European Journal of Operational Research 203 (2010) 706–713

Contents lists available at ScienceDirect

European Journal of Operational Research

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

Innovative Applications of O.R.

Benchmarking the operating efficiency of Asia container ports

Shiu-Wan Hung [a,1], Wen-Min Lu [b,*], Tung-Pao Wang [b,2]

[a] Department of Business Administration, National Central University, No. 300, Jung-Da Road, Jung-Li City, Tao-Yuan 320, Taiwan
[b] Department of Financial Management, National Defense University, No. 70, Section 2, Zhongyang North Road, Beitou, Taipei 112, Taiwan

ARTICLE INFO

Article history:
Received 28 June 2008
Accepted 3 September 2009
Available online 16 September 2009

Keywords:
Data envelopment analysis
Scale efficient targets
Bootstrap method
Asian container ports

ABSTRACT

The aim of this paper is to explore the operating efficiency, the scale efficiency targets, and the variability of DEA efficiency estimates of Asian container ports. This study applies data envelopment analysis (DEA) with the traditional DEA model, most productive scale size concept, returns to scale approach, and bootstrap method to assess the operating performance, set scale efficient targets, and determine efficiency rankings of Asian container ports. The results of this study can provide port managers with insights into resource allocation, competitive advantages, as well as optimization of the operating performance. The potential applications and strengths of DEA in assessing the Asian container ports are highlighted.

1. Introduction

The rate of growth in the East Asian container port markets has been dramatic in recent years. This has been driven by the globalization of the world economy and the rise of China as the world's manufacturing center. According to the *Containersation International Yearbook*, container throughput in East Asia expanded threefold over 1995–2005 and by 78% over 2000–2005 to 189.4 m Twenty-foot Equivalent Unit (TEU). Chinese ports have been at the forefront of development, but demand has expanded strongly in all parts of the region.

Ports form a vital link in the overall trading chain and, consequently, port efficiency is an important contributor to a nation's international competitiveness (Tongzon, 1989; Cullinane et al., 2002). To improve performance, port managers need to constantly evaluate the operations or processes related to providing, marketing, and selling of services to users. Productivity and efficiency are the two most important concepts in this regard and are frequently utilized to measure performance. Improving and measuring efficiency is important for encouraging progress in any organization. Efficiency is a major issue in contemporary port economics, on the grounds of a port's strategic position in connecting different countries in a globalized world, as well as connecting different locations inside the country (Cullinane et al., 2002).

The current study employs the Data Envelopment Analysis (DEA) as the fundamental tool for the following reasons: First, the use of single measures ignores any interactions, substitutions or tradeoffs among various firm performance measures in performance evaluation (Cook and Zhu, 2007; Chen et al., 2009; Amado and Dyson, 2008; Lu and Lo, 2007). DEA has been proven effective in performance evaluation when multiple performance measures are present (Cooper et al., 2007; Zhu, 2009; Kao, 2009). Second, DEA does not require a prior information about the relationship among multiple performance measures. DEA estimates the empirical tradeoff curve from the observations. Finally, a number of studies about container port efficiency in transportation economics have successfully used DEA (Cullinane and Wang, 2006b).

The objective of this paper is to contribute to the empirical evidence on container port efficiency in transportation economics by studying the efficiency of container ports in Asia. The important contributions of this study include: (1) to provide a benchmarking analysis based on the DEA to investigate Asian container ports and to assist port managers in improving the operational management of container ports; (2) to utilize an alternative approach for setting the scale efficient targets which can assist the scale inefficient container ports to optimize their economic scale; and (3) to explore how DEA, along with the smoothed bootstrap method, can be used in applied analysis to obtain more reliable efficiency rankings for container ports.

This paper is organized as follows. Section 2 introduces the related prior studies which have influenced this study. Section 3 provides the input/output factors used and data collection, while Section 4 explains the theoretical framework. The empirical results and interpretations are discussed in Section 5. Finally, Section 6 concludes with the findings of this study.

---

[*] Corresponding author. Tel.: +886 2 2898 6600x604981; fax: +886 2 2898 5927.
E-mail addresses: shiuwan@mgt.ncu.edu.tw (S.-W. Hung), wenmin.lu@gmail.com (W.-M. Lu), tungpao.wang@gmail.com (T.-P. Wang).
[1] Tel.: +886 3 4269903; fax: +886 3 2118558.
[2] Tel.: +886 2 2898 6600x604981; fax: +886 2 2898 5927.

0377-2217/$ - see front matter Crown Copyright © 2009 Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.ejor.2009.09.005

2. Literature review

Various studies have been done to adopt the DEA method to evaluate container port performance during the past few years. Roll and Hayuth (1993) first introduced the term DEA in container port performance research, which used single time hypothesized cross-section data to evaluate container port relative efficiency. Martinez-Budria et al. (1999) estimated the efficiency of 26 Spanish ports based on the data from 1993 to 1997, while Tongzon (2001) used DEA to provide an efficiency measurement of 4 Australian ports and 12 other international ports for the year 1996; Barros (2003) analyzed the Portuguese seaports with a Malmquist index. Cullinane et al. (2005) applied DEA and the Free Disposal Hull (FDH) to estimate the performance of 57 international container ports, and found that the available mathematical programming methodologies led to different conclusions. Additionally, the definition of input and output variables played critical roles in meaningful applications of DEA and FDH. Cullinane et al. (2006) adopted DEA and Stochastic Frontier Analysis (SFA) to compare the technical efficiency of 28 Port/terminal container ports. A detailed review/summary of the literature can be found in the reference (Cullinane and Wang, 2006b).

Despite various works having been completed to investigate the operating performance of global container ports, from the perspective of a research topic, Asian container ports performance evaluation is rarely taken as a research target except the work completed by Cullinane et al. (2002). Furthermore, the issue of setting the scale efficient targets and efficiency rankings thus far are discussed less frequently (Cullinane and Wang, 2006a) in the literature of the transport industry. Additionally, the previous works have never (1) simultaneously applied the DEA and the bootstrap methods to study ports' operating performance, (2) studied the efficiencies of 31 ports in 9 various countries in Asia, and (3) investigated the influence of geographical factors (e.g., Northeast, East, or Southeast Asia) on ports' performance. The aim of this current study is to provide such information regarding Asian ports' operations with insights into resource allocation and competitive advantage as well as help with strategic decision making, especially regarding operational styles under an intense competitive environment.

3. Data selection and description

From a systems perspective, organizational activities refer to the conversion of inputs in various resources to output. Output is a concrete measurement that an organization has reached its objectives. This study uses the production approach to design the performance model. The performance model measures the performance of container ports in using four inputs to produce one output. The choice of input and output variables used in the performance mode can be traced to the literature (Cullinane et al., 2005; Cullinane et al., 2006; Roll and Hayuth, 1993; Tongzon, 2001; Tongzon and Heng, 2005). The four input factors are the terminal area (in m^2), ship-shore container gantry cranes (in No.), container berths (in No.), and terminal length (in m). The terminal area is defined as the area of the container ship anchor. The terminal length is the length of berths at which container ships anchor. The third factor is the number of container berths. The fourth factor is the number of ship-shore container gantry cranes. This study measured output by one indicator: Container throughput, which is the total number of containers loaded and unloaded in 20 foot equivalent units (TEUs). The input/output variables should reflect actual objectives and the process of container port production as accurately as possible (Cullinane et al., 2004). The listing of the variables to be analyzed in the study can also be compared directly to those variables chosen in previous studies (Cullinane et al., 2005) employing a mathematical programming approach to the estimation of efficiency in container port or terminal production.

This study investigates 31 container ports in the Asia-Pacific region ranked among the world's leading 100 ports in 2003. Each of these container ports is treated as a decision making unit (DMU) in the DEA analysis. Table 1 presents descriptive statistics for our dataset. Input/output data are reported as the total number throughout for the year and can be found in the Containerisation International Yearbook, 2006. Table 2 shows the correlation matrix of inputs and outputs. Notice that all the correlation coefficients are positive. Therefore, these inputs and outputs exhibit an isotonic relationship, and thus, these variables are justified to be included in the model. To achieve a reasonable level of discrimination, the practitioner needs the number of DMUs to be at least triple the number of inputs and outputs considered (Cooper et al., 2001; Dyson et al., 2001). Consequently, the developed DEA model should have a high well construct of validity in this study.

4. Methodology

Firstly, this study employs the traditional DEA to measure technical, pure technical, and scale efficiencies and further determines the current returns to scale (RTS) for container ports. Secondly, based on the RTS estimation method, this study utilizes an alternative approach for setting the scale efficient targets which can assist the scale inefficient container ports to optimize economic scale. Finally, this article explores how DEA, along with the smoothed bootstrap method, can be used in applied analysis to obtain more reliable efficiency rankings for container ports. All DEA models are now described as follows.

4.1. Technical efficiency measure

Assume there are n ports which produce s outputs by consuming m inputs. Let $\mathbf{x}_j \in R^m$ and $\mathbf{y}_j \in R^s$ be the amount of the $(m \times 1)$ vector of inputs utilized and the amount of the $(s \times 1)$ vector of outputs produced by port j, respectively. It is common practice in economic analysis to describe the activity of a port by means of the production set $\mathbf{P}$ of physically attainable points $(\mathbf{x},\mathbf{y})$:

$$\mathbf{P} = \{(\mathbf{x},\mathbf{y}) \in R^{m+s} | \mathbf{x} \text{ can produce } \mathbf{y}\}. \quad (1)$$

Table 1
Descriptive statistics for the 31 Asia container ports.

Input/output	Mean	Minimum	Maximum	Std. Dev.	Valid *N*
Input					
Terminal area (m^2)	1,557,109	144,560.0	4,342,858	1,039,435	31
Ship-shore container gantry (No.)	31	5.0	131	27	31
Container berth (No.)	14	2.0	34	9	31
Terminal length (m)	3866	530.0	9595	2426	31
Output					
Container throughput (TEU)	5,021,130	707,900.0	21,984,000	5,637,858	31