Sources of efficiency changes at Asian container ports

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Abstract

Purpose – This study aims to investigate the efficiency changes of 23 major Asian container ports for the period from 2000 to 2007. In addition to assess the general trend, it also attempts to decompose the overall efficiency change into technological efficiency change, technical efficiency change and scale efficiency change to help port authorities to devise operational strategies.

Design/methodology/approach – The Malmquist index method is used, which is derived from data envelopment analysis. In this model, technological improvement comes from using state-of-the-art technologies, technical improvement is from rationalizing of port inputs and scale efficiency is from adjustment of port operational scales.

Findings – On average, the investigated ports have improved their efficiencies by 14.3 per cent. Such efficiency gains can be attributed to a 41 per cent increase in pure technical efficiency, a 47.5 per cent increase in scale efficiency and a 30.5 per cent decrease in technological efficiency. The scale efficiency contributes the most to the overall efficiency improvement, while technical and technological effects seem to have less impact. The fact that technological efficiency has little variance seems to suggest that this source of efficiency gain may not bring substantial competitive advantage.

Research limitations/implications – The sample period is 2000-2007, so the impact from the Asian financial crisis or the economic downturn was not covered. Also, the port throughputs data do not separate shipment and transhipment.

Originality/value – This study provides valuable suggestions to improve efficiency for container ports along the "Maritime Silk Road."

Keywords Productivity, Data envelopment analysis

Paper type Research paper

Introduction

Container ports and terminals form an essential component of the modern economy. Containerization since the middle of the twentieth century has largely reduced the transportation cost of international trade, resulting in dramatically growing demand for container transport. Physical expansion and efficiency improvement have been the two major approaches to enlarge container port capacity to cope with escalating trade volumes (Le-Griffin and Murphy, 2006). Yet in places where port expansion is constrained by a limited supply of land and increasing environmental concerns, improving port efficiency is more feasible and effective. It is then critical to assess the potential sources of port efficiency gains over time for governments and port operators to devise strategies accordingly. In particular, governments are able to optimize the collocation of the coastal resources to enhance the competitiveness of hinterlands while port operators may benchmark their performance with comparable ports to identify areas for improvement.

The Belt and Road Initiative, also known as One-Belt One-Road, is a strategic project that has been a major topic of discussion in countries along the twenty-first-century Maritime Silk Road of One-Belt One-Road. "One-Belt" denotes the Silk Road Economic Belt and includes countries such as Indonesia, Malaysia, Philippines, Singapore, Thailand, etc. It is believed that the Silk Road Economic Belt will serve as a vehicle to create economic prosperity for the world. Ports along the Silk Road Economic Belt is not only affecting the local economy but also reverberating across the worldwide economy.

Port has more to offer to businesses than just a maritime facility. Therefore, an efficient port will be substantially enhancing many economic activities around the port from trade to shipping, and from transport to warehousing. Previous research has not sufficiently addressed efficiency changes in large Asian container ports compared with those in developed regions. Few studies have tried to analyze the sources to which efficiency gains and losses can be attributed (Cullinane *et al.*, 2002; Yip *et al.*, 2011). In this study, we aim to fill these gaps by estimating the efficiency changes of major Asian container ports, many of which are along the Silk Road Economic Belt, for the period from 2000 to 2007. In addition to estimate the overall efficiency change, we intend to decompose the overall change into components related to technical, scale and technological efficiency and thereby derive policy implications to governments, port authorities and operators. Finally, a series of media reports have been published recently on the decline of Hong Kong Port (Heaver, 2017; Grinter, 2018), motivating us to examine in detail the performance of Hong Kong Port, and benchmark it with its main competitors. In this way, this study will provide valuable findings such that ports along the Silk Road Economic Belt will have possible options to enhance their efficiency.

We will first review the concept and methodologies of calculating efficiency changes before describing the data and scope of this study. We will then present the result of analysis and discuss its implications for port authorities and operators by providing an overview of efficiencies for all ports and examining in detail the sources of inefficiencies. The performance of Hong Kong Port, as well as its comparison with its major competitors, will be addressed. Finally, the limitations of this study and areas for further research will also be discussed.

Literature review

Widely used methods to calculate productivity include index number approach, traditional regression methods, corrected original least squares (COLS), stochastic frontier analysis (SFA), and data envelop analysis (DEA). Derived from DEA framework, recent studies have increasingly utilized the Malmquist productivity index (MI) method to measure productivity of container ports and terminals (Choen *et al.*, 2009; Song and Cui, 2014; Ding *et al.*, 2015). The MI method shares many of the advantages of DEA method, and is particularly useful to evaluate the productivity change of decision-making unit (DMUs) between two time periods. Furthermore, it has the advantage of decomposing overall productivity change into various components. In the following, we discuss in detail the intuition of each approach, as well as their advantages and limitations.

The index number approach attempts to capture the ability of DMUs to combine inputs and produce outputs. The total factor productivity (TFP) is the most widely used measure in the index number approach. Though easy to calculate, such index has limitation in distinguishing efficiency changes from the effects of scale economies and input substitution (Choen *et al.*, 2009).

Original least squares (OLS) estimation is another approach where a regression line is fitted into the existing data, representing the productivity of each DMU derived from the observed data. Yet this approach relies on the assumption of an optimal production or cost function and is therefore inaccurate as decisions of DMUs are not always optimized. Corrected original least squares (COLS) estimation is an improved method where the regression line in OLS is shifted to enclose all the data. The shifted line represents the efficiency frontier and the relative efficiency of each individual port can be measured against the frontier. However, the weakness of this approach includes its dependence on a priori production or cost function and its sensitivity to the frontier used (Liu, 2010).

Stochastic frontier analysis (SFA) is a parametric and stochastic approach to estimate productive efficiency. The major breakthrough of SFA compared to regression methods is that SFA calculates the inefficiency of DMUs based on distribution assumptions, so different entities can have different inefficiencies (Yip *et al.*, 2011; Merkel, 2018). In common with the COLS approach, SFA relaxes the assumption that the behavior of DMUs is optimized. As in COLS, the degree of (in)efficiency of individual DMUs can be measured against the frontier. The main advantage of the SFA method is that it considers statistical noise, and hence, it is possible to test the validity of certain assumptions and hypotheses and that there is great flexibility in specifying the production technology in functional form. However, similar to COLS, the drawbacks include the need to impose a priori structure when constructing the frontier functional form. Furthermore, the estimation results using SFA is sensitive to the assumptions concerning the distribution of the inefficiency terms.

Data envelopment analysis (DEA) is a mathematical programming approach to estimate efficiency. Similar to COLS and SFA, this approach also maps out a production frontier based on inputs and outputs information, and the relative efficiency of each DMU is estimated from its distance to the frontier. The strength of this method is that no priori structural assumptions is required. The drawbacks of this method lie in that the accuracy of it is sensitive to outliers, and that it does not consider the measurement error so that it is not possible to test the statistical significance of the estimated efficiency. A growing number of studies have used the DEA method to evaluate port efficiency (Panayides *et al.*, 2009). Roll and Hayuth (1993) is probably the first study which applies the Charnes, Cooper, and Rhodes (CCR) DEA model with the assumption of constant returns to scale (CRS) to the port sector. It uses a hypothetical example of 20 container ports to generate simulated results. Martínez -Budria *et al.* (1999) uses the Banker, Chames and Cooper (BCC) DEA model assuming variable returns to scale (VRS) to analyze 26 Spanish ports using input and output data during the years 1993-1997. Tongzon (2001) argues that to restrict the scope of analysis to a limited number of ports and a specific type of cargo is necessary for the multiplicity of ports and cargo handled. It uses both CCR DEA and DEA-additive models to analyze the efficiency of 4 Australian and 12 other international container ports for the year 1996. Valentine and Gray (2001) again use a CCR DEA model to compare the efficiency of 31 world-class container ports with different ownerships and organizational structures in 1998. Cullinane *et al.* (2005) investigate the relationship between privatization and efficiency by analyzing 25 container ports during 1992-1999. Nguyen *et al.* (2016) used bootstrapped DEA to measure efficiency of Vietnamese ports.

The Malmquist productivity index (MI), based on DEA models, is one of the prominent indices for measuring the relative productivity change of DMUs over time. Using this method, the estimated efficiency changes are decomposed into frontier shift effects (due to technological advancement) and catch-up effects. The catch-effects are further separated into pure technical efficiency effects and scale efficiency effects, indicating the extent to which an operator catches up with the best practice in the field and optimize the scale of its operations to meet the demand side. This index has been used to measure efficiency changes in other regulated infrastructure sectors such as electricity (Hjalmarsson and Veiderpass, 1992), natural gas (Price and Weyman-Jones, 1996), and airports (Abbot and Wu, 2002). For the port sector, this type of research has been conducted for countries like Yugoslavia and Mexico (Nishimizu and Page, 1982; Estache *et al.*, 2004; Choen *et al.*, 2009) have also applied MI to 98 world scale container ports and major national gateway ports. Ding *et al.* (2015) applied MI to coastal secondary ports in China. The following section will discuss in detail the methodology of calculating the MI.

Methodology

Based on information on the inputs and outputs of DMUs in two periods, the MI method can determine whether the variation of performance is due to technical efficiency change (TEC) and/or technological change (TC). Following Estache *et al.* (2004), the MI calculated for year t and $t+1$ can be calculated as the following:

$$M_0 = \left[\frac{D_0^t\left(x_0^{t+1}, y_0^{t+1}\right)}{D_0^t\left(x_0^t, y_0^t\right)} \cdot \frac{D_0^{t+1}\left(x_0^{t+1}, y_0^{t+1}\right)}{D_0^{t+1}\left(x_0^t, y_0^t\right)} \right]^{1/2}.$$

Here, the $D_0^t\left(x_0^s, y_0^s\right)$ represents the distance from the period s observation to the period t technology. When M_0 is greater than 1, it indicates productivity growth, and when M_0 is smaller than 1, it indicates productivity deterioration. The MI can be decomposed into two components: the technical efficiency change (TEC) and the shift of productivity frontier due to technological change (TC):

$$M_0 = \frac{D_0^{t+1}\left(x_0^{t+1}, y_0^{t+1}\right)}{D_0^t\left(x_0^t, y_0^t\right)} \times \left[\frac{D_0^t\left(x_0^t, y_0^t\right)}{D_0^{t+1}\left(x_0^t, y_0^t\right)} \cdot \frac{D_0^t\left(x_0^{t+1}, y_0^{t+1}\right)}{D_0^{t+1}\left(x_0^{t+1}, y_0^{t+1}\right)} \right]^{1/2} = \mathrm{TEC} \times \mathrm{TC}.$$

The first component measures how close the DMU is to the frontier in year $t+1$ compared with year t, and therefore, with TEC greater than 1, the DMU has moved closer to the frontier in year $t+1$ than in year t, and vice versa. The second component captures the change in technology between the two periods. If TC is greater than 1, it indicates technological progress, and vice versa.

Given that the MI measure is derived from DEA, its decomposition also depends on the assumptions on returns to scale. The TEC and TC indices above are calculated under the assumption of CRS, that is, assuming that all DMUs are already operating at the optimal scale. As illustrated in Grilo and Santos (2015), the TEC calculated under the assumption of CRS can be further decomposed into pure technical efficiency change (PTEC) and scale efficiency change (SEC) under the assumptions of VRS:

$$M_0 = \mathrm{PTEC} \times \mathrm{SEC} \times \mathrm{TC}.$$

$$\text{PTEC} = \frac{D_{0\text{VRS}}^{t+1}\left(x_0^{t+1}, y_0^{t+1}\right)}{D_{0\text{VRS}}^{t}\left(x_0^{t}, y_0^{t}\right)}.$$

$$\text{SEC} = \frac{D_{0\text{CRS}}^{t+1}\left(x_0^{t+1}, y_0^{t+1}\right)/D_{0\text{VRS}}^{t+1}\left(x_0^{t+1}, y_0^{t+1}\right)}{D_{0\text{CRS}}^{t}\left(x_0^{t}, y_0^{t}\right)/D_{0\text{VRS}}^{t}\left(x_0^{t}, y_0^{t}\right)}.$$

PTEC captures changes in technical efficiency resulting from improvements in operations and management practices, that is, the least inputs are used in producing the outputs. SEC captures the productivity change associated with the movements of DMUs inside the frontier and assess whether the movements are in the right direction to attain the CRS point, which is the optimal scale point.

In this study, we use the MI method to investigate the overall efficiency changes at major Asian container ports from 2000 to 2007. We further look into the contributions from improvements in pure technical efficiency, scale efficiency and technological progress for each port. The performance of Hong Kong Port will be benchmarked with the overall statistics and with its major competitors. Finally, a statistical test will be run to reveal the correlation between overall efficiency change, that is MI, and PTEC, SEC or TC, which indicates the contribution of each source to the overall efficiency improvement/deterioration.

Data and scope

Ideally, all activities and resources involved in container port operations should be taken into account when calculating efficiency. This decision of which input and output variables to be included, however, largely depends on the availability and quality of data.

The specification of inputs in the literature is not unified. Some studies consider labor and capital as input variables (Liu, 1995; Coto-Millan *et al.*, 2000; Estache *et al.*, 2002; Cullinane and Song, 2003). Some others specify inputs based on the infrastructure and machineries of the ports, that is, quay length, terminal area, number of cargo handling equipment and storage capacity (Tongzon and Heng, 2005; Cullinane *et al.*, 2002; Cullinane and Song, 2006; Sun *et al.*, 2006). Though important for port operations, labor inputs may not be necessary or suitable for determining productivity for several reasons. First, a fairly close relationship exists between the number of workers in a container terminal and the number of gantry cranes. The labor input can thereby be derived by a function of the facilities of the terminal (Notteboom *et al.*, 2000). Second, many operations during cargo handling are outsourced to third-party logistics firms, making the port's statistics data on labor less reliable. Finally, in the era of containerization, many port operations are standardized. The efficiency differences caused by labor are not very significant (Liu *et al.*, 2006). In contrast, the infrastructure and machineries inputs reflect a more accurate configuration of the ports (Notteboom *et al.*, 2000). In this case, given the characteristics of container ports operations and the limitation of information, total container berth length (in meter), container terminal area (in square meter), and landside container crane capacity (in ton) are selected as the inputs for analysis. Other input factors, such as berth working hours, berth waiting time and other equipment, are not included from the consideration of both data availability and avoidance of the problem of multicollinearity.

The specification of outputs in the literature is more unified. Though some recent studies have started to incorporate multiple outputs (Barros, 2005; Rodriguez-Alvarez *et al.*, 2007), the annual container throughput (in TEU) is still the most widely accepted indicator for container transport activities. In addition, to reduce the impact of severe output fluctuation that might have been caused by external shocks (e.g. labor dispute), the average of three successive years' throughput is used as the final output (e.g. the average value of 1998, 1999 and 2000's output is used as the output data for 2000)[1].

The scope of this research is for Asia and a total number of 23 containers ports will be investigated (see Figure 1 for their geographic locations). We first identify 27 ports whose throughput in 2008 were at least two million TEUs, and they contributed to more than 80 per cent of the total throughput of Asian container ports in that year. Then for Asian countries not covered by these ports, we will include their largest container ports as well. However, the final sample size is reduced due to data availability. Specifically, data on port input and output are mainly collected from *Containerization International Yearbook*, whose information is collected directly from the terminal operating organizations. Other data sources include *China's Port Yearbook* and port authorities' websites, etc. Output and input data are available for 28 ports for year 2007, but this number decreases to 23 ports for year 2000. Therefore, the final sample will be restricted to the 23 Asian container ports that have data for both years.

The 23 investigated container ports are represented by 14 countries/regions, Singapore, China, Hong Kong (China), Korea, Taipei (China), Malaysia, Thailand, Japan, India, Indonesia, Sri Lanka, Philippines, Pakistan and Brunei, and therefore shall have different policies, management structures and regulatory characteristics. Their output variables (throughput in TEU) and input variables (berth length in meter, terminal areas in square meter, crane capacity in ton) are presented in Table I, for year 2000 and year 2007

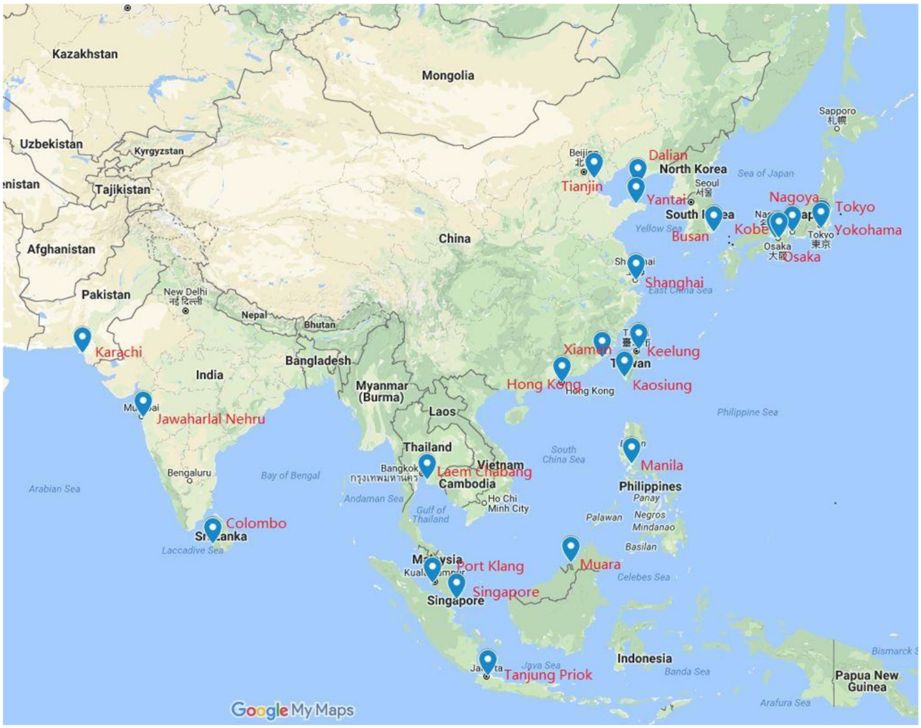

Figure 1.
The location of the 23 major Asian container ports

	Output		Input	
	Throughput (TEU)	Berth length (meter)	Terminal area (square meter)	Crane capacity (ton)
Year 2000				
Singapore	16,040,116.7	2,946.0	1,785,200.0	710.0
Shanghai	4,296,333.3	2,281.0	858,000.0	482.0
Hong Kong	16,297,597.3	6,059.0	2,180,000.0	1796.0
Busan	6,641,863.3	4,897.0	2,472,736.0	1,646.6
Kaosiung	6,894,082.0	4,048.0	1,138,000.0	580.0
Tianjin	1,342,141.0	1,300.0	575,000.0	80.0
Port Klang	2,525,730.0	4,579.0	1,407,600.0	1,615.0
Laem Chabang	1,860,865.3	1,600.0	10,000.0	90.0
Xiamen	859,900.0	500.0	400,000.0	82.0
Dalian	742,034.0	300.0	560,000.0	61.0
Tokyo	2,587,861.3	2,944.0	938,000.0	760.0
Jawaharlal nehru	916,288.7	680.0	471,000.0	106.5
Tanjung priok	2,215,841.0	1,410.0	635,351.0	255.0
Yokohama	2,193,942.7	5,150.0	1,281,816.8	1,369.9
Colombo	1,717,107.0	1,899.0	262,000.0	105.0
Nagoya	1,645,652.0	3,370.0	876,600.0	1,164.1
Manila	2,287,054.7	3,707.0	1,790,000.0	657.4
Kobe	2,180,960.0	8,785.0	3,198,886.0	581.5
Osaka	1,293,393.7	3,065.0	895,905.0	524.9
Keelung	1,774,945.7	3,192.0	339,000.0	955.0
Yantai	347,000.0	180.0	30,000.0	50.0
Karachi	549,303.3	600.0	136,220.0	150.0
Muara	49,039.3	515.0	6,070.0	37.0
Year 2007				
Singapore	25,305,533.3	6,565.0	2,600,000.0	4,067.4
Shanghai	21,981,333.3	7,356.0	6,169,837.0	3,967.0
Hong Kong	23,379,553.0	10,999.0	3,438,820.0	5,903.0
Busan	12,381,050.3	7,076.0	3,408,202.0	2,791.2
Kaosiung	9,834,185.0	6,714.0	1,421,374.0	915.0
Tianjin	5,951,333.3	2,450.0	1,004,400.0	385.0
Port Klang	6,377,383.0	5,513.0	1,736,300.0	2,117.5
Laem Chabang	4,177,001.7	7,660.0	3,546,800.0	2,868.5
Xiamen	3,996,000.0	1,490.0	480,000.0	234.0
Dalian	3,480,397.3	2,808.0	1,663,150.0	1,161.0
Tokyo	3,970,743.0	4,016.0	1,020,901.0	1,000.0
Jawaharlal nehru	3,341,624.7	1,280.0	688,400.0	642.0
Tanjung priok	3,593,860.0	3,192.0	1,656,000.0	855.0
Yokohama	3,167,090.7	5,430.0	1,911,256.0	1,522.8
Colombo	2,972,040.7	3,154.0	472,300.0	1,013.0
Nagoya	2,713,032.0	3,755.0	1,368,240.0	1,289.3
Manila	2,751,349.0	3,556.0	1,672,200.0	663.4
Kobe	2,382,547.0	6,985.0	1,766,413.0	1,684.8
Osaka	2,211,870.3	4,065.0	1,303,767.0	930.2
Keelung	2,145,252.7	3,192.0	339,000.0	955.0
Yantai	1,604,426.3	1,681.0	470,000.0	411.0
Karachi	1,157,546.0	1,200.0	346,000.0	364.0
Muara	141,436.0	250.0	98,000.0	80.0

Table I.
Port output and input variables

respectively. The output throughput for 2000 is the average number of the throughput of 1998, 1999 and 2000. Similarly, the output for 2007 is the average of that in 2005, 2006 and 2007. The summary statistics of the input and output variables are reported in Table II. In the following section, the MI analysis will be implemented with the 23 ports that have data on both years.

Findings

Table III has summarized the efficiency changes and their sources at the investigated ports from 2000 to 2007 using the MI method. Overall, the major Asian container ports have improved their efficiency by 14.3 per cent (with average MI = 1.143). The sources of efficiency gains/losses can be attributed to:

- a 41 per cent increase in pure technical efficiency (average TEC = 1.41);
- a 47.5 per cent increase in scale efficiency (average SEC = 1.475); and
- a 30.5 per cent decrease in technological efficiency (average TC = 0.695).

Nine ports appear to have improved their efficiency while the remaining fourteen have retrogressed. Busan Port is the best-performing port according to our analysis, with MI = 2.805. This increase in MI mainly comes from its improvement in technical efficiency (TEC = 2.439) and scale efficiency (SEC = 1.428), while its TC score is less than 1 (TC = 0.805). It is worth noting that all ports have a TC index that is smaller than 1, which indicates deterioration in technological improvement, that is, no innovation in technologies.

Table II. Summary statistics of port output and input variables

	Output		Input	
	Throughput (TEU)	Berth length (meter)	Terminal area (square meter)	Crane capacity (ton)
Year 2000				
Mean	3,359,089.3	2,782.9	967,277.6	602. 6
Medium	1,860,865.3	2,944.0	858,000.0	524.9
Standard deviation	4,392,986.7	2,154.8	845,059.1	571.0
Standard error	916,001.0	449.3	176,207.0	119.1
Skewness	2.4	1.0	1.1	0.9
Maximum	16,297,597.3	8,785.0	3,198,886.0	1,796.0
Minimum	49,039.3	180.0	6,070.0	37.0
N	23	23	23	23
Year 2007				
Mean	6,478,982.1	4,364.7	1,677,450.4	1,557.4
Medium	3,480,397.3	3,755.0	1,421,374.0	1,000.0
Standard deviation	7,289,607.7	2,648.5	1,402,237.6	1,457.7
Standard error	1,519,988.3	552.3	292,386.8	303.9
Skewness	1.9	0.6	1. 7	1.7
Maximum	25,305,533.3	10,999.0	6,169,837.0	5,903.0
Minimum	141,436.0	250.0	98,000.0	80.0
N	23	23	23	23
t-test of mean difference of port output and input data between 2000 and 2007				
Mean difference (2007 minus 2000)	3,119,892.8	1,581.8	710,172.8	954.8
p-value	0.0857	0.0315	0.0434	0.0054
t-value	1.7580	2.2217	2.0803	2.9251

	MI	*Rank*	TEC	*Rank*	SEC	*Rank*	TC	*Rank*
Busan	2.805	*1*	2.439	*4*	1.428	*3*	0.805	*5*
Port Klang	2.541	*2*	3.353	*2*	0.955	*17*	0.794	*6*
Kobe	2.535	*3*	3.846	*1*	0.852	*20*	0.774	*9*
Yokohama	2.303	*4*	2.506	*3*	1.111	*6*	0.827	*2*
Jawaharlal Nehru	2.022	*5*	2.042	*6*	1.286	*5*	0.770	*10*
Muara	1.882	*6*	0.641	*18*	10.783	*1*	0.272	*20*
Nagoya	1.697	*7*	2.260	*5*	1.024	*11*	0.733	*13*
Osaka	1.418	*8*	1.752	*7*	0.993	*13*	0.815	*4*
Kaosiung	1.068	*9*	1.397	*9*	1.075	*7*	0.711	*14*
Manila	0.949	*10*	1.651	*8*	0.766	*23*	0.750	*11*
Tianjin	0.776	*11*	1.034	*10*	0.878	*19*	0.844	*1*
Colombo	0.747	*12*	0.971	*12*	1.044	*9*	0.736	*12*
Dalian	0.730	*13*	0.596	*20*	1.804	*2*	0.680	*15*
Xiamen	0.670	*14*	0.610	*19*	1.366	*4*	0.805	*5*
Singapore	0.666	*15*	1.000	*11*	1.000	*12*	0.666	*16*
Shanghai	0.641	*16*	0.858	*15*	0.958	*15*	0.780	*7*
Keelung	0.620	*17*	0.909	*14*	1.042	*10*	0.654	*17*
Tanjung priok	0.605	*18*	0.915	*13*	1.056	*8*	0.647	*18*
Tokyo	0.507	*19*	0.771	*16*	0.845	*21*	0.779	*8*
Karachi	0.479	*20*	0.703	*17*	0.832	*22*	0.819	*3*
Hong Kong	0.292	*21*	1.000	*11*	0.957	*16*	0.305	*19*
Laem Chabang	0.196	*22*	1.000	*11*	0.906	*18*	0.217	*21*
Yantai	0.141	*23*	0.175	*21*	0.975	*14*	0.827	*2*
Average	1.143		1.410		1.475		0.696	

Table III. MI, TEC, SEC and TC of major Asian container ports from 2000 to 2007

This result contradicts the general belief that most large Asian container ports have rapidly improved their container handling, managerial and security technologies. In addition, in light of Choen *et al.* (2009), ports like Singapore and Hong Kong have made strategic and aggressive capital investment in the most cut-edging technologies, yet their respective TC is only 0.666 and 0.305.

Moreover, a series of media reports have been published recently on the decline of Hong Kong Port (Heaver, 2017; Grinter, 2018). From our analysis, Hong Kong Port ranks as 21st with its MI = 0.292, TEC = 1.000, SEC = 0.957 and TC = 0.305. This indicates decreased efficiency with deterioration in all three sources. All these indexes are below the average. Compared with its major competitors, the port of Singapore and Shanghai also lag behind the regional average in almost all indexes (except for Shanghai's TC). Yet both ports are performing better than Hong Kong in technological development (TC). As for another major competitor, the port of Kaosiung, it has a better ranking of 9th and a higher TC figure of 0.711. In this sense, the port of Hong Kong may first want to improve its technological efficiency, which involves both capital investment and technology utilization. After that, it has to investigate and improve all three areas (technical, scale and technological).

Table IV has summarized the correlations between MI and its three sources. First, the pure technical efficiency seems to have the strongest impact on a port's overall efficiency improvement (correlation = 0.85). Such pure technical efficiency gains are achieved by rationalizing port inputs to generate the maximum output, which usually involves port reforms, strategic long-term planning, and efforts to catch up with the best practices in the industry (Gosasang *et al.*, 2018). SEC and TC seem to have a smaller impact on the overall efficiency gains and losses, with correlations equaling 0.21 and 0.24, respectively. This implies the limitation of simply adjusting port operations scales and adopting the state-of-art technologies to improve port overall efficiency. From Table V, which reports the summary statistics of the (in)efficiencies, it is worth noting that TC has the smallest variance with a standard deviation of 0.18. This implies that ports may easily assimilate with each other in the use of technologies. In this sense, capital investment in new technologies is to be strategic, yet not likely to create sustainable competitive advantage.

Limitations of the study

Apart from the sensitivity to the frontier used and the inability to test for significance of the DEA method, this paper also has several other limitations. First, in addition to inputs, other exogenous factors may influence the efficiency of container ports, such as the transport networks of the operators, the regulations of the regional governments and the general economic trends that affect demand for container transportation. The method used in this study, however, is unable to quantify and separate the efficiency changes from these exogenous factors. Following this, it can be unfair to penalize port operators with deteriorating SEC indexes as external demand is usually driven by the economic sizes and strengths of port hinterlands. According to Estache *et al.* (2004), it will be more appropriate to assess port efficiency changes using MI net SEC ($MI^* = MI/SEC$). We follow this approach and report the bet MI of major Asian container ports in Table VI. Once ruling out the effect of pure scale economies and focusing on technical and technological improvements, Port Kobe seems to have outperformed other ports while Port Muara experienced the least productivity improvement during our sample period.

In addition, the DEA model used here presumes that any port different enough from the others to be the outlier and therefore identify it as the best practice. Yet this port may still be inefficient to some extent. In this sense, this study may not be able to help port operators to fully exploit efficiency gains and other research results shall be used in combination for port authorities/operators to devise proper strategies.

Furthermore, the basic requirement for reliable port efficiency analysis and benchmarking is the appropriate selection of homogenous DMUs. While our choice of

Table IV. Correlation between MI and the three sources of efficiency change

	MI	TEC	SEC	TC
MI	1.00	0.85	0.21	0.24
TEC	0.85	1.00	−0.19	0.27
SEC	0.21	−0.19	1.00	−0.50
TC	0.24	0.27	−0.50	1.00

Table V. Summary statistics of MI, TEC, SEC and TC

	MI	TEC	SEC	TC
Mean	1.143	1.410	1.475	0.696
Medium	0.747	1.000	1.000	0.770
Standard deviation	0.824158	0.935002	2.042023	0.180645
Standard error	0.171849	0.194961	0.425791	0.037667
Skewness	0.800552	1.239775	4.69844	−1.93546
Maximum	2.805	3.846	10.783	0.844
Minimum	0.141	0.175	0.766	0.217
N	23	23	23	23

	MI	SEC	MI*	MI-MI*
Busan	2.805	1.428	1.964	−0.841
Port Klang	2.541	0.955	2.661	0.120
Kobe	2.535	0.852	2.975	0.440
Yokohama	2.303	1.111	2.073	−0.230
Jawaharlal Nehru	2.022	1.286	1.572	−0.450
Muara	1.882	10.783	0.175	−1.707
Nagoya	1.697	1.024	1.657	−0.040
Osaka	1.418	0.993	1.428	0.010
Kaosiung	1.068	1.075	0.993	−0.075
Manila	0.949	0.766	1.239	0.290
Tianjin	0.776	0.878	0.884	0.108
Colombo	0.747	1.044	0.716	−0.031
Dalian	0.730	1.804	0.405	−0.325
Xiamen	0.670	1.366	0.490	−0.180
Singapore	0.666	1.000	0.666	0.000
Shanghai	0.641	0.958	0.669	0.028
Keelung	0.620	1.042	0.595	−0.025
Tanjung priok	0.605	1.056	0.573	−0.032
Tokyo	0.507	0.845	0.600	0.093
Karachi	0.479	0.832	0.576	0.097
Hong Kong	0.292	0.957	0.305	0.013
Laem Chabang	0.196	0.906	0.216	0.020
Yantai	0.141	0.975	0.145	0.004
Average	1.143	1.475	1.025	−0.018

Table VI.
MI net of SEC (MI*)

limiting the sample to include only large Asian container ports may to some extent ease the concern, there is uninventable heterogeneity in terms of the tasks and objectives of the ports, market conditions they face, other institutional or cultural factors, etc. In this case, one should be cautious when interpreting and generalizing the findings of this study.

Another important limitation is that port throughputs are not decomposed into direct shipment and transhipment. The development of short-sea shipping around the Malacca Straits is phenomenal. However, most official statistics do not report the direct transhipment and transhipment separately, which makes further analysis impossible at this stage.

Finally, the data set includes container ports during 2000-2007. Either the impact from the Asian financial crisis or the economic downturn from the end of 2007 was not covered by the current study. While focusing on a period when external market is relatively stable is beneficial to efficiency analysis, given that estimated efficiency deterioration can result from shrinking market demand, instead of real deterioration in technical, scale, or technological efficiency, we do acknowledge this as a limitation of our study. Future studies on the efficiency dynamics of Asian container ports are needed, particularly for the post-2007 period.

Conclusions

This study has investigated the overall efficiency changes at 23 major Asian container ports from 2000 to 2007. It also decomposes the sources of such changes into purely technical, scale and technological efficiency gains by using the Malmquist index equation from Estache *et al.* (2004). Overall, these ports have improved their efficiency by 14.3 per cent with improvement in technical and scale efficiency but with deterioration in technological development. The port of Hong Kong seems to underperform in all aspects investigated. In particular, it may first improve its technological adoption as this aspect lags behind its major competitor the most (Choy *et al.*, 2016).

In addition, this study reveals that the pure technical efficiency may have had the most direct effect on the overall efficiency improvement given a high correlation between the two (0.85). Scale and technological effect seem to have less direct impact with relatively low correlation with the overall efficiency improvement (<0.25). Furthermore, the fact that technological efficiency has little variance among the ports investigated suggests that this source may not bring substantial competitive advantage. Given the fact that port authorities and operators are given little control over the demand side, it may be more appropriate to assess port overall efficiency by looking at the total efficiency change net scale effect. After all, the Malmquist index is just one type of indicators and should be used in combination with others in decision-making.

Finally, container ports are important infrastructure that support their countries' economic development. Although most of these ports are located along the Silk Road Economic Belt, their efficiencies vary from port to port across countries. Efficient ports will help to reduce shipping and trade costs in the region and efficiency growth of these ports will benefit the worldwide economy.

Note

1. The main purpose of using a three-year average of port throughput to measure output is to reduce the noise in the output data caused by external shocks. Port input variables (e.g. berth length, terminal areas and crane capacity as we used in the study), on the other hand, are less subject to external shocks. Hence, we simply use the raw data of year 2000 and 2007, instead of three-year averages.

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Appendix 1

	Year 2000				Year 2007			
	1998	1999	2000	Average	2005	2006	2007	Average
Singapore	15,135,557	15,944,793	17,040,000	16,040,117.0	23,192,200	24,792,400	27,932,000	25,305,533.0
Shanghai	3,066,000	4,210,000	5,613,000	4,296,333.3	18,084,000	21,710,000	26,150,000	21,981,333.0
Hong Kong	14,582,000	16,210,792	18,100,000	16,297,597.0	22,601,630	23,538,580	23,998,449	23,379,553.0
Busan	5,945,614	6,439,589	7,540,387	6,641,863.3	11,843,151	12,030,000	13,270,000	12,381,050.0
Kaosiung	6,271,053	6,985,361	7,425,832	6,894,082.0	9,471,056	9,774,670	10,256,829	9,834,185.0
Tianjin	1,018,000	1,300,000	1,708,423	1,342,141.0	4,801,000	5,950,000	7,103,000	5,951,333.3
Port Klang	1,820,018	2,550,419	3,206,753	2,525,730.0	5,715,855	6,326,294	7,090,000	6,377,383.0
Laem Chabang	1,559,112	1,828,460	2,195,024	1,860,865.3	3,765,967	4,123,124	4,641,914	4,177,001.7
Xiamen	645,000	850,000	1,084,700	859,900.0	3,342,300	4,018,700	4,627,000	3,996,000.0
Dalian	475,102	740,000	1,011,000	742,034.0	2,655,000	3,212,000	4,574,192	3,480,397.3
Tokyo	2,168,543	2,695,589	2,899,452	2,587,861.3	3,819,294	3,969,015	4,123,920	3,970,743.0
Jawaharlal nehru	669,108	889,978	1,189,780	916,288. 7	2,666,703	3,298,328	4,059,843	3,341,624.7
Tanjung priok	1,898,069	2,273,303	2,476,152	2,215,841.3	3,281,580*	3,600,000*	3,900,000*	3,593,860.0
Yokohama	2,091,420	2,172,919	2,317,489	2,193,942.7	2,873,277	3,199,883	3,428,112	3,167,090.7
Colombo	1,714,077	1,704,389	1,732,855	1,717,107.0	2,455,297	3,079,132	3,381,693	2,972,040.7
Nagoya	1,458,076	1,566,961	1,911,920	1,645,652.3	2,491,198	2,751,677	2,896,221	2,713,032.0
Manila	1,845,906	2,147,422	2,867,836	2,287,054.7	2,665,015	2,719,585	2,869,447	2,751,349.0
Kobe	2,100,884	2,176,004	2,265,992	2,180,960.0	2,262,066	2,,412,767	2,472,808	2,382,547.0
Osaka	1,155,980	1,250,000	1,474,201	1,293,393.7	2,094,275	2,231,516	2,309,820	2,211,870.3
Keelung	1,704,264	1,666,000	1,954,573	1,774,945.7	2,091,458	2,128,816	2,215,484	2,145,252.7
Yantai	347,000	N/A	N/A	347,000.0	819,541	1,779,107	2,214,631	1,604,426.3
Karachi	505,413*	527,473	615,024	549,303.3	1,145,528*	1,107,386	1,219,724	1,157,546.0
Muara	59,238	61,543	26,337	49,039.3	131,430	N/A	151,442	141,436.0

Note: *Estimated Data from Containerization International Yearbook

Table AI.
Port output data (in TEU)

Appendix 2

	Berth length (meter)	Terminal area (square meter)	Crane capacity (ton)
Year 2000			
Singapore	364	955,200	70
exclude general cargo/bulk	275	830,000	35
	945		35
	233		210
	916		280
	213		80
Total	2,946	1,785,200	710
Shanghai	640	218,000	35.5
	858	337,000	91.5
	783	303,000	30
			30
			35
			105
			30
			30
			35
			60
Total	2,281	858,000	482
Hong Kong	305	165,000	135
exclude ro-ro	640	300,000	328
	1,082	796,000	41
	740	919,000	943
	3,292		72
			164
			41
			72
Total	6,059	2,180,000	1,796
Busan	350	148,104	121.5
	350	148,749	40.6
	350	148,750	81.2
	350	156,803	120
	350	647,566	121.8
	1,447	1,038,534	400
	1,200	184,230	152.5
	500		162.4
			284.2
			162.4
Total	4,897	2,472,736	1,646.6
Kaosiung	214	105,000	80
	204	1,033,000	80
	230		35
	200		70
	320		120
	320		35
	320		80
	320		80
	320		
	320		
	640		
	320		
	320		

(*continued*)

Table AII.
Port input data (available upon request)

	Berth length (meter)	Terminal area (square meter)	Crane capacity (ton)
Total	4,048	1,138,000	580
Tianjin	397	575,000	80
	903		
Total	1,300	575,000	80
Port Klang	1,079	43,600	140
	1,200	160,000	80
	1,100	794,000	40
	1,200	410,000	35
			360
			600
			360
Total	4,579	1,407,600	1,615
Laem Chabang	1,600	10,000	90
Xiamen	500	400,000	82
			70
Total	500	400,000	152
Dalian	300	560,000	61
Tokyo	285	100,000	80
Exclude common use terminal	250	92,000	90
	300	111,000	200
	300	111,000	60
	350	115,000	30
	600	222,000	30
	285	100,000	40
	574	87,000	30
			30
			80
			90
Total	2,944	938,000	760
Jawaharlal nehru	680	471,000	106.5
			120
Total	680	471,000	226.5
Tanjung Priok	900	635,351	30
	510		225
Total	1,410	635,351	255
Tokohama	600	221,000	30
Include multi/container	250	84,000	40
	300	105,000	30
	350	175,000	70
	350	153,500	61
	300	105,000	121.5
	300	10,500	121.8
	600	221,000	121.8
	1,000	206,687	91.5
	620	129.751	160.2
	480		91.5
			100.5
			40.6
			122
			167.5
Total	5,150	1,281,817	1,369.9
Colombo	300	207,000	70
	332	55,000	35

(*continued*)

Table AII.

	Berth length (meter)	Terminal area (square meter)	Crane capacity (ton)
	330		
	330		
	182		
	150		
	275		
Total	1,899	262,000	105
Nagoya	350	175,000	173.7
	800	17,600	48
	350	289,000	47.7
	300	170,000	95.4
	250	225,000	37.5
	620		102.2
	700		92.2
			97.2
			48
			98.2
			46.4
			112.6
			165
Total	3,370	876,600	1,164.1
Manila	387	940,000	280
Exclude Marine Slipway and all piers	615	850,000	105
	582		80
	823		50
	1,300		142.4
	3,707	1,790,000	657.4
	300	103,500	40
	700	105,000	80
	925	125,636	121.5
	600	175,000	140
	600	244,750	200
	300	2,445,000	
	960		
	300		
	300		
	300		
	350		
	700		
	350		
	700		
	350		
	350		
	700		
Total	8,785	3,198,886	581.5
Osaka	240	116,400	91.5
	240	104,152	80
	185	105,044	60.1
	350	104,610	81.2
	350	119,999	91.5
	350	120,000	40.6
	350	126,000	80
	300	99,700	
	350		

Table AII. *(continued)*

	Berth length (meter)	Terminal area (square meter)	Crane capacity (ton)
	350		
Total	3,065	895,905	524.9
Keelung	300	339,000	70
	1,952		80
	120		80
	200		35
	620		480
			105
			105
Total	3,192	339,000	955
Yantai	180	30,000	50
Karachi	600	136,220	150
Muara	515	6,070	37
Year 2007			
Singapore	900	960,000	120
	400	840,000	162.4
	275	800,000	150
	364		160
	2,319		1,260
	945		1,200
	233		1,015
	916		
	213		
Total	6,565	2,600,000	4,067.4
Shanghai	640	218,051	250
	857	307,375	350
	1,250	1,550,000	732
	1,290	1,630,000	80
	900	500,000	700
	1,635	1,659,822	600
	784	304,589	1,100
			30
			30
			35
			60
Total	7,356	6,169,837	3,967
Hong Kong	305	167,000	65
	740	285,400	120
	2,322	926,100	480
	3,000	650,320	160
	640	300,000	560
	3,992	1,110,000	605
			1,500
			328
			41
			41
			540
			180
			943
			70
			160
			40
			70

(*continued*)

Table AII.

	Berth length (meter)	Terminal area (square meter)	Crane capacity (ton)
Total	10,999	3,438,820	5,903
Busan	700	297,500	283.5
Excluding conventional Pier	203	8,815	60
	350	149,000	50.8
	1,447	647,425	81.2
	350	156,803	406
	1,200	810,000	30.5
	1,500	1,012,159	121.8
	826	308,000	51
	500	18,500	121.8
			585
			162.4
			284.2
			350
			203
Total	7,076	3,408,202	2,791.2
Kaosiung	431	105,000	80
	520		
	684	450,000	70
	320	233,187	150
	752	633,187	90
	917		35
	640		250
	320		240
	320		
	320		
	675		
	815		
Total	6,714	1,421,374	915
Tianjin	397	575,000	80
	903	429,400	40
	1,150		70
			195
Total	2,450	1,004,400	385
Port Klang	1,079	436,000	70
	534	410,000	80
	1,300	890,300	200
	2,600		40
			115
			412.5
			1,200
Total	5,513	1,736,300	2,117.5
Laem Chabang	5,600	2,445,800	1,595
	300	105,000	120
	300	130,000	120
	360	180,000	50
	400	407,000	120
	300	105,000	280
	400	174,000	220
			120
			50
			72
			121.5

Table AII. (*continued*)

	Berth length (meter)	Terminal area (square meter)	Crane capacity (ton)
Total	7,660	3,546,800	2,868.5
Xiamen	210	480,000	164
	640		70
	640		
Total	1,490	480,000	234
Dalian	300	560,000	61
	1,856	848,000	840
	652	255,150	260
Total	2,808	1,663,150	1,161
Tokyo	252	88,361	40
	660	259,000	40
	250	92,000	160
	300	48,000	40
	350	81,000	30
	350	116,000	30
	600	222,000	30
	680	27,540	60
	574	87,000	80
			160
			240
			90
Total	4,016	1,020,901	1,000
Jawaharlal nehru	680	388,400	302
	600	300,000	180
			160
Total	1,280	688,400	642
Tanjung priok	2,338	1,280,000	30
	450	306,000	225
	404	70,000	120
			170
			150
			160
Total	3,192	1,656,000	855
Yokohama	250	84,000	61
including multi/container	350	175,000	121.8
	350	153,500	121.8
	300	105,000	121.8
	300	105,000	121.8
	700	350,000	325
	200	106,000	91.5
	250	490,000	67
	1,390	206,687	83.5
	620	136,069	40.6
	480		178
	240		122
			67
Total	5,430	1,911,256	1,522.8
Colombo	940	250,000	240
	300	207,000	120
	332	15,300	246
	330		284
	330		123
	150		

(*continued*)

Table AII.

	Berth length (meter)	Terminal area (square meter)	Crane capacity (ton)
	182		
	390		
	200		
Total	3,154	472,300	1,013
Nagoya	400	88,000	95.4
	735	359,240	48
	350	289,000	173.7
	300	170,000	116.8
	250	237,000	58.6
	620	225,000	110.2
	400		106.2
	700		110.2
			48
			98.2
			46.4
			112.6
			165
Total	3,755	1,368,240	1,289.3
Manila	1,300	822,200	280
excluding Pier 2,4,6,8,10,12,14,16	859	850,000	105
	1,397		120
			36
			122.4
Total	3,556	1,672,200	663.4
Kobe	300	78,653	98.4
including heavy-life/container berth	240	26,400	47.1
	130	26,600	111
	350	55,393	44
	555	38,850	55
	600	107,169	54
	960	67,368	46.5
	350	117,000	55
	350	134,300	93.8
	350	251,090	120
	350	251,090	120
	350	367,500	200
	350	245,000	200
	350		160
	350		80
	350		200
	350		
	350		
Total	6,985	1,766,413	1,684.8
Osaka	240	160,400	122
	240	104,152	80
	185	175,000	81.2
	350	175,000	81.2
	350	105,044	61
	350	104,610	81.2
	350	119,999	40
	350	120,000	61
	350	126,062	122
	300	113,500	40.6

Table AII. (*continued*)

	Berth length (meter)	Terminal area (square meter)	Crane capacity (ton)
	300		80
	350		80
	350		
Total	4,065	1,303,767	930.2
Keelung	300	339,000	70
	200		80
	620		80
	120		35
	1,952		480
			105
			105
Total	3,192	339,000	955
Yantai	500	30,000	81
	608	440,000	110
	573		220
Total	1,681	470,000	411
Karachi	600	210,000	200
	600	136,000	164
Total	1,200	346,000	364
Muara	250	98,000	80
excluding multi-purpose berth			

Table AII.

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