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Dredging the depths of knowledge: Efficiency analysis in the maritime port sector

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A B S T R A C T

Maritime port efficiency is a research area that has received considerable attention in recent years. While the accumulated empirical evidence concerning the drivers of port efficiency is large, there has not been any attempt at systematically assessing the causes of (in)efficiency through quantitative meta-analysis. This study therefore uses a compounded dataset of port efficiency estimates from 52 studies and regresses these estimates on port and country characteristics, while controlling for study-specific and methodological effects. Surveying the literature, we find that there is a lack of attention paid to the user side of port service production, which has crucial implications for the interpretation of efficiency estimates. At the cross-country level, we find a negative relationship between GDP per capita and estimated port efficiency, as well as a negative relationship between intra-port competition and estimated efficiency. We discuss the interpretation of these findings in the context of partial production functions, and argue that a large portion of the applied methods do not capture substitution between producer and user inputs. We also find that the ratio of military spending to GDP is positively related to estimated port efficiency, while a higher degree of product concentration in trade flows is associated with lower levels of estimated efficiency.

1. Introduction

The role of maritime ports in the economics of trade and transport is one of importance and complexity. Improving port efficiency, especially in countries where ports are relatively inefficient, is likely to reduce the cost of trade and transport significantly (Wilmsmeier et al., 2006). Efficiency in port services is also considered vital for the competitive strength of regional shipping relative to other modal alternatives (Medda and Trujillo, 2010). However, the multitude of ways in which ports are owned, located, operated and specialized makes for a difficult unit of analysis.

To investigate the relative efficiency levels of a group of ports, or to determine the impact of a policy or an event on the efficiency of ports, researchers have utilized various techniques of efficiency analysis and benchmarking. These techniques originate from the work of Farrell (1957) and were later developed, notably by Charnes et al. (1978) and Banker et al. (1984). Benchmarking in the port sector has been applied with different objectives, such as mapping and ranking the efficiency of ports within a region (Martinez-Budria et al., 1999; Coto-Millan et al., 2000; Barros and Athanassiou, 2004; Al-Eraqi et al., 2008; Barros, 2006; Hung et al., 2010), analyzing the impacts of reform in the port sector (Estache et al., 2002; González and Trujillo, 2008a), analyzing the effects of competitive intensity (Figueiredo De Oliveira and Cariou, 2015; Yuen et al., 2013), or investigating the relationship between ownership structure and efficiency (Cullinane et al., 2002; Tongzon and Heng, 2005). The application of benchmarking techniques to maritime ports has seen a large growth in popularity during the last decade. Despite this growth, the wide range of applied methods is evidence in itself that there is little consistency regarding measurement, model specification or choice of variables. Attempts to synthesize and summarize the experience from previous research have with various approaches aimed to discuss and measure the impacts of different methodology in port efficiency benchmarking (Panayides et al., 2009; González and Trujillo, 2008b; Odeck and Bråthen, 2012). Odeck and Bråthen (2012) apply meta-regression to analyze the impact of methodological choices and study characteristics on average technical efficiency scores of previous studies. There is, however, no previous research that uses aggregated data to study how the estimated efficiency of individual ports varies with characteristic features of ports and the economic environment in which they operate. Considering that port efficiency is a rather new area of study, it is of interest to assess the rapidly accumulating evidence through meta-analysis. This paper offers as a contribution some understanding

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regarding the determinants of port efficiency in a cross-country setting through systematic analysis of previous studies.

The objective of this study is to explore differences in estimated technical efficiency of ports with regard to such characteristics as infrastructure dimensions, degree of competition between and within ports, economic development and structure of trade flows. The aim of using meta-analysis as a research method is to provide findings that are less sensitive to sample specificity and methodological choice, and to guide future analysis and policy considerations into what factors are relevant for improving efficiency in maritime ports.

2. Overview of efficiency analysis

Efficiency analysis as originally conceived by Farrell (1957) is concerned with measuring the extent to which a decision-making unit (DMU), commonly a firm, is able to produce a maximum level of output given a set of inputs, and combine these inputs in an optimal way. The first of these components, the maximization of output given a set of inputs, is what we call technical efficiency (TE). The second, the optimal selection of input proportions, is called allocative efficiency (AE). Combined, they provide a measure of economic efficiency (EE) (see for instance Coelli et al. (2005). for a more comprehensive exposition).

$$EE = TE^{*}AE \tag{1}$$

The objective of proportionately reducing inputs in order to efficiently produce a level of output is known as an input-oriented measure and is illustrated in the left-hand panel of Fig. 1. The simplified case that is illustrated assumes constant returns to scale and a two-input, one-output firm, where X1 and X2 denote the levels of inputs, while Q denotes the level of output. The isoquant curve ZZ′ shows all possible input combinations for a given level of output. The isocost curve WW′ is sloped according to the ratio of input prices. The point of production that exhibits both full technical and allocative efficiency (i.e. the economically efficient point) is D, in which tangency of ZZ′ and WW' is found. A firm producing at the point A is inefficient both in terms of technical and allocative efficiency. The degrees of efficiency can be expressed as:

$$TE = \frac{OB}{OA}, \quad AE = \frac{OC}{OB} \tag{2}$$

The output-oriented case, in which the objective is to increase the output for a given quantity and proportion of inputs, can just as easily be illustrated. In the right-hand panel of Fig. 1, this is shown for a two-output, one-input firm, where Q1 and Q2 denote the output levels while x denotes the level of the single input. The production possibility curve ZZ′ shows all combinations of outputs 1 and 2 that can be produced for a given level of input x. The isorevenue curve WW′ is sloped according to relative prices of the outputs. The economically efficient point D is found at the point of tangency between WW′ and ZZ'. The technical and allocative degrees of efficiency for the firm producing at point A can therefore be expressed as:

$$TE = \frac{OA}{OB}, \quad AE = \frac{OB}{OC} \tag{3}$$

Again, these illustrations only show efficient points of production under the assumption that the firm under consideration is subject to globally constant returns to scale. If the production technology would have increasing- or decreasing returns to scale, the firm may benefit from scaling up or down its production while keeping the same input- or output mix (Coelli et al., 2005). There are ways of incorporating scale into efficiency analysis, as will be discussed.

Empirical measurement of firm efficiency requires a method of estimating production frontier functions, to which firm performances can be compared. The two principally applied methods are data envelopment analysis (DEA) and stochastic frontier analysis (SFA) (Lovell, 1993). As these are also the predominant methods in the seaport efficiency literature, we will focus on briefly reviewing them in turn. For a more extensive review, see for instance Coelli et al. (2005). or Bogetoft and Otto (Bogetoft et al., 2011). As the reviewed literature shows, most analyses of seaport efficiency is focused solely on estimating technical efficiency, and is the reason why this paper does not treat measures of allocative efficiency. This focus is however not unique to port efficiency studies. A possible reason why most efficiency analysis focuses solely on TE is the general difficulty in obtaining data concerning the relative prices of inputs and outputs that are required to construct the isocost or isorevenue curves.

DEA is a non-parametric mathematical programming approach to frontier estimation. It was first proposed in input-oriented, constant returns to scale (CRS) form by Charnes et al. (1978), and subsequently extended by Banker et al. (1984). to accommodate variable returns to scale (VRS). If a firm is operating with scale inefficiency, a TE_{VRS} estimate will always be higher than its TE_{CRS} counterpart, while the case where $TE_{VRS} = TE_{CRS}$ by definition implies that the underlying production technology exhibits CRS (Coelli et al., 2005). DEA can be applied to both input- and output-oriented approaches, and the results can be expected to differ when returns to scale are not constant.

The non-parametric aspect of DEA means that the constructed frontier does not include a stochastic element, making the use of statistical testing of hypotheses and the construction of confidence intervals impossible. This problem can be alleviated in some cases by applying bootstrap resampling methods, but this is not without its limitations (Simar and Wilson, 2000). A more common approach to stochastic analysis is the use of econometric methods, the most common of which is SFA.

First proposed by Meeusen and van den Broeck (Meeusen and Broeck, 1977) and Aigner et al. (Aigner and Chu, 1968), SFA involves the estimation of a cost or production function with a composite error term

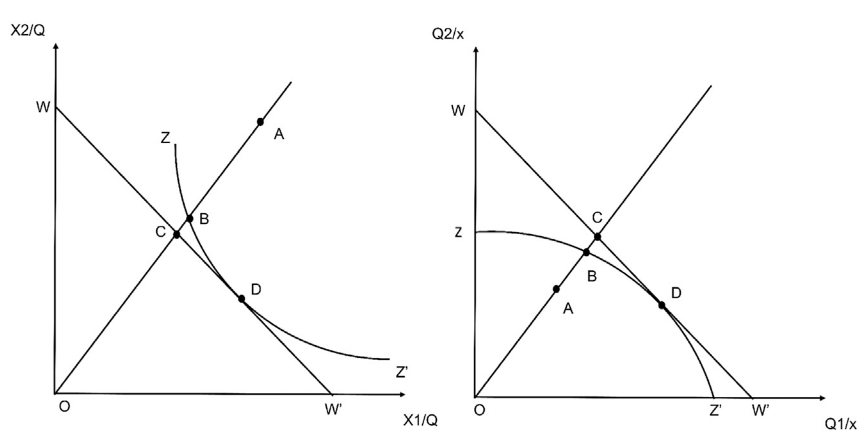

Fig. 1. Input and output oriented efficiency.