Competitive intensity and inefficiency in European container ports

An empirical investigation using SFA

Received 11 January 2018
Revised 14 February 2018
Accepted 21 February 2018

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Abstract

Purpose – The purpose of this paper is to empirically examine the relationship between intensity of competition and technical efficiency of large European container ports, accounting for regional diversities and spatial aspects of inter-port competition.

Design/methodology/approach – The analysis consists of applying a stochastic production frontier approach to a dataset of 77 large European container ports over the period 2002-2012, with inefficiency terms simultaneously modeled as a function of (among other factors) a constructed index of competitive intensity at different spatial levels.

Findings – The results indicate that there is no significant negative effect of competitive intensity on efficiency. In fact, for competing European ports within a proximity of 300 km, a higher level of competition is found to be associated with a higher level of technical efficiency.

Originality/value – The originality of the paper stems from its particular focus on European port regions and its novel findings in this context, which have implications for the discussions regarding pro-competitive port policy and regulation in the European Union.

Keywords Stochastic frontier analysis, Inter-port competition, Port policy

Paper type Research paper

1. Introduction

Over the past two decades, development of a common policy framework regulating the governance of major European seaports has been in progress. Simultaneously, several governments of European Union member states have implemented own institutional reforms in their port sectors (Chlmoudis and Pallis, 2005; Baird and Valentine, 2007; Pallis and Syriopoulos, 2007; Valleri *et al.*, 2006). A recurring objective of proposed common port policies has been to increase the autonomy and transparency of port finances, imposing stricter control on national subsidization to achieve greater competitive pressure between ports. In drafting the principles of a uniform port policy, the European Parliament stated that overcapacity has been a problem for the European container port sector, recognizing also that competitive investment, i.e. a "spiraling" effect of ports competing with infrastructure size to attract and accommodate a fleet of continuingly expanding vessels, was a potential cause of this overcapacity (European Parliament, 1999). Such concerns cannot be seen as unfounded, as various studies have pointed out that higher competition in container port service production is a potential inducer of excess capacity (Haralambides, 2002; Haralambides *et al.*, 2002). At the same time, there is an obvious role for competition in

Maritime Business Review
Vol. 3 No. 2, 2018
pp. 165-184
Emerald Publishing Limited
2397-3757
DOI 10.1108/MABR-01-2018-0003

promoting and producing efficient outcomes through the deterrence of monopolistic pricing and related practices, which is similarly emphasized by seminal work on the subject (Goss, 1990).

Increasing the autonomy of important European seaports and harmonizing differences in the institutional governance between member states to create a more competitive environment could have a significant impact on the efficiency of the European maritime and multimodal transport system. There is a wide array of existing research related to applying efficiency measurement and benchmarking methods to seaports (Tongzon and Heng, 2005; Cullinane and Song, 2006; Trujillo and Tovar, 2007). However, the explicit relationship between intensity of competition between ports and estimated efficiency has been the subject of only two published studies, none of which pertain to the European market specifically. Using an international sample of 200 container ports, De Oliveira and Cariou (2015) applied a data envelopment analysis (DEA) framework to study how the intensity of competition within different degrees of proximity from each port explained efficiency estimates. Their findings indicate that within a radius of 400-800 km, efficiency decreases with increasing competitive intensity, yielding support for the hypothesis that regional competition between ports may induce excessive investment. On the other hand, Yuen *et al.* (2013) found that competitive intensity, both within and between Chinese ports, is positively related to DEA estimates of technical efficiency. The published evidence as to whether inter-port competition may cause inefficiency is thus mixed, making it a relevant topic to pursue. Even though there have been long-running attempts to promote increased competition through Union policy (Chlmoudis and Pallis, 2002), existing studies of port efficiency in European countries using stochastic frontier analysis (SFA) or DEA (Barros and Athanassiou, 2004; Barros, 2006; Coto-Millan *et al.*, 2000; Cullinane and Wang, 2006; Cullinane and Song, 2006; Trujillo and Tovar, 2007; Martinez-Budria *et al.*, 1999; Rodrigues-Álvarez and Tovar, 2012) do not account for competitive intensity as a factor influencing the performance of port service production. The contribution of this study is therefore an empirical test of the hypothesis that increased competition between European ports induces inefficiency through excessive investment. If it is the case that a high level of competition between ports tends to cause overcapacity, we should expect to find that intensity of competition has a significantly negative impact on efficiency. To account for differences in governance structures and policy, five major port regions with diverse institutional features are compared. Using European ports as objects of analysis is valuable because it can potentially yield findings relevant to the development and desirable direction for a harmonized policy framework.

This paper is structured in the following way. In Section 2, previous research regarding port policy, competition and efficiency is reviewed. In Section 3, the methodology for analyzing the relationship between competition and efficiency is outlined. In Section 4, the data are introduced and empirical models are specified. In Section 5, the results of estimation are presented. Section 6 is devoted to a short discussion regarding possible implications for port policy, and Section 7 summarizes the conclusions drawn from the study.

2. Background and theoretical aspects

2.1 Port competition and policy in Europe

Issues of port governance, such as determination of user charges, degree of public subsidization, financial autonomy and economic objectives, lie at the heart of the study of seaports in economics. The European port system has historically comprised fragmented aspects of policy in this area, but there have been notable developments toward policy harmonization. An important example is the "framework for the provision of port services and common rules on the financial transparency of ports" (European Union, 2017a, 2017b). This constitutes a regulatory framework, which mandates among other things that the direct or indirect receipt of public funds in ports has to be transparently disclosed. The provision applies from 2019 and will concern the 329 ports included in the trans-European transport network (TEN-T).

Surveying the historical development, it is clear that there have been expressed intentions by European policymakers to harmonize institutional factors in a common "European Ports Policy" for several decades. Among the objectives of such a policy, as stated by the European Parliament (1993), would be to promote free and fair competition among ports. The European Parliament advocated controlling subsidies to ports by limiting direct national governmental support, while also increasing the transparency of port accounts (Chlmoudis and Pallis, 2002). Facilitating controlled financial flows to European ports that are considered essential to the transport system was intended to level the playing field and lead to more competition between ports. While the proposed policy plan was not executed, it was updated in a follow-up report (European Parliament, 1999), where structural changes in the port industry such as liberalization of port operations from public control and technology changes in shipping were addressed. The report also addressed overcapacity because of large infrastructure investments, citing figures estimating the overcapacity in the North Sea and Mediterranean to be at 52 per cent and 35 per cent, respectively, while also acknowledging that this might be caused by competitive behavior. Overcapacity was in this context defined as the "the positive difference between the capacity of the port and the existing traffic" (European Parliament, 1999). It is not fully clear how the capacity, i.e. the maximum achievable amount of throughput, was found. It is worth noting that overcapacity is a complicated term, which suggests that capacity exceeds a certain level that is considered sufficient. However, it is easily shown that some degree of excess capacity in ports is both common and arguably rational due to the time it takes to expand capacity and the volatile nature of demand. As a spike in demand can only be met by an increased capacity utilization rate in the short run, "excess capacity" may be a necessary measure to mitigate bottlenecks or congestion problems. Following a subsequent series of reports and policy proposals (Chlmoudis and Pallis, 2005, for an extensive review), the diversity of the industry and the heterogeneous institutional structures of member states posed as a barrier toward the implementation of a common policy. However, the above-mentioned provision aimed to give European ports more autonomy in setting infrastructure charges while also increasing the transparency of public funding was ratified by the European Parliament in 2016 (European Union, 2017b).

An argument for increasing the autonomy of port authorities is that this would allow them to be flexible in responding to changes in the transport sector, while also relieving administrative burden on central governments (European Parliament, 1999). In addition, high levels of autonomy may spur rivalries between ports, which could incentivize efficiency improvements. An argument against increased autonomy is that a lack of a centralized authority yields duplication of efforts: excessive capacity expansions, aiming to secure local economic benefits could be undertaken in too many areas. A potential downside of a high level of port autonomy is inefficiency because of competitive over-investment. This is not a new issue. In fact, Jansson and Shneerson (1982) showed that using an approach based on queueing theory that under optimal pricing and investment principles, a fully decentralized system of ports (each port decides with complete autonomy its capacity) and a fully centralized system of ports (capacity is allocated to all ports by a central planner) yield identical and efficient outcomes. Optimal investment and pricing principles are however unlikely to be applied in practice. In empirical work, port pricing is seldom found to bear any relation to the notion of social efficiency (Meersman *et al.*, 2014) and port investment under competition is subject to a variety of complicating factors. Musso *et al.* (2006) distinguish between four categories of economic impact that arise from port investments, namely, financial returns to investors, microeconomic benefits in the form of reduced generalized cost of using the port, local effects on employment (as well as possible multiplier effects) and negative effects in terms of environmental externalities. The local public ownership structure of ports in most of northern Europe means that port investment may act as an instrument for regional competition for local macroeconomic benefits. In multi-country port regions, public authorities' attempt to strengthen the competitive position of nationally important ports could induce a higher degree of competition between ports (Verhoeff, 1981). From the standpoint of the individual country or region, economic benefits in the form of attracting/retaining jobs and industrial activity may be seen as justifiable motives for large port infrastructure investments. From the perspective of the European Union, however, such benefits may rather be seen as being diverted from elsewhere within Europe, while at the same time potentially exacerbating overcapacity. This can be seen as an important factor for levying controls on national subsidization of ports.

2.2 Regional divisions in European port governance

Port governance is a multifaceted concept, which can be analyzed with respect to a variety of parameters. Verhoeven and Vanoutrive (2012) identify seven such parameters: devolution, corporate governance, operational profile, functional autonomy, functional pro-activeness, investment responsibility and financial autonomy. While there has been development toward integration, the European port industry has until now eluded a common policy framework. Institutional differences in port governance are prevalent and the variation is largely regional (Suykens and Van de Voorde, 1998; Chlmoudis and Pallis, 2002; Verhoeven, 2011; Verhoeven and Vanoutrive, 2012). Verhoeven (2011) identifies in a comprehensive survey of European ports' governance structures three large and distinct styles of governance: Hanse, Latin and Anglo–Saxon. The Hanse style of governance applies to northern continental Europe and Scandinavia and is distinguished by local municipal autonomy in port governance. The Latin category comprises southern European countries on the Mediterranean and Atlantic coast (France, Portugal, Spain, Italy and Greece) and is characterized by a more centralized public governance structure. Finally, the Anglo–Saxon category consists of the UK and Ireland and is distinguished by independence and financial autonomy with little public intervention.

Regional divisions of the European port system are made in different ways in the literature. Chlmoudis and Pallis (2002) identify four distinct regions: the Baltic Sea region, the North Sea region (including the UK), the Atlantic region and the Mediterranean Sea region. This is similar to the regional distinction found in Notteboom (2009), which divides the European container port system into Hamburg-Le Havre, Mediterranean, UK (including Ireland), Atlantic, Baltic and Black Sea regions.

2.3 Port competition and operational efficiency

Efficiency in port operations could informally be defined as the ability with which a port produces its core services given its current input factors. A port that is efficient, relative to some benchmark, will have a low level of slack capacity, meaning that inputs to the production of port services are not idle to a large degree. The empirical measurement of port efficiency using benchmarking techniques have been applied with varied purposes. These range from estimating effects of policy reform and regulation (Estache *et al.*, 2002; Gonzáles and Trujillo 2008, Chang *et al.*, 2018) to studying differences in ownership structure (Cullinane *et al.*, 2002;

Tongzon and Heng, 2005) or providing a mapping of ports' efficiencies in a region (Martinez-Budria *et al.*, 1999; Barros, 2006; Hung *et al.*, 2010; Serebrisky *et al.*, 2016). This wide array of existing port efficiency literature shows that there are numerous methods available for studying the relationship between competitive intensity and performance. There is also a large body of research dedicated to studying inter-port competition, ranging from early studies such as Verhoeff (1981) and Slack (1985) to more recent work such as Wang *et al.* (2012) and Homosombat *et al.* (2016). A notable portion of this work has treated port competition from a game-theoretic standpoint, studying strategic aspects of investment levels (Anderson *et al.*, 2008) and pricing competition (Ishii *et al.*, 2013). The notion that competition between autonomous ports can spur improvements in efficiency is somewhat complicated. Port investments are subject to a significant time lag between initialization and completion, and they are largely of a "sunk cost" nature, meaning that it is difficult to divest in port capacity (Musso *et al.*, 2006). Being of an irreversible nature, such investments may be subject to what Abel and Eberly (1999) term the "hangover effect", meaning that firms typically find themselves with large capital stocks because they cannot sell capital even when it has a low marginal revenue product. Not all assets in ports are irreversible investments. For instance, while investing in a wide and deep approach channel is permanent, cargo-handling equipment may be sold to another goods handler. However, once a sunk investment in a particular factor of production is made, other factor inputs may become more productive, reducing incentives for divestment of sellable capital units or even stimulating further investment. If ports subject to more intense competition tend to invest in capacity to a larger degree, we should therefore expect to see a greater level of capacity in competitive port regions. Barring a counteracting improvement of efficiency because of competitive pressure, increased competition between ports could be expected to lead to reduced efficiency.

While the efficiency of seaports has been studied extensively, few such studies attempt to incorporate competition as an element potentially affecting performance. One study that does analyze the impact of competition on efficiency finds that estimated port efficiency decreases with the intensity of regional competition (De Oliveira and Cariou, 2015). Another study (Yuen, *et al.*, 2013) finds that the efficiency of container terminals is positively correlated with the level of inter-port competition. Conceptually, this study follows that of De Oliveira and Cariou (2015), but with some key differences. First, while their study has global coverage, this study is applied to the European container port sector in particular. If port policy interacts with competition and efficiency, this motivates the study of specific regions to develop and further the literature on European port policy and governance. Second, while their study applies a non-parametric approach to determining efficiency, this study uses an econometric framework. Though this approach requires potentially restricting assumptions of a functional form and error term distribution, it has advantages in that it can accommodate random noise in the data in a straightforward way (Coelli *et al.*, 2005). Another advantage with the parametric approach applied is that efficiency frontier estimation and analysis of inefficiency determinants can be accommodated in a one-step procedure. This will be elaborated upon in the Methodology section.

3. Methodology

The aim of efficiency analysis is to measure the extent to which a firm or some other decision-making unit (DMU) achieves a maximum level of output given a set of inputs, combined in an optimal way (Farrell, 1957). The measurement of efficiency is based on an estimated distance between the firm's actual level of production and an efficient frontier of maximum achievable production for given sets of inputs. Empirical analysis of efficiency requires some method of estimating this benchmark frontier. The two dominating methods are DEA and SFA (Lovell, 1993). The former is a non-parametric linear programming approach that has the advantage that it does not require any presupposition of the firm's production technology (Charnes *et al.*, 1978). As a drawback, non-parametric methods complicate statistical testing of hypotheses, a problem which can be solved using a stochastic approach. In stochastic frontier analysis, a cost or production function is estimated with a two-part composite error term. One part is an inefficiency effect indicating distance from the frontier, and the other part is some well-behaved noise term (commonly assumed to be normally distributed) (Meeusen and van den Broeck, 1977; Aigner *et al.*, 1977). In SFA, choice of functional form is crucial. In empirical applications, the chosen approaches are often that of the simple Cobb–Douglas, which restricts the returns to scale in production to be a constant (not to be confused with returns to scale being constant) or the generalized translog form, which adds cross-product terms for each input and does not restrict substitution elasticities to be unity (Coelli *et al.*, 2005). For the N-input, single output case, the Cobb–Douglas function is:

$$\mathrm{Y_i} = \beta_0 \prod_{n=1}^{N} \beta_n X_{n,i} \tag{1}$$

And the translog function is:

$$\mathrm{Y_i} = \exp\left[\beta_0 + \sum_{n=1}^{N} \beta_n \ln X_{n,i} + \frac{1}{2}\sum_{n=1}^{N}\sum_{m=1}^{N} \beta_{n,m} \ln X_{n,i} \ln X_{m,i}\right] \tag{2}$$

The Cobb–Douglas and translog functional forms are, respectively, first- and second-order approximations of an unknown relationship. The latter could generally be said to be more attractive, as the more flexible form reduces the amount of potentially restrictive assumptions required in specifying the function to be estimated. In practice, the advantage of the translog over the Cobb–Douglas form can be assessed through a likelihood-ratio (LR) test (Wooldridge, 2010). Once estimated, the functions allow for tests of other statistical hypotheses. Of particular interest in assessing industry regulation and policy is testing whether the production of container port services exhibits constant returns to scale (CRS). In the Cobb–Douglas model, the assumption of CRS can be tested by imposing the restriction that the sum of output elasticities is equal to one, i.e.:

$$\{\beta_1 + \beta_2 + \beta_3 + \beta_4 = 1\} \tag{3}$$

where, $\boldsymbol{\beta}' = (\beta_1, \beta_2, \beta_3, \beta_4)$ are Cobb–Douglas parameters in a four-input model. The four-input example is convenient to use here, as it directly applies to the subsequent empirical analysis. For the translog model, the CRS assumption can be stated as the set of joint restrictions under which the model reduces into a CRS Cobb–Douglas function:

$$\left\{\begin{array}{l} \beta_1 + \beta_2 + \beta_3 + \beta_4 \quad = 1 \\ \beta_{11} + \beta_{12} + \beta_{13} + \beta_{14} = 0 \\ \beta_{12} + \beta_{22} + \beta_{23} + \beta_{24} = 0 \\ \beta_{13} + \beta_{23} + \beta_{33} + \beta_{34} = 0 \\ \beta_{14} + \beta_{24} + \beta_{34} + \beta_{44} = 0 \end{array}\right\} \tag{4}$$

The validity of these restrictions can be tested using the Wald test principle (Wooldridge, 2010). In the previous literature dedicated to estimating seaport efficiency, both DEA (Martinez-Budria *et al.*, 1999; Cullinane and Wang, 2006; Barros, 2006) and SFA (Liu, 1995, Coto-Millan *et al.*, 2000; Trujillo and Tovar, 2007; Estache *et al.*, 2002) approaches have been used. Among the SFA applications, functional form is usually decided by estimating both a Cobb–Douglas and translog variant and assessing whether the more restrictive Cobb–Douglas is adequate through a LR test. The Cobb–Douglas form is in some cases found to be sufficient (Trujillo and Tovar, 2007; Tongzon and Heng, 2005), while in other cases the translog form is found to be superior (Coto-Millan *et al.*, 2000; Estache *et al.*, 2002). The rationale for choosing Cobb–Douglas and translog functional forms in this study is that they provide, respectively, a parsimonious and flexible model. The choice of model is ultimately determined by a LR test. As the production function variables in this dataset (to be introduced) do not include zeroes, there is also no issue of constructing logarithms.

In many applications of efficiency analysis, the purpose is to investigate the determinants of inefficiency, i.e. to explain why some DMUs do not perform as well as their studied counterparts. In DEA applications, it is common to use a two-step approach, such as that proposed by Simar and Wilson (2007). This approach takes into account the potentially complex serial dependence and truncation that characterizes DEA estimates of efficiency. Two-step methods that involve first estimating the efficiency of units, and then regressing these on explanatory factors have also been proposed for SFA (Pitt and Lee, 1981). An arguably better approach is to account for the inefficiency determinants directly in the estimation of the production frontier (Kumbhakar *et al.*, 1991; Battese and Coelli, 1995). In fact, Wang and Schmidt (2002) show in a simulation study that for SFA, the two-step approach for explaining inefficiency leads to significant bias, favoring the one-step approach. The one-step approach can be described by first assuming for the (log-linearized) production function:

$$\ln Y_{it} = \beta_0 + \beta_1 \ln X_{1,it} + \ldots + \beta_k \ln X_{k,it} + v_{it} - u_{it} \tag{5}$$

where, k is the number of entered factors of production (X), that u is a non-negative inefficiency term composed by:

$$u_{it} = \alpha_0 + \alpha_1 Z_{1,it} + \ldots + \alpha_l Z_{l,it} + W_{it}. \tag{6}$$

In the latter equation, u is assumed to depend on a set of l factors ($\boldsymbol{Z}$) which characterize the production environment of port i at time t. The distribution of the inefficiency term is assumed to be:

$$u_{it} \sim i.i.d\ N^{+}\left(\alpha\mathbf{Z} + W, \sigma_u^2\right) \tag{7}$$

where, W is a normally distributed random variable, truncated at ($-\alpha\boldsymbol{Z}$). Using the above described estimation framework, it is possible to specify hypothesized determinants of inefficiency as variables in $\boldsymbol{Z}$. The main effect of interest in this study is that of competitive intensity. To account for other factors that have been shown to influence inefficiency, variables from previous studies are also incorporated.

In assessing the impact of port competition on estimated efficiency, previous proxies for competition have included distance to nearest port (Yuen *et al.*, 2013, Merkel and Holmgren, 2017) and a Herfindahl–Hirschman index (HHI) of market concentration (De Oliveira and Cariou, 2015). The advantage of the market concentration index over the more simplistic distance measure is that it considers the extent to which market shares are unequally distributed and is therefore a more telling measure of competition. In addition, the HHI can be constructed to reflect competition at different spatial levels. As argued by De Oliveira and Cariou (2015), ports may be subject to competition at the local, regional and global level. These can be approximated by limiting the relevant competitors to a specified distance radius. As this paper deals only with European ports, the global level of competition is not included.

4. Empirical production functions and data

This study takes a production function approach to deriving estimates of technical efficiency of seaports. Before arriving at an estimable function, a few conceptual features of port services should be noted. Jansson and Shneerson (1982) note that port services are (as all services) non-storable. This implies that production and consumption need to occur simultaneously. From this obvious reasoning, two general statements can be made:

(1) In some theoretically complete model of port service production, the time and effort provided by the user of services should be accounted for as inputs to production.

(2) There may exist significant substitution between producer and user inputs. A lack of modern handling equipment on part of the port or terminal will inevitably require an increased amount of user time, while a greater level of capital inputs will enable less time usage on part of the consumer. This is analogous to the statement that a high (low) level of capacity utilization yields a low (high) cost of capacity and high (low) expected total waiting times.

While the points made above imply that the user side of port services should be included in a complete production function, data availability is a hindrance. Turnaround times in port are theoretically observable, but there are large difficulties in gathering and harmonizing such data with the historical record of port assets and aggregated throughput levels (not least in studies with many DMUs). In some studies (Akinyemi, 2016), waiting time is included as a factor of production, but in most studies it is not (for a review of this issue, see Merkel and Holmgren, 2017). Noting that omission of user inputs is a second-best solution does however at least allow one to keep in mind that what is being estimated is technical efficiency with regard only to producer inputs. This has important implications and certain limitations for the interpretation of results and findings.

This study considers four inputs to the production of container throughput (TP), measured as annual number of 20-foot-equivalent container units (TEUs) handled. The inputs are total terminal area (TA) in square meters, total berth length (BL) in meters, total number of quay cranes and reach stackers/front end handlers with a carrying capacity of at least 25 tons (NC) and maximum allowed depth of the deepest berth in the port (MD) in meters. Terminal area and berth length both correspond to a port's endowment of land, while the number of cargo handling machinery units correspond to capital. Depth can be considered a semi-natural resource; ports situated on natural harbor sites are well suited to accommodate deep-draft ships. It is semi-natural in the sense that existing facilities can be augmented through dredging operations. Because of the trend of increasing container ship sizes during the period of study, draft has become a bottleneck for ports, and is therefore assumed to reflect a source of competitive advantage. As in a large number of similar analyses of port efficiency, labor does not enter the estimated production function. The reason for having to ignore labor inputs is scarcity of data, as well as a lack of data consistency, in cross-country samples. However, it has been argued (So *et al.*, 2007; Cullinane *et al.*, 2002; Tongzon and Heng, 2005; Serebrisky *et al.*, 2016) that labor occurs in more or less fixed proportion to capital inputs. If this should be the case, it means that variation in the use of labor as a factor of production is contained in the variation of capital inputs. This assumption, stated explicitly, is that the operating labor requirements for the capital equipment units measured in this study are the same across large European container ports.

For a total of 77 ports and six biennial years of observation, data for input factors was gathered from Containerisation International Yearbook (2002, 2004, 2006, 2008, 2010, 2012), and throughput data for the same years was retrieved from the Eurostat (2016b) database. The use of biennial years of observation is necessitated by the fact that for the ports in the sample, infrastructure variables are unavailable or missing for several years. As a criterion for inclusion, ports with an average annual throughput lower than 10 000 TEUs during the period 2002-2012 were excluded. The reason for applying such a criterion is to ensure a higher level of data consistency and because of the assumption that very small ports do not have a large effect on the competitive intensity of port regions. In total, data collection yielded a panel dataset of 462 observations. The ports included for analysis can be divided into five regions: the Mediterranean, the Atlantic, the UK, Scandinavia/Baltic and Hamburg-Le Havre. Out of the sample of 77 ports, 57 are classified as "core" parts of the trans-European transport network and the other 20 are classified as "comprehensive" (European Union, 2017a). The variables entered as factors of production are summarized in Table I and the development in total throughput per region is visualized in Figure 1.

A Herfindahl–Hirschman index (HHI) is constructed to serve as an indicator for the competitive environment facing ports. This index is calculated as the squared sum of all market shares within a specified proximity. This method is similar to that of De Oliveira and Cariou (2015). The index is constructed as follows:

$$HHI_{i,t}(d) = \sum_{j}^{N_i(d)} s_{j,t}^2 \quad \text{For } j = 1, 2, \ldots i, \ldots, N_i(d) \tag{8}$$

$$s_{j,t} = \left(\frac{TEU_{j,t}}{\sum_{j}^{N_i(d)} TEU_{j,t}} \right) \tag{9}$$

where, d is the specified distance (kilometers) within which ports are assumed to be in competition for services, $N_i(d)$ is the number of ports within the specified distance of port i and $s_{j,t}$ is the market share of port j at time t. The index is bounded from below by $\left(\frac{1}{N(d)}\right)$, indicating perfectly symmetric market shares, and from above by 1, indicating a perfectly

Variable	Mean	SD	Minimum	Maximum
TP	849,859	1,797,961	831	11,418,324
TA	778,020	1,271,267	6,000	7,654,073
BL	2,303	2,685	100	16,205
NC	27	34	1	228
MD	13	5	5.5	45

Sources: Containerisation International Yearbook (2002, 2004, 2006, 2008, 2010, 2012); Eurostat, (2016b)

Table I. Production function variables

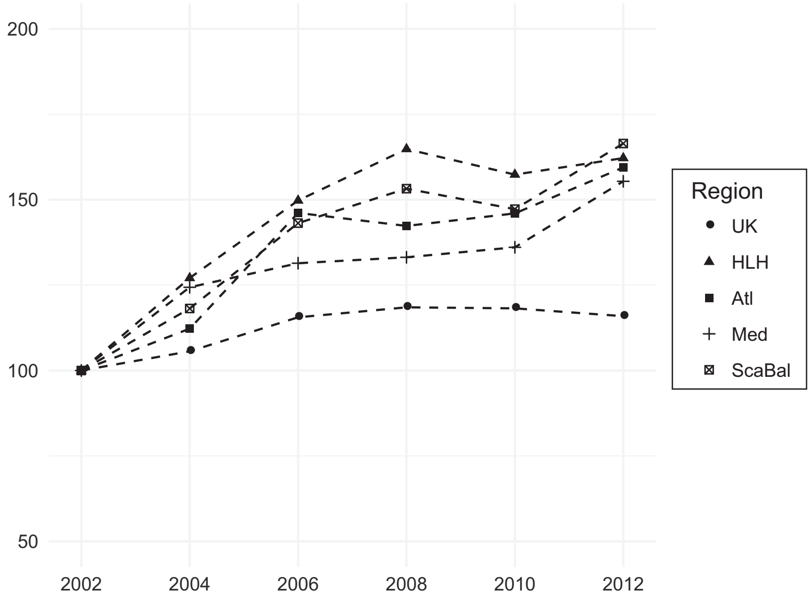

Figure 1.
Total throughput volume develoment per region (measured as total number of TEUs with 2006 = 100)

Source: Own elaboration of Eurostat (2016b)

monopolistic market. To account for competition at different spatial levels, the index is constructed for three different values of *d*: 300, 500 and 700 km. To construct the indices, Euclidian distances are calculated for each port pair. The reason for constructing three distance levels rather than for example separate levels for each 100 km interval is related to the quality of the index. To identify differences in the effect of competition on efficiency for different spatial levels, it is necessary for there to be distinct differences between market concentration levels in the distance categories. The maximum cut-off value of 700 km is chosen to reflect a distance outside of which ports would generally not be considered to be in competition. Within 700 km, the intermediate cut-off values of 300 and 500 km are chosen because there is on average the same number of regional competitor ports within each these radiuses. For each distance level (300, 500 and 700 km), the average port in the sample faces competition from four additional ports. It should be noted that the HHI measure constructed only captures within-region competition, which is a limitation of this study. This means, for instance, that the competition faced by Mediterranean transshipment ports from African ports is not accounted for.

Disaggregating the HHI values by port region averages, it can be seen that the lowest levels of port concentration are found in the Hamburg-Le Havre region, indicating that this is the region where competition is the most intense. The region where market concentration is highest is the Mediterranean. These differences are shown in Figure 2.

An important determinant of port performance is hinterland market size. It can be expected, and has been shown in previous research (Yuen *et al.*, 2013; De Oliveira and Cariou, 2015), that ports serving larger local markets tend to be more efficient. To account for this effect, it is necessary to provide some measure of hinterland market size. One option is to use population data as a proxy for market size (De Oliveira and Cariou, 2015). The use of such a proxy alone would implicitly state that the number of inhabitants in a port city or

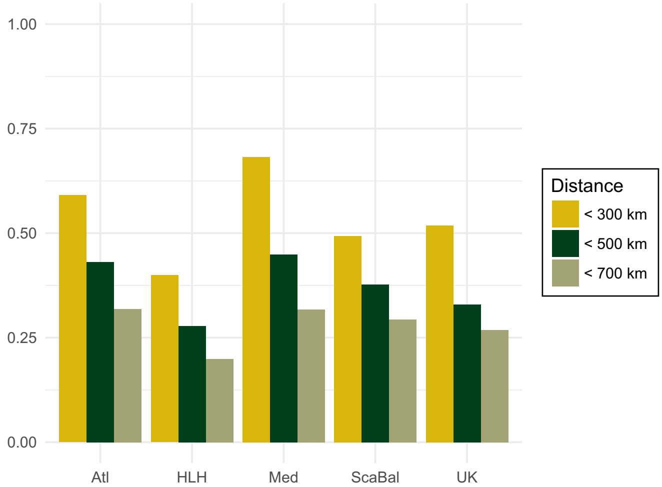

Figure 2.
HHI average, by distance and region

region mirrors the extent of business available to the port. A complementary measure of market size, used by Yuen *et al.* (2013), is regional or provincial economic output in the area of the port. Accordingly, this study uses two proxies to capture the effect of market size on efficiency. Gross regional product (GRP) series at the NUTS 3 level are gathered from Eurostat (2016c) and expressed in constant prices (in million EUR) to approximate the economic size of a port's hinterland market. Population figures at the NUTS 2 level (the highest level available for sample period) are also gathered from Eurostat, (2016a) and used to provide a complementary measure of market size.

The dummy variable L is assigned to 1 for large ports, with an average annual throughput exceeding 1 million TEUs. It could be argued that any effect of scale on efficiency ought to be captured by a flexible-form production function. However, there is evidence in previous research (Tongzon and Heng, 2005; Cullinane and Song, 2006) of a residual relationship between estimated efficiency and size. One reason for such a relationship could be that size not only reflects scale effects on efficiency such as better usage of common infrastructure and a higher degree of intra-port competition but also serves as an indicator for unmeasured features of efficient ports such as apt locality and competence of management. Another reason for larger ports to be found more efficient is if the transshipment share of throughput is higher. As recognized by Serebrisky *et al.* (2016), transshipment cargo services typically requires a faster process of unloading and offloading, as well as a lesser use of storage and customs procedures. Ideally, it would be appropriate to account for these differences in service production characteristics by including a measure of transshipment cargo share in each port at each period. Such a measure is however not readily available. Instead, this effect is partially captured by the size measure L, as the largest ports in the sample are typically characterized as hubs and will in general serve a relatively high proportion of transshipment cargo.

Regional dummy variables are included to account for structural and institutional differences between different European regions as described in Section 2.2. Finally, a set of year-specific dummy variables is included to account for common industry shocks and business cycle effects on efficiency in the observed periods (Table II).

The empirical Cobb–Douglas and translog functions are (after log-linearization), respectively:

Table II. Environmental variables

Variable	Mean	SD	Minimum	Maximum
HHI (d < 300 km)	0.55	0.23	0.24	1
HHI (d < 500 km)	0.38	0.17	0.16	0.99
HHI (d < 700 km)	0.29	0.12	0.13	0.79
Population	2,570,344	1,800,684	377,235	8,377,810
GRP	29,225	27,787	1,991	167,106
L	0.21	0.40	0	1
HLH	0.16	0.36	0	1
Med	0.32	0.47	0	1
ScaBal	0.27	0.45	0	1
UK	0.14	0.35	0	1
Atl	0.10	0.31	0	1

Sources: Containerization International Yearbook (2002, 2004, 2006, 2008, 2010, 2012); Eurostat (2016a, 2016b, 2016c)

$$\ln TP_{i,t} = \beta_0 + \beta_1 \ln TA_{it} + \beta_2 \ln BL_{it} + \beta_3 \ln MD_{it} + \beta_4 \ln NC_{it} + v_{it} - u_{it} \tag{10}$$

and:

$$\begin{aligned}\ln TP_{it} = {} & \beta_0 + \beta_1 \ln TA_{it} + \beta_2 \ln BL_{it} + \beta_3 \ln MD_{it} + \beta_4 \ln NC_{it} + \frac{1}{2}\beta_{11} \ln TA_{it}^2 \\ & + \beta_{12} \ln TA_{it} \ln BL_{it} + \beta_{13} \ln TA_{it} \ln NC_{it} + \beta_{14} \ln TA_{it} \ln MD_{it} + \frac{1}{2}\beta_{22} \ln BL_{it}^2 \\ & + \beta_{23} \ln BL_{it} \ln NC_{it} + \beta_{24} \ln BL_{it} \ln MD_{it} + \frac{1}{2}\beta_{33} \ln NC_{it}^2 + \beta_{34} \ln NC_{it} \ln MD_{it} \\ & + \frac{1}{2}\beta_{44} \ln MD_{it}^2 + v_{it} - u_{it}\end{aligned} \tag{11}$$

With inefficiency component to be estimated simultaneously:

$$\begin{aligned}u_{it} = {} & \alpha_0 + \alpha_1 L_i + \alpha_2 HHI_{it} + \alpha_3 \ln Pop_{it} + \alpha_4 Med_i + \alpha_5 HLH_i + \alpha_6 UK \\ & + \alpha_7 ScaBal_{it} + \alpha_9 D04 + \alpha_{10} D06 + \alpha_{11} D08 + \alpha_{12} D10 + \alpha_{13} D12 + W_{it}.\end{aligned} \tag{12}$$

where, v_{it} is a normally distributed noise term and W_{it} is as defined in Section 3.2. All variables are as previously defined, and D04-D12 represent year-specific dummy variables. The functions are estimated as pooled panel models, with the simplifying assumption that for all i and t, u_{it} and v_{it} are treated as independent. This specification treats inefficiencies as observation-specific rather than port-specific. An alternative estimation procedure would be to follow the example of Rodrigues-Álvarez and Tovar (2012) and introduce port-specific fixed effects. However, as the number of periods in the data is only six, this approach would lead to biases in both parameter and efficiency estimates (Greene, 2005). Instead, the time-invariant efficiency determinants corresponding to size and region can be seen to account for some (but not all) time invariant heterogeneity. A maximum likelihood estimator is applied, using a procedure based on FRONTIER 4.1 (Coelli, 1996). The estimates of technical efficiency for the i:th port at time t can be retrieved as:

$$\hat{TE}_{i,t} = \exp[-u_{it}] = \exp[-\alpha\mathbf{Z} - W] \quad (13)$$

Which gives the ratio of actual level of production to maximum achievable production level given the observed input set and the production environment of the port. The purpose of estimating this particular system of equations is to test the following hypotheses for each spatial level of competition:

$$H_0 : \alpha_2 = 0$$

$$H_1 : \alpha_2 < 0$$

$$H_2 : \alpha_2 > 0 \quad (14)$$

Where rejection of the null hypothesis in favor of *H1* indicates that, for the specified distance radius, market concentration and inefficiency are negatively related. This is analogous to the statement that competition and efficiency are negatively related. Rejection of the null in favor *H2* instead indicates that ports subject to a higher degree of competition are found to be more efficient, other things equal.

5. Results

In Table III, the estimation results of the stochastic frontier production function are presented. The two columns are results for the Cobb–Douglas and translog models [equations (10) and (11)]. A Likelihood–Ratio test confirms that the Cobb–Douglas functional form can be rejected in favor of the translog at a significance level of 1 per cent. The output elasticities, which can be conveniently read from the Cobb–Douglas estimation results, show

Variable	Cobb-Douglas	Translog
Constant	3.96*** (0.53)	14.73*** (4.48)
lnTA	0.46*** (0.04)	−2.99*** (0.85)
lnBL	0.22** (0.09)	1.79 (1.23)
lnNC	0.47*** (0.06)	−0.21 (0.94)
lnMD	0.36* (0.21)	4.96** (2.34)
0.5 × lnTA^2		0.18*** (0.06)
lnTA × lnBL		0.13 (0.10)
lnTA × lnNC		−0.27*** (0.06)
lnTA × lnMD		0.45 (0.30)
0.5 × lnBL^2		−0.64*** (0.18)
lnBL × lnNC		0.41*** (0.12)
lnBL × lnMD		0.05 (0.42)
0.5 × lnNC^2		−0.04 (0.12)
lnNC × lnMD		0.46* (0.27)
0.5 × lnMD^2		−4.56*** (1.09)
σ_u^2	2.87*** (0.27)	1.96*** (0.20)
γ	0.94*** (0.02)	0.89*** (0.03)
LogLik	−612	−562
Num Obs	429	429
Mean efficiency	0.40	0.45
W-CRS	7.71***	55.64***

Notes: ***; **and *denote significance at the 1, 5 and 10% level, respectively

Table III. Results of production frontier estimation that an increase in 1 per cent in terminal area is roughly associated with a 0.46 per cent increase in throughput. The corresponding elasticities for berth length and number of cranes is 0.22 per cent and 0.47 per cent, respectively. The estimated output elasticity of maximum depth also has the expected positive sign but is not significant at a confidence level threshold of 5 per cent. For both specifications, an imposed restriction of CRS can be rejected. The sum of input parameters in the Cobb–Douglas function is 1.51, indicating increasing returns to scale in the production of port services. While the translog model parameters cannot be directly interpreted as output elasticities, partial elasticities can be calculated for each parameter. Such estimates are derived by calculating the percentage increase in fitted output resulting from a corresponding increase in a single input. The elasticities differ depending on the levels at which the variables are evaluated. Table IV (second column) shows these estimates when the median input values are used. This can be considered to approximate a typical port in the sample. While the elasticities can be interesting in themselves, they are not further discussed or analyzed in this study. Rather they serve as a robustness check to see that the estimated production functions appear to give reasonable results.

Table V details the results from simultaneous estimation of equation (12). The null hypothesis described by equation (14) is rejected in only one of the model variants. For competition measured within a range of 300 km, the positive and significant parameter estimate shows that a higher level of market concentration is associated with a higher level

Table IV.
Partial elasticities of output

Input factor	Cobb-Douglas	Translog
ε_{TA}	0.46	0.60
ε_{BL}	0.22	0.01
ε_{NC}	0.47	0.39
ε_{MD}	0.36	0.46

Notes: Output elasticities from estimated production functions in Table III. For the translog model, elasticities are calculated for the variables evaluated at their median values

Table V.
Inefficiency determinants

Variable	Translog (d = 300 km)	Translog (d = 500 km)	Translog (d = 700 km)
α_0	4.85*** (1.86)	5.21*** (2.00)	5.60*** (1.79)
L	−3.81*** (0.76)	−3.96*** (0.94)	−3.57*** (0.68)
HHI (< d)	1.22*** (0.39)	0.45 (0.50)	−0.95 (0.68)
lnPop	−0.32** (0.13)	−0.32** (0.14)	−0.33*** (0.13)
lnGRP	0.01 (0.09)	−0.01 (0.10)	0.04 (0.09)
Med	0.87*** (0.29)	1.05*** (0.33)	1.04*** (0.31)
HLH	1.55*** (0.38)	1.52*** (0.43)	1.22*** (0.40)
UK	−0.02 (0.36)	0.03 (0.39)	−0.06 (0.36)
ScaBal	0.73** (0.30)	0.72** (0.33)	0.60* (0.33)
D04	−0.03 (0.28)	0.01 (0.28)	0.02 (0.28)
D06	−0.16 (0.26)	−0.15 (0.27)	−0.17 (0.27)
D08	−0.15 (0.26)	−0.13 (0.27)	−0.15 (0.27)
D10	−0.06 (0.26)	−0.02 (0.27)	−0.04 (0.27)
D12	−0.02 (0.26)	0.05 (0.27)	0.05 (0.27)

Note: ***; **and *denote significance at the 1, 5 and 10% level, respectively of technical inefficiency. This means that an increased intensity of local competition is associated with significantly higher levels of efficiency. At the same time, such effects are not distinguishable for competition at wider spatial levels. The sign in front of market concentration within 500 km is positive, while the sign in front of market concentration within 700 km is negative. A negative effect of market concentration on efficiency would indicate that a higher level of competition between ports could cause inefficiency, which would be consistent with the conjecture that competition leads to overcapacity. Such a result is however not distinguishable in this analysis.

A marginal effect of local competition on estimated efficiency can be calculated using equations (12) and (13) to find that:

$$\frac{\delta \widehat{TE_{i,t}}}{\delta HHI(d < 300 \ km)_{i,t}} = - \ \alpha_2 * \exp[-\alpha \mathbf{Z} - W] = \ - \ \alpha_2 * \widehat{TE_{i,t}} \tag{15}$$

Such a calculation shows that a 1 percentage point increase in market concentration in the local area of a fully efficient port gives a predicted efficiency decrease of 1.2 percentage points.

The results also show that regional population size is negatively related to inefficiency, which implies that ports with larger hinterland markets tend to be more efficient. This is a reasonable result, given that serving a larger market should result in a more consistent level of demand and consequently better possibilities for accurate capacity planning. The effect of economic hinterland size, holding population constant, is not significantly different from zero. For the dummy variable distinguishing larger ports, the parameter estimates indicate large and significant differences in estimated efficiency. This indicates that larger ports, holding other factors equal, are estimated to be more efficient than smaller ports. This is in line with previous empirical results in the literature.

6. Possible implications for port policy and research

The finding that the intensity of local competition is positively related to port efficiency could be seen to suppress some of the concern that inter-port competition is in itself a cause of overcapacity. Further, it implies that levelling competition between ports could be a suitable direction for policy aimed to improve efficiency. While the analysis does not show any distinguishable negative effect of competition (for any spatial level) on efficiency in a panel that comprises a decade's worth of observations, it is important to note that the somewhat crude nature of production frontier estimation makes it difficult to account for heterogeneity in port service production. With more refined data, particularly including the user side of production, the use of efficiency analysis techniques would be able to provide a higher level of accuracy and policy relevance in its results.

The results of the analysis conform in some respects to previous work and differs in some ways. The sign and significance of essential control variables, such as hinterland market size and port scale are largely in line with the literature. On the other hand, the finding that close-range competition is positively related to efficiency is a novel result. While Yuen *et al.* (2013) did find that the efficiency of Chinese container terminals improved with higher inter-port competition, this result was based on a pure distance measure and did not distinguish between different levels of competition. The result is also markedly different from that of De Oliveira and Cariou (2015), whose analysis suggested the opposite effect: a negative relationship between competition and efficiency. Whether any of these results hold generally is difficult to determine from the existing evidence. However, as the current study is focused on the European container port market specifically, it is arguably more telling of the situation pertaining to European container ports. The question is ultimately complicated by the fact that competition is difficult to accurately measure. Further research into the issue could do well to go beyond region- or distance-based measures of competition to account for the fact that proximity is not always a determinant of competitive intensity.

When efficiency is estimated using only producer inputs (as in this and most similar applications), the measure does not capture the cost (time or monetary) incurred on the user. If an expansion of capacity gives rise to a reduction in freight transport costs (for instance through the utilization of larger vessels) that is large enough to offset the cost of the expansion, it is justified on a socio-economic basis. It is not possible to infer from the above analysis whether large capacity increases over the studied years have been justifiable on such a basis. As reviewed in Section 2, the proposed framework for a common ports policy has included limitations to government subsidization of national ports. As a way to combat overcapacity, it appears recommendable that such limitations should include that any proposed large investment in port infrastructure passes a cost-benefit test. If there are non-negligible effects on efficiency of improving the competitive intensity in the vicinity of large ports, as this paper finds, such effects could appropriately be considered in appraisal.

7. Conclusions

Proposals for a common ports policy framework in the European Union have advanced during the past decades. A recurring objective of such proposals has been to increase the autonomy of ports and to achieve more competitive markets. A concern that is often voiced with regard to this objective is that competition may exacerbate perceived problems of excess capacity in container ports, which can be harmful to the efficiency of the maritime transport system. In this study, the relationship between intensity of competition and technical efficiency is analyzed using a stochastic frontier approach and a dataset of 77 large European container ports over the period 2002-2012. The results indicate that there is no significant negative effect of competition on efficiency. In fact, for ports within a proximity of 300 km, a higher level of competition is found to be associated with a higher level of efficiency. The analysis suggests that reducing the market concentration by 1 per cent in the local area of a port may yield an efficiency increase of roughly 1.2 per cent. This implies that while excessive capacity expansion may sometimes result because of fierce inter-port competition, this does not appear to have been the general outcome for large European container ports during the studied period. The policy-relevant conclusion is that focusing efforts to reduce monopolistic powers of ports in local networks could be a viable way to improve efficiency. It is notable that this study, similar to most studies of port efficiency, would benefit from a greater level of access to micro-level data in ports. This includes turnaround times of vessels, terminal-level outputs and labor data. Gathering and using such data for the purpose of port efficiency analysis and policy evaluation is a difficult but recommendable task for future research.

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