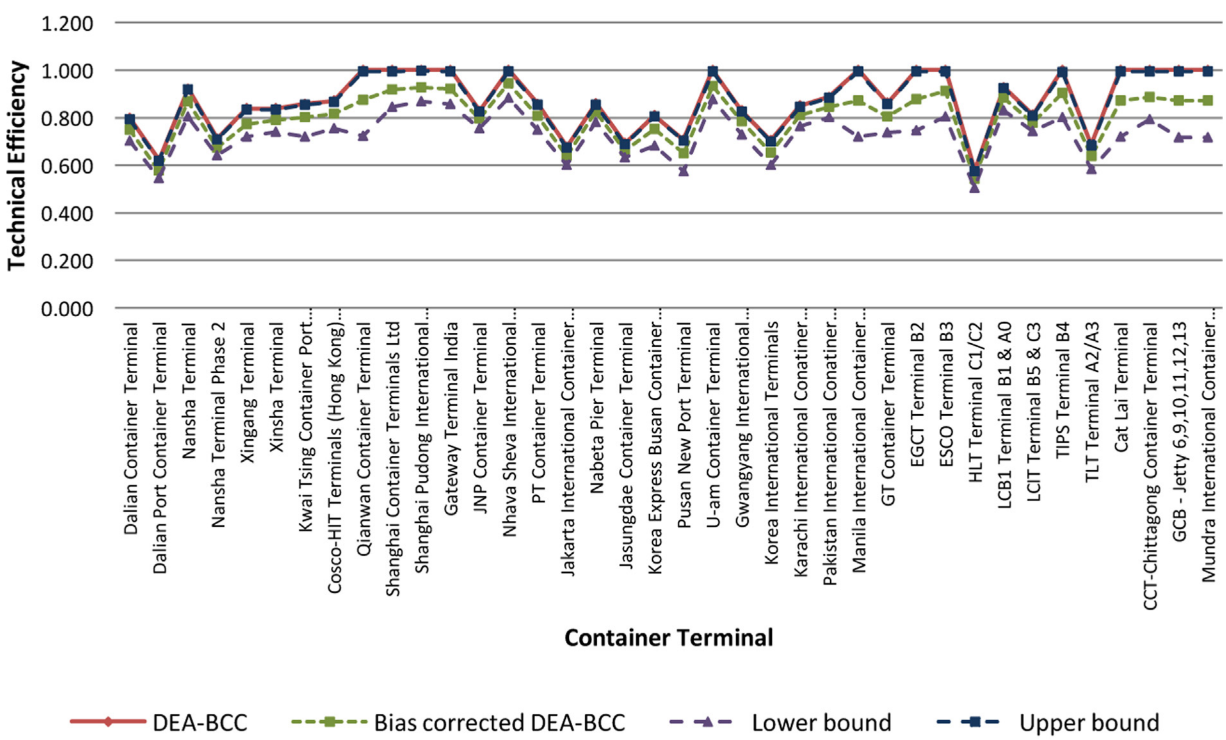
Fig. 1 shows that the efficiency score of a container terminal changes when corrected for bias. Scale-efficient container terminals become less efficient when corrected for bias. For instance, Quianwan Container Terminal (China), Mundra International Container Terminal (India), Cat Lai Terminal (Vietnam) and GCB Terminal (Bangladesh) are scale-efficient container terminals (see Table 2), but their efficiency levels drop during the bootstrapping process (see Fig. 1). However, the ranking of terminals remains the same in Table 2 and Fig. 1. Fig. 1 also presents the upper-bound (2.5% CI) and lower-bound (97.5% CI) confidence intervals for the estimated efficiency scores, where the upper-bound almost coincides with the original technical efficiency estimates.

## 5. Technical efficiency and service level — a case study

The concept of technical efficiency as a driver of port competitiveness has been well-examined (Tongzon & Heng, 2005). Existing maritime literature views high technical efficiency (TE = 1) of a




(a) Confidence intervals and DEA-CCR bootstrap efficiency




(b) Confidence intervals and DEA-BCC bootstrap efficiency

**Fig. 1.** Bootstrap DEA technical efficiency estimates.

terminal or port production as a positive feature. While researchers are busy investigating the drivers of port efficiency (e.g. Chang & Tovar, 2014; Serebrisky et al., 2016; Tongzon & Heng, 2005), it may be the case that the highly efficient terminals are not the most competitive ones in terms of service level, particularly, because they do not invest actively in resource expansion (Cullinane & Wang, 2010). In the same vein, Merkel and Holmgren (2017) argue that the user side of port production has been largely overlooked in port efficiency studies.

From the users' perspective, the major components of the port service level are the berth-time of ships and the port-time of cargoes (Sha & Huang, 2010). Similarly, Li, Yu, Tang, Li, and Zhang

(2017) define port service level as the ratio between average waiting time and average service time of a vessel at port. Any reduction in time periods of these port operation process leads to more satisfied customers. Moreover, according to Yeo, Roe, and Dinwoodie (2008), port service level comprises of a port's ability to respond to customer needs promptly, a 24/7 service opening hour and zero waiting time. Thus, we refer to the port service level as the availability of berth for vessels on arrival at the port and the ability to serve vessels without any waiting time.

### 5.1. Context of the case

In the previous section, we find the four technically efficient container terminals on all of the applied frontier approaches. Hence, we design an in-depth case study focusing on Chittagong Port — one of the ports in the sample hosting two of the highly efficient container terminals (GCB and CCT terminals). In 2019, Chittagong Port was ranked the 64th busiest port in the world, that is, one-rank ahead of Cartagena (Colombia) and one-rank behind Kobe (Japan).[2] Given various approaches to case selection, we consider the three main criteria: (1) the match between the context of the case and the phenomenon under investigation; (2) availability of data; and (3) accessibility of information. The Chittagong Port of Bangladesh certainly meets these criteria. Such *single-case* studies are appropriate "... when a case is revelatory. This means that we can observe and study a phenomenon which was previously not accessible and which can provide useful insights" (Ghauri & Firth, 2009, p. 32).

The Chittagong Port (CP) is the principal port of Bangladesh, handling over 90% of the country's import and export. Although the port governance body, Chittagong Port Authority, was established in 1976, the existence of CP dates back to the fourth century BC (see Munim, Saeed, and Larsen (2019 for detail about CP). Also, CP has enormous potential to become an intermodal container transhipment hub in the region (Munim & Haralambides, 2018). Similar to the current study, CP has been found to be highly technically efficient by Wu and Goh (2010). However, port service level issues of CP, such as long vessel turnaround time, have also been identified as crucial by Dappe and Suárez-Alemán (2016). Thus, CP provides an excellent context for investigating the association between technical efficiency and port service level.

On the input–output based efficiency ranking methods such as DEA, FDH and SFA, the capacity (port infrastructure and availability of equipment) of the terminal and/or port plays a major role in determining efficiency ranks. While inadequate capacity leads to congestion, abundant but idle capacity indicate inefficiency. To achieve the optimum trade-off between inadequate and surplus capacity, it is challenging to make capacity expansion decisions. The purpose of this case study is not to scrutinise capacity expansion decisions, but to shed light on the association between technical efficiency and service level, through an in-depth case study following a step-wise process suggested by Eisenhardt (1989).

### 5.2. Data collection

Data triangulation, that is, collecting data on the same phenomenon from multiple sources, improves the validity of a study and reduces the likelihood of misinterpretation (Ghauri & Firth, 2009). Thus, we collect data from three sources: (1) two semi-structured interviews, (2) 10 online media sources, and (3) archival documents from CPA. A theoretical sampling approach is employed to select the interviewees and to curtain online media data (see Appendix A for detail). The sample of the personal interviewees consists of an employee of Chittagong Port with over 20 years of experience and an employee of an international shipping line company agent in Chittagong with over six years of experience. Both interviewees are contacted multiple times during the qualitative analysis process. As a second source of data, 10 relevant online media sources are retrieved. For reliability purposes, online sources of four different stakeholder category of the port (shipping line, domestic news portal, international news portal and an international logistics service provider) are selected. The third data source, archival data, consisted of yearly overview reports and comprehensive yearbooks, published by the port authority.

### 5.3. Case analysis and findings

We use the NVivo 11 software for qualitative analysis. Qualitative text data about common topics are coded into two major nodes: technical efficiency and port service level. Port throughput and facilities are coded as a child node of technical efficiency, as these are the main deciding variables of technical efficiencies in frontier approaches such as DEA and FDH. The rest of the child nodes emerged during the content analysis of data, following an iterative process (see an overview of node coding in Appendix B). Data of CP on each of the input variables considered for technical efficiency ranking are presented against the output variable in Fig. 2, which shows that investment into port resources usually occur in phases rather than continuously. For example, CP had 11 yard gantries during 2007–2012 and 15 in 2013. Instead of buying one gantry carne each year, CP bought four after an interval of five years.

Technical efficiency scores of ports and terminals help the respective port authorities to make strategic decisions regarding governance model choice, capacity expansion, market penetration etc. In the frontier approaches such as DEA, technical efficiency is estimated based on port throughput (output) and available port resources (input). The ratio of input and output is usually lower in ports with higher technical efficiency than in more inefficient ports. Meanwhile, Merkel and Holmgren (2017) find a negative association between port production efficiency and per capita GDP. This indicates that ports from the lower-income countries are more technically efficient. Being a major gateway port in a developing country, the case of Chittagong Port is no different.

> "*About 90% of the country's export and import is done through Chittagong port. [...] Chittagong port is experiencing 16% to 17% growth in cargo and container handling for the past few years.*" *[Hussain, 2017, July 20]*
> "*In 2017, the container throughput crossed 2.4 million. [...] Being a small port, we are handling a couple of millions of TEUs. [...] Such high technical efficiency is obvious for CPA as we handle a large volume of containers with a comparatively lower number of equipment [...]*"
> *[Respondent A, 2018, January]*

However, the service level at the Chittagong Port is questionable. Chittagong Port has faced capacity issues leading to severe congestion in handling the rapidly growing throughput demand. Based on the combined analysis of qualitative and quantitative data, port throughput has grown dramatically over the years, but the port authority did not undertake continuous capacity expansion initiatives (see Fig. 3). According to *Respondent B*, the quality of equipment is not up to standard, while accidents and unskilled employees make the situation worse.

> "*Inadequate infrastructure at Chittagong port has created severe congestion of cargo vessels at the outer anchorage.*" *[Milad, 2017, July 18]*

[2] Accessed from 'https://lloydslist.maritimeintelligence.informa.com/one-hundred-container-ports-2019' on February 10, 2020.

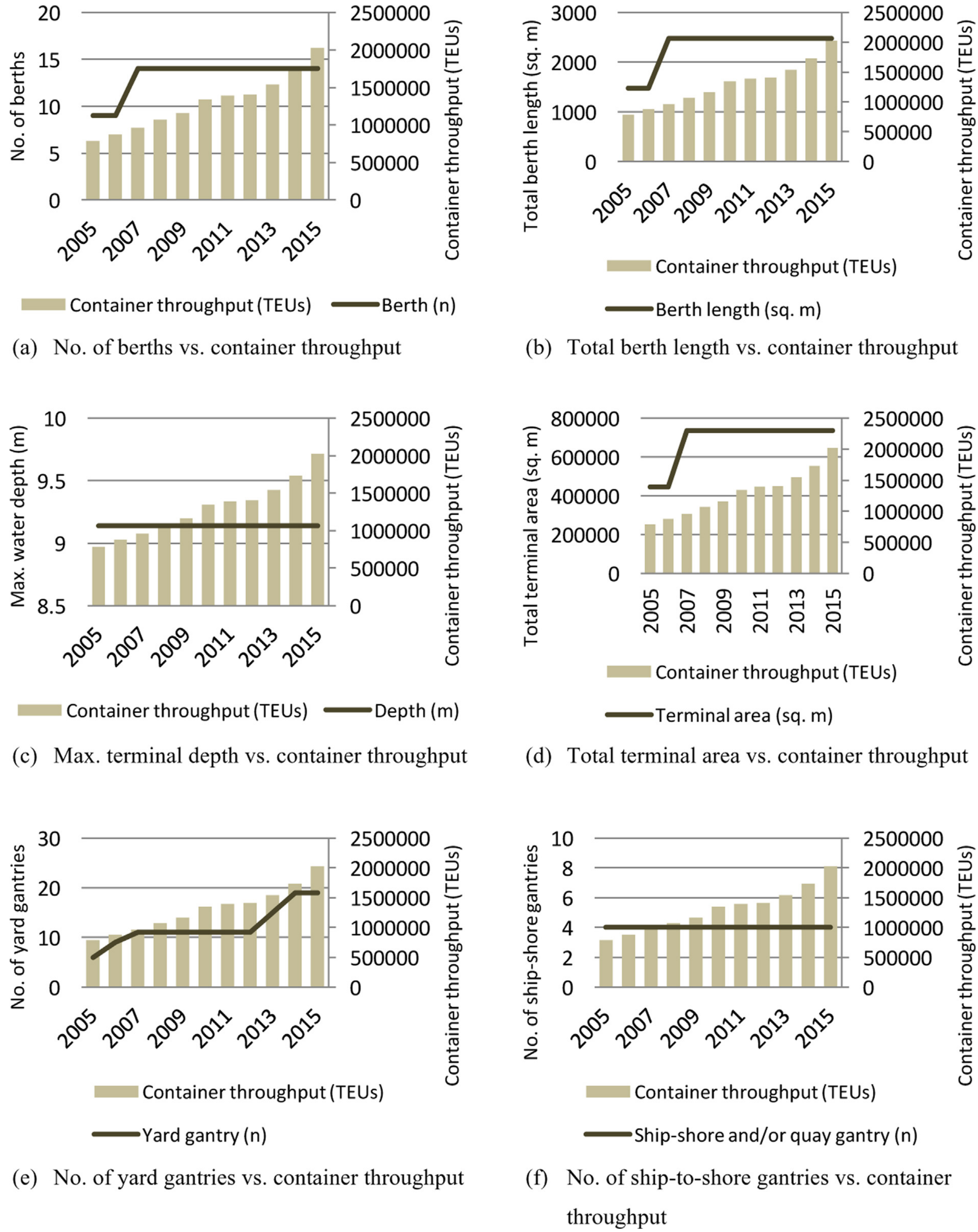



**Fig. 2.** Input–output magnitudes of container productivity in Chittagong Port.

*Source*: CPA (n.d.) and HPC (2014).

> "*To make things worse, the two gantry cranes which were damaged following an accident on June 25 has substantially disrupted the container handling operations of the port. . ..[. . .] The port has been facing huge vessel congestion for the last two months, delaying berthing schedules to many ships waiting at the outer anchorage.*" *[Hussain, 2017, July 20]*

Due to the poor service level at the port, the end-users – the shippers – suffer the most. While congestion peaked in 2017, evidence of charging surcharge due to congestion at CP was existent in 2010 (Emirates Shipping Line, 2010, May 21). The major contributing industry to the country's economy, the ready-made garments (RMG) industry, was about to collapse in 2017. The estimated total

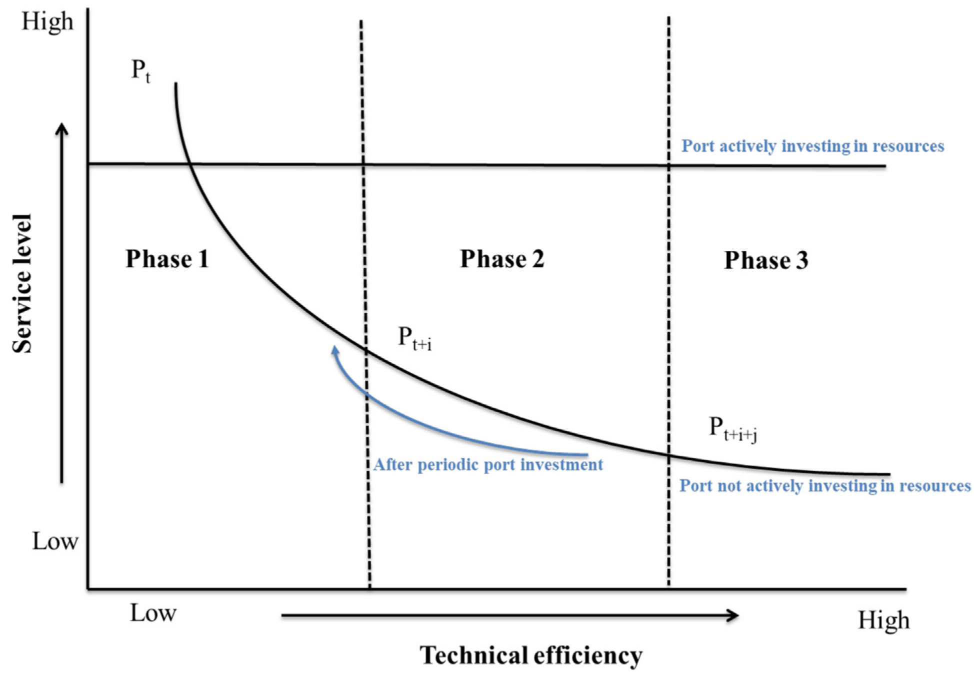



**Fig. 3.** Relationship between technical efficiency and service level.

monthly loss of the local businesses could be up to USD 9.64 million due to surcharges imposed by the shipping lines (Milad, 2017, July 18).

Despite the poor service level at the port, the stakeholders do express hope of improvement in the future. Recently, the port authority has taken some initiatives to improve the service level, even though these should have been initiated earlier. These initiatives involve the procurement of new equipment for building new terminals. While the port may be improving in service level following such initiatives, the relative technical efficiency of the port may drop due to increased capacity in the short-term.

> "*. . . In around 1994–95, the containerization started at the port but was not flourishing until the early 2000s. In 2007, the Bangladesh Army created many off-docks to ease the pressure on the port. [. . .] During 2010–2011, the congestion situation was a little bit better. But starting from 2013–2014, the situation has kept worsening until now. However, many initiatives were taken recently — expansion of existing and development of new port terminals . . . the situation will be much better in the future . . . around 2025.*" *[Respondent A, 2018, January]*
> "*The Chittagong port . . . received 46 pieces of container-handling equipment, which shippers have long demanded to boost capacity at the oft-congested port that is operating well beyond its designed TEU capacity.*" *[Islam, 2017, August 11]*

As stated above, the Bangladesh Army had to create off-docks to handle the container throughput pressure at the port in 2007. The technical efficiency of the port at that time would certainly have been high. After the Newmooring Container Terminal (NCT) of Chittagong Port started operating at the end of 2007, the situation improved, but no new initiatives have been taken for a few years, and the service level started to worsen again in 2013–2014. Due to the recent initiatives, all of the port stakeholders are expecting better service level by 2025. Thus, assuming continuous port throughput growth over time, the following propositions are derived:

**Proposition 1.** *For ports that do not actively invest in resources, the higher their technical efficiency, the lower their service level.*

**Proposition 2.** *For ports that actively invest in resources, the association between their technical efficiency and service level remain constant.*

### *5.4. Discussion on the propositions*

To elaborate on the propositions, Fig. 3 presents three phases in port development that explains the proposed association between technical efficiency and service level. In Phase 1, a terminal starts its operation at time $P_t$ and excels in service level due to the new modern infrastructure and superstructure, but experiences relatively low technical efficiency as container throughput may be low due to the time it takes for a terminal to get the attention of its users. This phase refers to the condition of Chittagong Port in 1994–1995, when the port started handling containers with newly developed berths and newly procured container handling equipment (CPA Yearbook, 1996–1998).

Phase 2 refers to the situation at the time $P_{t+i}$ in Fig. 3, usually 5–10 years from the start of port operation, when the container throughput increases gradually. The port increases its technical efficiency, but the service level starts to suffer in terms of increased waiting times for berthing compared to Phase 1 (assuming that no further investment has been made since the beginning of terminal operation). Congestion within container yards of the port may also be observed in this phase. In the case of CP, container throughput almost doubled between 1995 and 2000 (CPA Yearbook, 2002). Vessel turnaround time increased from 4.69 days in 1997 to 5.9 days in 2000 and even reached 7.11 days during 1998 (CPA Yearbook, 2002).

With the continuous increase in container throughput, a port enters into the Phase 3, at the time $P_{t+i+j}$ in Fig. 3, usually 5–10 years from the Phase 2 (again, assuming no substantial port investment in recent years), where the port is highly technically efficient but suffers greatly in terms of service level. To remain competitive and maintain high service level, it is important for a port to invest in improvement and expansion after reaching $P_{t+i}$, and continue active investment to keep the association between technical efficiency and service level constant. In December 2006 (11 years since 1995) the vessel turnaround time at CP reached a new extreme to

11 days (CPA Yearbook, 2010). Higher turnaround time means loss of money to all port users and may also lead to damage of goods due to the chaos in container handling. The reason behind such low service level is that CPA did not invest actively in the improvement and expansion of the port even after entering the Phase 3. In 2007, the port authority made a large investment and a new container terminal named NCT started operation. Thus, the situation was expected to improve soon and move back to a similar level as in $P_{t+i}$. Indeed, this was reflected in a reduced turnaround time of 2.42 days in June 2008 (CPA Yearbook, 2010). Such expansion decisions should be taken ahead of time, before reaching at the intersection between Phase 1 and 2, based on the forecast of future port throughput, as building terminals or installing new equipment in terminals can typically take two to five years.

*"The current port infrastructure and superstructure are exactly the same as it was in 2012–2013. The port authority has the forecast data of gradually increasing yearly port throughput, and they were to increase capacity accordingly. I would say that the capacity was already low in 2012, and now in 2017, port throughput increased a lot from 2012. It is no more possible to handle the current throughput with the same capacity of 2012." [Respondent B, 2018, January]*

In recent years of port operations, the managerial learnings from the technical efficiency and service level paradox during the 1995–2007 period were not reflected in the actions of the CPA. They hardly procured any new equipment and did not implement any substantial expansion project after the inauguration of NCT in 2007 (see Fig. 3). This is also reflected in the statement by Respondent B above. Again, after facing a situation like in $P_{t+i+j}$ in 2017, CPA ordered 10 new ship-shore gantry cranes for the NCT terminal, six of which are to be installed in October 2018 (Respondent A, 2018, February). With the capacity expansion initiatives taken by CPA at the end of 2017, it is expected that service level might improve in the upcoming years, but at the same time, technical efficiency may drop.

The purpose of an in-depth case study is not to generalise but to reveal a new phenomenon for further investigation. The phenomenon in Proposition 1 has been observed in other high technically efficient ports, too, for example, in Qingdao (Li, 2009) and Ho Chi Minh (Boyd, 2018). There exist inefficient ports in the world, for example, the Port of Oslo (TE < 1) (Schøyen & Odeck, 2013) that provides excellent service level with zero waiting time for container vessels calling at the port. Anderson, Fornell, and Lehmann (1994) also observed the same phenomenon as stated in *Proposition 1*, for other business organisations. Proposition 2 fit with ports that yield a rather constant degree of service level and technical efficiency over time. For example, the Port of Singapore maintains a constant but high service level and technical efficiency over time. Such a balance between technical efficiency and service level is typically achieved by actively investing in port resources based on port throughput forecast.

## 6. Conclusion and future research

This study benchmarks the technical efficiency of 38 Asian container terminals using DEA and FDH methods. Both methods employ the input-oriented efficiency measurement, and for DEA, technical efficiency estimates are under both constant and variable return-to-scale assumptions. Most of the port efficiency studies (e.g., De Oliveira & Cariou, 2015; Hung et al., 2010; Cheon et al., 2010) considered ports as DMUs, which limits the potential for strategic decision-making in terms of adjusting scales among port terminals to achieve a higher level of efficiency. Therefore, in this study, container terminals are taken as DMUs. Also, the bootstrap method is used to validate the accuracy of the DEA estimates. Finally, an in-depth case study explores the characteristics of the highly technical efficient port, particularly investigates the association between service level and technical efficiency.

Only four of the 38 container terminals (one Bangladeshi, one Chinese, one Indian and one Vietnamese) meet the best-in-class scale efficiency. Although the technical efficiency scores of all terminals drop slightly in the bootstrap DEA estimates, the ranking of terminals remained the same. Among the top four, Chittagong Port was found highly efficient by Wu and Goh (2010), too. Thus, an in-depth case study focusing on Chittagong Port, combining both quantitative and qualitative data derive to a proposition on the association between service level and technical efficiency in the context of port operations.

Based on the findings, higher technical efficiency of a DMU does not mean that it has the highest service level. For instance, terminals from Chittagong Port are highly technically efficient (CCT and GCB both scored one in DEA-BCC and FDH), but face capacity problems leading to severe congestion. GCB is a multipurpose terminal with six dedicated berths for container handling and can only serve geared vessels. This requires less resource from a port production point of view, which makes the terminal more efficient, in a purely technical sense, than its peers with similar output.

Technical efficiency ranking from frontier approaches can vary depending on the number of input and output variables used in the study. For instance, the GCB terminal of CP does not have any yard gantry cranes but uses straddle carriers to move container within the terminal (Respondent A, 2018, February). The inclusion of straddle carriers as an input variable may influence the efficiency score of GCB, and this can be true for many other container terminals of the world. Also, consideration of regional or country-specific factors such as port governance model can have an impact on efficiency ranking (Nguyen, Nghiem, & Chang, 2018). Furthermore, as argued in this study and in line with Suárez-Alemán, Trujillo, and Cullinane (2014), taking service level into account by means of waiting time, can change the efficiency rankings completely.

This study offers important implications for the literature and policymakers. In an earlier study, an informal inspection of the highly efficient ports revealed that some of the ports were inefficient because they were investing actively "[...] in either port equipment or infrastructure with the objective of being remaining or becoming competitive in the long-term" (Cullinane & Wang, 2010, pp. 735–736). Through the exploration of an in-depth case study of Chittagong Port – a high technically efficient port – this study provides evidence of the same phenomenon. Terminals and ports that do not actively invest in port resource eventually become high technically efficient in the short-run but suffer in terms of service level in the long-run. However, ports that invest actively in resources based on the long-term forecast of port throughput, maintain a constant technical efficiency and service level.

From the port management perspective, the implications of the findings are threefold. First, strategic decisions taken by port authorities should not only be based on technical efficiency scores but also the service level. Furthermore, poor service level (e.g. long waiting time for berthing) has severe environmental impacts, as Poulsen, Ponte, and Sornn-Friese (2018) stated that "with a guaranteed berth upon arrival the ship can slow steam, avoid idle anchor time, and reduce GHG and air pollution at sea" (p. 85). Second, port authorities must perform long-term forecast of container throughput every year and adjust their expansion decisions accordingly. Finally, terminals with below-average scale efficiency may consider cooperating with other highly efficient terminals of the same port or neighbouring ports, and vice versa. To improve the scale efficiency levels, some terminals may formulate a cluster of logistics network with the efficient or inefficient terminals depending on their current returns-to-scale.

Future research should test the proposition using quantitative data. The use of simulation techniques may serve the purpose of testing the proposition (Davis, Eisenhardt, & Bingham, 2007). Another approach would be to adopt a multiple case study approach. The sample of case studies could be expanded with more container terminals from European and American ports that may provide evidence in support of the proposition of this study or offer other interesting insights regarding the association between service level and technical efficiency. In the same line of thought, it would be interesting to investigate whether the high technically efficient terminals are the most resilient ones to disruptions. This study also observed that congestion at Chittagong Port leads to shipping lines stocking up containers in transhipment ports (such as in Singapore). Thus, future research should investigate the impact of congestion in a peripheral port on its respective transhipment ports.

## Conflict of interest

None declared.

## Acknowledgement

The author would like to thank Professor Kevin Cullinane and Associate Professor Meifeng Luo for useful suggestions in an earlier version of this manuscript.

## Appendix A. Case study data source

*Data source 1: Two personal interviews*

| No. | Interviewee[a] | Role | Position | Years of experience | Times contacted |
|---|---|---|---|---|---|
| 1 | Respondent A | Port Authority | Top management | 25 | 4 |
| 2 | Respondent B | Carrier | Mid-level manager | 6 | 3 |

[a] Names have been anonymised.

*Data source 2: Online news search*

| No. | Reference/source |
|---|---|
| 1 | ANL (2017, July 6) Chittagong Port Congestion Surcharge. Retrieved on February 14, 2018 from https://www.anl.com.au/news/501/chittagong-port-congestion-surcharge |
| 2 | Barua, Dwaipayan (2017, September 7) Ctg port faces fresh congestion: Lack of transport turns container congestion acute. *The Daily Star.* Retrieved on February 14, 2018 from http://www.thedailystar.net/business/ctg-port-faces-fresh-congestion-1458688 |
| 3 | Islam, Syful (2017, August 11) Congested Chittagong port further restricts ship calls. *Journal of Commerce*. Retrieved on February 14, 2018 from https://www.joc.com/port-news/asian-ports/port-chittagong/chittagong-port-further-restricts-ship-calls-fight-congestion_20170811.html |
| 4 | Islam, Syful (2017, September 11) New equipment to help ease Chittagong port congestion. *Journal of Commerce*. Retrieved on February 14, 2018 from https://www.joc.com/port-news/port-equipment/new-equipment-help-ease-chittagong-port-congestion_20170911.html |
| 5 | Hussain, Anwar (2017, July 20) Chittagong port congestion may result in huge losses for businesses. *Dhaka Tribune*. Retrieved on February 14, 2018 from http://www.dhakatribune.com/business/2017/07/20/businesses-fear-loss-vessel-congestion-hits-chittagong-port |
| 6 | Huang, Ethan (2017, August 23) Major delays at Chittagong Port. *More Than Shipping.* Retrieved on February 14, 2018 from https://www.morethanshipping.com/major-delays-chittagong-port/ |
| 7 | COSCO Shipping Line (2017, August 27) The continuous port congestion at Chittagong Port. Retrieved on February 14, 2018 from http://lines.coscoshipping.com/home/News/detail/15010621062040435553/50000000000000231 |
| 8 | Emirates Shipping Line (2010, May 21) Chittagong Port Congestion Surcharge. Retrieved on February 14, 2018 from http://www.emiratesline.com/chittagong-port-congestion-surcharge/ |
| 9 | Gateway-Group (2017, August 28) Demurrage fees are doubled at Chittagong Port to ease congestion. Retrieved on February 14, 2018 from https://gateway-group.com/demurrage-fees-doubled-chittagong-port-ease-congestion |
| 10 | Milad, Masud (2017, July 18) Severe congestion slows down Ctg port. *Prothom Alo.* Retrieved on February 14, 2018 from http://en.prothomalo.com/bangladesh/news/153999/Severe-congestion-slows-down-Ctg-port |

*Note*: On Feb 14, 2018, a Google search was conducted using the term "congestion in Chittagong port" and the 10 website links were assessed based on relevance, among which three are from shipping companies' websites, three from Bangladeshi news channels, three from international news channels and one from the website of an international logistics service provider. The list of news titles and their respective electronic source links are presented in the table above.

*Data source 3: Other archival documents*

| No. | Reference/source[a] |
|---|---|
| 1 | Overview: Chittagong Port Authority (1997, 1998, 2006, 2007, 2014, 2015). |
| 2 | Year Book: Chittagong Port Authority (1996–1998, 2002, 2010) |

[a] Years in parenthesis.

## Appendix B. Nodes compared by number of coding references

| Nodes | Child Node Level 1 | Child Node Level 2 | Child Node Level 3 | # coding references | Aggregate # coding references | Aggregate # items coded |
|---|---|---|---|---|---|---|
| Port service level | | | | 17 | 71 | 11 |
| Port service level | Accidents | | | 6 | 6 | 5 |
| Port service level | Congestion | | | 10 | 21 | 8 |
| Port service level | Congestion | Delays | | 11 | 11 | 6 |
| Port service level | Damages | | | 2 | 26 | 7 |
| Port service level | Damages | Competitive advantage | | 7 | 7 | 2 |
| Port service level | Damages | Monetary loss | | 17 | 17 | 7 |
| Port service level | Port Staff | | | 1 | 1 | 1 |
| Technical efficiency | | | | 2 | 46 | 10 |
| Technical efficiency | Port facilities | | | 11 | 35 | 9 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Technical efficiency | Port facilities | Equipment | | 11 | 11 | 4 |
| Technical efficiency | Port facilities | Terminal | | 8 | 13 | 7 |
| Technical efficiency | Port facilities | Terminal | Storage shortage | 5 | 5 | 4 |
| Technical efficiency | Port throughput | | | 9 | 9 | 5 |

*Source*: Author's compilation from the analysis of 10 online news/media article and two personal interviews using NVivo software.

## References


Anderson, E. W., Fornell, C., & Lehmann, D. R. (1994). Customer satisfaction, market share, and profitability: Findings from Sweden. *Journal of Marketing*, *58*(3), 53–66.

Banker, R. D., Charnes, A., & Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science*, *30*(9), 1078–1092.

Barros, C. P. (2006). A benchmark analysis of Italian seaports using data envelopment analysis. *Maritime Economics & Logistics*, *8*(4), 347–365.

Barros, C. P., & Athanassiou, M. (2004). Efficiency in European seaports with DEA: Evidence from Greece and Portugal. *Maritime Economics & Logistics*, *6*(2), 122–140.

Bichou, K. (2006). Review of port performance approaches and a supply chain framework to port performance benchmarking. *Research in Transportation Economics*, *17*, 567–598.

Bichou, K., & Gray, R. (2004). A logistics and supply chain management approach to port performance measurement. *Maritime Policy & Management*, *31*(1), 47–67.

Blonigen, B. A., & Wilson, W. W. (2008). Port efficiency and trade flows. *Review of International Economics*, *16*(1), 21–36.

Boyd, A. (2018). *Overloaded ports weigh down Vietnam*.. Retrieved from http://www.atimes.com/article/overloaded-ports-weigh-vietnam/

Chang, V., & Tovar, B. (2014). Drivers explaining the inefficiency of Peruvian and Chilean ports terminals. *Transportation Research Part E: Logistics and Transportation Review*, *67*, 190–203.

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, *2*(6), 429–444.

Cheon, S. (2009). Impact of global terminal operators on port efficiency: A tiered data envelopment analysis approach. *International Journal of Logistics: Research and Applications*, *12*(2), 85–101.

Cheon, S., Dowall, D. E., & Song, D.-W. (2009). Typology of long-term port efficiency improvement paths: Malmquist total factor productivity for world container ports. *Journal of Infrastructure Systems*, *15*(4), 340–350.

Cheon, S., Dowall, D. E., & Song, D.-W. (2010). Evaluating impacts of institutional reforms on port efficiency changes: Ownership, corporate structure, and total factor productivity changes of world container ports. *Transportation Research Part E: Logistics and Transportation Review*, *46*(4), 546–561.

Containerisational International. (2012). *Containerisational international yearbook*. UK: Informa.

CPA. (n.d.). Chittagong Port Authority. Chittagong, Bangladesh.

Cullinane, K., & Song, D.-W. (2003). A stochastic frontier model of the productive efficiency of Korean container terminals. *Applied Economics*, *35*(3), 251–267.

Cullinane, K., Song, D.-W., & Gray, R. (2002). A stochastic frontier model of the efficiency of major container terminals in Asia: Assessing the influence of administrative and ownership structures. *Transportation Research Part A: Policy and Practice*, *36*(8), 743–762.

Cullinane, K., Song, D.-W., Ji, P., & Wang, T.-F. (2004). An application of DEA windows analysis to container port production efficiency. *Review of Network Economics*, *3*(2).

Cullinane, K., Song, D.-W., & Wang, T. (2005). The application of mathematical programming approaches to estimating container port production efficiency. *Journal of Productivity Analysis*, *24*(1), 73–92.

Cullinane, K., Wang, T.-F., Song, D.-W., & Ji, P. (2006). The technical efficiency of container ports: Comparing data envelopment analysis and stochastic frontier analysis. *Transportation Research Part A: Policy and Practice*, *40*(4), 354–374.

Cullinane, K., & Wang, T. (2010). The efficiency analysis of container port production using DEA panel data approaches. *OR Spectrum*, *32*(3), 717–738.

Dappe, M. H., & Suárez-Alemán, A. (2016). *Competitiveness of South Asia's container ports: A comprehensive assessment of performance, drivers, and costs. directions in development infrastructure*. Washington, DC: The World Bank.

Davis, J. P., Eisenhardt, K. M., & Bingham, C. B. (2007). Developing theory through simulation methods. *Academy of Management Review*, *32*(2), 480–499.

De Borger, B., Kerstens, K., Moesen, W., & Vanneste, J. (1994). A non-parametric free disposal hull (FDH) approach to technical efficiency: An illustration of radial and graph efficiency measures and some sensitivity results. *Swiss Journal of Economics and Statistics*, *130*(4), 647–667.

De Oliveira, G. F., & Cariou, P. (2015). The impact of competition on container port (in) efficiency. *Transportation Research Part A: Policy and Practice*, *78*, 124–133.

Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of Management Review*, *14*(4), 532–550.

Estache, A., de la Fe, B. T., & Trujillo, L. (2004). Sources of efficiency gains in port reform: A DEA decomposition of a Malmquist TFP index for Mexico. *Utilities Policy*, *12*(4), 221–230.

Ghauri, P. N., & Firth, R. (2009). The formalization of case study research in international business. *Der Markt*, *48*(1–2), 29–40.

González, M. a. M., & Trujillo, L. (2008). Reforms and infrastructure efficiency in Spain's container ports. *Transportation Research Part A: Policy and Practice*, *42*(1), 243–257.

Ha, M.-H., & Yang, Z. (2017). Comparative analysis of port performance indicators: Independency and interdependency. *Transportation Research Part A: Policy and Practice*, *103*, 264–278.

Haralambides, H., Hussain, M., Barros, C. P., & Peypoch, N. (2010). A new approach in benchmarking seaport efficiency and technological change. *International Journal of Transport Economics/Rivista Internazionale di Economia dei Trasporti*, *37*(1), 77–96.

Heaver, T. D. (2002). The evolving roles of shipping lines in international logistics. *International Journal of Maritime Economics*, *4*(3), 210–230.

HPC. (2014). *Strategic Master Plan for Chittagong Port*. Chittagong, Bangladesh: Hamburg Port Consulting GmbH.

Hung, S.-W., Lu, W.-M., & Wang, T.-P. (2010). Benchmarking the operating efficiency of Asia container ports. *European Journal of Operational Research*, *203*(3), 706–713.

Li, S. (2009). *Qingdao port: Seeking chances in challenges*.. Retrieved from http://www.chinatoday.com.cn/ctenglish/se/txt/2009-09/27/content_219737.htm

Li, N., Yu, J., Tang, G., Li, D., & Zhang, Y. (2017). Container terminals capacity evaluation considering port service level based on simulation. In *Proceedings of the 31st European Conference on Modelling and Simulation (ECMS)* (pp. 197–203).

Merkel, A., & Holmgren, J. (2017). Dredging the depths of knowledge: Efficiency analysis in the maritime port sector. *Transport Policy*, *60*, 63–74.

Munim, Z. H., & Haralambides, H. (2018). Competition and cooperation for intermodal container transhipment: A network optimization approach. *Research in Transportation Business & Management*, *26*, 87–99.

Munim, Z. H., Saeed, N., & Larsen, O. I. (2019). 'Tool port' to 'landlord port': A game theory approach to analyse gains from governance model transformation. *Maritime Policy & Management*, *46*(1) http://dx.doi.org/10.1080/03088839.2018.1468936

Munim, Z. H., & Schramm, H.-J. (2018). The impacts of port infrastructure and logistics performance on economic growth: The mediating role of seaborne trade. *Journal of Shipping and Trade*, *3*(1), 1–19.

Nguyen, H. O., Nguyen, H. V., Chang, Y. T., Chin, A. T., & Tongzon, J. (2016). Measuring port efficiency using bootstrapped DEA: The case of Vietnamese ports. *Maritime Policy & Management*, *43*(5), 644–659.

Nguyen, H. O., Nghiem, H. S., & Chang, Y. T. (2018). A regional perspective of port performance using metafrontier analysis: The case study of Vietnamese ports. *Maritime Economics & Logistics*, *20*(1), 112–130.

Notteboom, T., Coeck, C., & Van Den Broeck, J. (2000). Measuring and explaining the relative efficiency of container terminals by means of Bayesian stochastic frontier models. *Maritime Economics & Logistics*, *2*(2), 83–106.

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

Panayides, P. M. (2006). Maritime logistics and global supply chains: Towards a research agenda. *Maritime Economics & Logistics*, *8*(1), 3–18.

Poulsen, R. T., Ponte, S., & Sornn-Friese, H. (2018). Environmental upgrading in global value chains: The potential and limitations of ports in the greening of maritime transport. *Geoforum*, *89*, 83–95.

Robinson, R. (2002). Ports as elements in value-driven chain systems: The new paradigm. *Maritime Policy & Management*, *29*(3), 241–255.

Roll, Y., & Hayuth, Y. (1993). Port performance comparison applying data envelopment analysis (DEA). *Maritime Policy and Management*, *20*(2), 153–161.

Schøyen, H., & Odeck, J. (2013). The technical efficiency of Norwegian container ports: A comparison to some Nordic and UK container ports using Data Envelopment Analysis (DEA). *Maritime Economics & Logistics*, *15*(2), 197–221.

Serebrisky, T., Sarriera, J. M., Suárez-Alemán, A., Araya, G., Briceño-Garmendía, C., & Schwartz, J. (2016). Exploring the drivers of port efficiency in Latin America and the Caribbean. *Transport Policy*, *45*, 31–45.

Sha, M., & Huang, X. (2010, January). A system dynamics model for port operation system based on time, quality and profit. In *2010 International Conference on Logistics Systems and Intelligent Management (ICLSIM)*. IEEE.

Simar, L., & Wilson, P. W. (1998). Sensitivity analysis of efficiency scores: How to bootstrap in nonparametric frontier models. *Management Science*, *44*(1), 49–61.

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

Tongzon, J. (2001). Efficiency measurement of selected Australian and other international ports using data envelopment analysis. *Transportation Research Part A: Policy and Practice*, *35*(2), 107–122.

Tongzon, J., & Heng, W. (2005). Port privatization, efficiency and competitiveness: Some empirical evidence from container ports (terminals). *Transportation Research Part A: Policy and Practice*, *39*(5), 405–424.

Wang, T.-F., & Cullinane, K. (2006). The efficiency of European container terminals and implications for supply chain management. *Maritime Economics & Logistics*, *8*(1), 82–99.

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

Wiegmans, B. W., Ubbels, B., Rietveld, P., & Nijkamp, P. (2002). Investments in container terminals: Public private partnerships in Europe. *International Journal of Maritime Economics*, *4*(1), 1–20.

WTO. (2016). *Trade statistics and outlook*. WTO: 2016 press releases.

Wu, Y.-C. J., & Goh, M. (2010). Container port efficiency in emerging and more advanced markets. *Transportation Research Part E: Logistics and Transportation Review*, *46*(6), 1030–1042.

Yeo, G. T., Roe, M., & Dinwoodie, J. (2008). Evaluating the competitiveness of container ports in Korea and China. *Transportation Research Part A: Policy and Practice*, *42*(6), 910–921.

Yuen, A. C.-l., Zhang, A., & Cheung, W. (2013). Foreign participation and competition: A way to improve the container port efficiency in China? *Transportation Research Part A: Policy and Practice*, *49*, 220–231.

**Ziaul Haque Munim** is Associate Professor of Maritime Logistics at the Faculty of Technology, Natural and Maritime Sciences of the University of South-Eastern Norway. His main research interests include maritime economics and logistics, forecasting, supply chain management and research methods. He holds a PhD degree in International Management from the University of Agder and an MSc degree in Supply Chain Management from the Vienna University of Economics and Business. His publications have appeared in leading journals such as Resources, Conservation & Recycling, Maritime Policy and Management, Journal of Business Research, Research in Transportation Business & Management, and others. He received the Palgrave Macmillan Best Paper Award at the IAME 2016 conference and the KLU Young Researcher Best Paper Award at the IAME 2018 conference.