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Market access and seaport efficiency: the case of container handling in Norway

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Abstract

Comprehensive studies on the impact of market access on port efficiency are scarce, and the problem that market access indicators are potentially endogenous lacks treatment in maritime economics. This paper offers both theoretical and empirical advances to fill these research gaps. First, it pioneers in the use of Stochastic semi-Nonparametric Envelopment of Z variables Data for measuring port efficiency, and further develops the methodology for panel data and proposes an instrumental variable extension for dealing with endogenous market access indicators. Second, it advances the empirical port literature by developing a unique panel dataset on Norwegian container ports encompassing a comprehensive set of foreland and hinterland connectivity measures. Our comprehensive assessment suggests that the role of market access in determining port efficiency is uncertain.

Keywords: Productivity and competitiveness, Container seaports, Port efficiency, Market access, StoNEZD estimator

Introduction

Aligned with their objectives to develop a green, competitive, and resource efficient transport system, the European Union and Norway pursue modal shifts for 30% of road freight over 300 kilometer by 2030 and more than 50% by 2050 (European commission 2011). The achievement of these ambitious goals is contingent on the continuous improvement of port performances in supply chains (Schøyen et al. 2018). Seaports are operating in a complex ecosystem of maritime shipping and onshore freight transportation. Their locations and sizes are typically caused by geographical and historical conditions, as well as political and power lines. Please confer Rodrigue (2020) for an overview of key external impacts that influence seaport performance, Ha et al. (2017) for a stakeholder perspective on port performance and interdependencies, and Notteboom et al. (2022) for a broader and multidisciplinary perspective on the contemporary port industry. These factors influence the performance of seaports, inter alia by influencing the terms for foreland and hinterland market access, scope and scale properties. Previous studies indicate a negative correlation between container port efficiency and transport costs (Suárez-Alemán et al. 2016).[1]

[1] In this paper we estimate technical efficiency relative to the best-practice benchmark technology. Efficiency is one factor of the broader notion of seaport performance (González and Trujillo 2009).

While there is an abundant literature on port efficiency measurement and internal economies of scale and scope in port production (see e.g. Rødseth and Wangsness 2015 for a review), empirical analyses of the impacts of external economies of scale and scope on port productivity are scarce. Ducruet et al. (2009) argue that the efficiency measurement literature ignores the dependence of port efficiency on the quality of hinterland connections. There is also a lack of empirical studies on how supply chain integration affects port agglomeration (Alexandru 2013). Based on our own review of the literature (cf. "Use of Market Access Indicators in Port Efficiency Studies" section), we conclude that the port efficiency literature is not sufficiently developed to draw robust conclusions regarding the impact of market access on port efficiency. In contrast, there is a growing consensus in economic geography that economic density impacts firm productivity (e.g., Graham et al. 2010; Behrens et al. 2014).

Theoretical justifications for these impacts include transport costs savings (cf. Shirley and Winston 2004; Venables 2007), agglomerations synergies (cf. Duranton and Puga 2004; Rosenthal and Strange 2004), and competition (cf. Melitz and Ottaviano 2008; Behrens et al. 2014).[2] These interactions are the primary focus of studies on the wider economic impacts of transport appraisal (e.g. Wangsness et al. 2017; Graham and Gibbons 2019; Holmen et al. 2022), and an abundant literature on the measurement of the impact of agglomeration on productivity exists (cf. Melo et al. 2009; Holmen and Hansen 2023 for overviews). New insights into this matter can carry important implications for transport policy as ports' market access can be affected by port system planning, as well as rail and road hinterland infrastructure investments. Tovar and Wall (2022) pioneer in analysis of how port-level connectivity correlates with port efficiency. They find a strong positive relationship between connectivity and efficiency. However, their assessment does neither distinguish among market potential and actual trade flows nor mitigate associated endogeneity problems.

In this paper, we ask: "Is market access promoting container port efficiency?" Herein, we tackle endogeneity issues whilst undertaking a comprehensive analysis of the impact of market access—also referred to as connectivity in the maritime literature—on container port efficiency. Our paper pioneers in the use of Stochastic semi-Nonparametric Envelopment of Z variables Data (StoNEZD) for measuring port efficiency. We further develop the StoNEZD methodology for panel data and propose an instrumental variable (IV) extension of the method for dealing with endogenous market access indicators.

This paper is organized as follows. "Literature review" section sets the stage by reviewing market access measures, their use in the current literature on port efficiency and challenges related to endogeneity of market access measures for port efficiency measurement. "Methodology" section presents the basic StoNEZD model and our extensions, while "Data" section describes the dataset. "Results" section reviews the empirical results, while "Conclusions" section concludes.

[2] In addition, some national appraisal guidelines for transport consider organizational impacts within the logistics and transport industry (e.g. Department for Transport, Tourism and Sport 2016 and Bundesamt für Strassen 2018), but the related academic literature remains thin.

Literature review

This section provides a selective review of the literature on port market access, its treatment in current studies on port efficiency measurement, and related endogeneity issues for port efficiency analysis. Herein, we focus on productivity and efficiency analysis of ports, and do not provide a detailed account of studies within the broader context of port performance and its determinants.

Market access indicators

A port's access to markets can be divided in two, yet interlinked, parts; foreland and hinterland connections. Another important line of demarcation is the distinction between market access indicators reflecting market potential and actual trade flows. As we will later argue in "Endogeneity" section, the latter distinction is important when considering whether a port market access indicator constitutes an *exogenous* or *endogenous* regressor.

Market access

The New Economic Geography tradition considers market access to depend on proximity to economic activities. Market access functions reflect how impulses on a subject from activities nearby decrease over transportation frictions, a phenomenon known as 'agglomeration decay' or 'distance decay'. Similar concepts have also been referred to as 'accessibility', 'connectivity', 'economic density', 'market potential' or 'spatial gravity'. These concepts share the same characteristics. Yet, there are some smaller differences between these concepts, as they have somewhat different focus on direct versus indirect impacts, and potential versus realized outcomes. The latter distinction is especially important for our application, as it regards the endogeneity of the concepts. We understand 'connectivity' as the degree to which a location is connected to other destinations of different magnitude. Furthermore, we recognize 'market access' as more sophisticated weighting of access to realized and potential market connections at different locations, where the importance of proximity is accounted for (through agglomeration or distance decay). As the extent of connectivity in practice mostly coincides with the magnitude of market access, the implications for port efficiency will largely be the same. Consequently, the words can in practice be used to describe the same phenomena in our application, although we aware of the semantic differences. We refer to Graham et al. (2010), Sevtsuk and Mekonnen (2012), Redding and Rossi-Hansberg (2017) and Holmen (2022a) for detailed reviews of these concepts.

We can operationally define market potential by potential market connections (e.g., measured by amounts of people or production) weighted by a measure of friction over space (e.g. by travel time or distance). We apply various specifications of the Harris (1954) market access measure, which is popular within the trade and urban economics literatures and commonly used in investigations on wider economic impacts of transport infrastructure. Let $Mass_j \in \Re_+$ denote the economic mass of region j, which is located adjacent to the port region i. The Harris market potential of port i can thus be defined as:

$$HMP_i = \sum_{j=1, j\neq 1}^{R-1} \frac{Mass_j}{\text{Distance}_{i,j}} \tag{1}$$

In more general frameworks, distances may be replaced by generalized transport costs. These may be non-linear in travel distance and time. Furthermore, they may depend on other conditions such as customs costs and other direct transaction costs, as well as cultural and economic integration. In this study, we focus on ports in the same country, making this heterogeneity somewhat less prevalent with physical distances constituting a decent agglomeration decay measure.

Actual trade flows

Two set of measures considered herein are centrality measures and composite indices. Centrality is a key concept in network analysis, which assesses the relative significance of a vertex within a graph. Wang and Cullinane (2016) use degree, closeness and betweenness centrality to assess the integration of a port in the maritime transport network. In this paper, we focus on degree centrality, which amounts to identifying the number of ports and/or countries connected to the port under consideration. A similar approach can be found in Low et al. (2009), who define a connectivity index as the ratio of the number of origin–destination pairs served by a port to the number of origin–destination pairs in the network. A more complex approach is offered by Jiang et al. (2015), who consider the impact to the transport network of interrupted service at a given port. Jia et al. (2017) criticize this approach, noting that it is based on theoretical rather than empirical transport flows and that the two measures (time and capacity) are treated separately.

Jia et al. (2017) argue that the Liner shipping connectivity index (LSCI) developed and provided annually by the United Nations Conference on Trade and Development (UNCTAD) is a more appropriate measure of connectivity compared to centrality measures. UNCTAD's LSCI, which is available at the country level, comprises five components; (1) number of ships, (2) ship capacities, (3) maximal vessel size, (4) number of liner services and (5) the number of carriers. Jia et al. (2017) extend and develop the LSCI to identify connectivity at the port level using Automatic Identification System (AIS). Their index comprises four components; (1) number of distinct vessels calling from abroad, (2) number of domestic visits by distinct vessels, (3) maximal vessel size and (4) maximum carrying capacity. The LSCI is calculated by; (1) identifying the maximum per component for all ports under consideration; (2) calculating ratios of port-specific and maximal components from step 1; (3) calculating arithmetic mean of component-specific ratios from step 2 per port; (4) identify the maximal port-specific arithmetic mean from step 3; and (5) calculate the ratios of port-specific means from step 3 and maximal means from step 4 and multiply by 100. This provides a score between 0 and 100, where 100 can be interpreted as maximal market access relative to peers.

Use of market access indicators in port efficiency studies

The literature on port efficiency measurement is abundant. While Stochastic Frontier Analysis (SFA)—a parametric efficiency model which accommodates random noise—and DEA are the dominating methods, port efficiency studies are increasingly based on the deterministic, non-parametric DEA method that does not require the specification of a functional form (Odeck and Bråthen 2012). Many studies analyze the impact of contextual factors (i.e. factors which are not under the jurisdiction of ports) on port productivity and efficiency.

In DEA, the impact of contextual factors on efficiency is usually considered in a two-stage approach, in which contextual factors are regressed on efficiency scores obtained in the first stage (cf., Simar and Wilson 2007). The two-stage DEA is used by a majority of the port efficiency studies we have reviewed. This approach is only valid under the separability condition that contextual variables do not influence production possibilities, but only efficiencies. This is generally ignored by empirical studies. Hampf and Rødseth (2019) undertake rigorous testing and find that many conventional empirical model specifications are not in compliance with separability.

An overview of variables used by the most relevant references for our study is provided by the "Appendix". This overview shows that several previous papers have attempted to control for the impacts of hinterland population, employment, and income on port productivity. However, with a few notable exceptions (especially Cheon 2009; de Oliveira and Cariou 2015), measures focusing on the geographical distance and travel times to markets are lacking. Moreover, several studies rely on data on the country level, rather than at the port or regional level. For example, several studies use the LSCI, which is published at the country level (cf. "Appendix").

Some studies find that hinterland size enhances efficiency (e.g. Cheon 2009; Wanke 2013), while others find that connectivity facilitates port efficiency (e.g. Serebrisky et al. 2016). Yuen et al. (2013) explores how efficiency levels and growth rates are impacted by market access, calculated for population within different catchment ranges and gross domestic product. They find mostly insignificant results. Investigating port efficiency and competition, Oliveira and Cariou (2015) find that port efficiency decreases with competition when measured in a range of 400–800 km, but that it is unaffected by competition at local level.

Our overall judgement is that the two-stage port efficiency literature is fragmented with regards to model specification and variable definition. Furthermore, many of the variables used are coarse measures of market access. Moreover, the reviewed studies pay little attention to endogeneity issues for market access indicators, a topic which we return to in the proceeding section. Consequently, we argue that the port efficiency literature is not sufficiently developed to draw robust conclusions regarding the impact of market access on port efficiency.

A few studies that do not focus specifically on the impact of contextual variables are also worth mentioning in relation to our study. Lam and Zhang (2011) propose the use of DEA to evaluate the coordination among ports and maritime clusters, while Chen and Lam (2018) propose a network DEA model to jointly benchmark port and port city performance.

We also note that while comprehensive studies of economic density effects on port efficiency are in shortage, several areas of the ports and maritime literature deal with aspects of market access. There is an abundant literature on the impact of ports on the economic development of hinterland regions (e.g. Bottasso et al. 2014; Park and Seo 2016). Some studies have also emphasized the impact of hinterland regions on port cargo throughput (Cheung and Yip 2011).

Yet another strand of the maritime literature emphasizes port regions and inter-port competition and cooperation. Notteboom (2009) coined the terms substitute and complement ports, describing whether users are willing to substitute one load center for another or whether load centers always are consumed together. Focusing on the foreland dimension, Schøyen et al. (2017) undertook an empirical analysis of complementarity and substitutability of small and medium-sized container ports in the Oslo Fjord (Norway) using Automatic Identification System (AIS) data. They found that half of feeder ship roundtrips to the fjord visited multiple ports in this region. Port and maritime clusters have also received much attention in other studies (e.g., Arvis et al. 2018; Bouchery et al. 2020; De Langen 2002; Hung et al. 2010; Zhen et al. 2019).

To sum up, several port efficiency studies have attempted to control for impacts of hinterland population, employment, and income on port productivity. However, with a few notable exceptions (especially Cheon 2009; de Oliveira and Cariou 2015), measures focusing on the geographical distance and travel times to markets are lacking within the literature on productivity and efficiency analysis of ports. Moreover, several studies rely on data on the country level, rather than at the port or regional level. For example, several studies use the LSCI at the country level. The main exception is Tovar and Wall (2022), who apply the LSCI at the port level. However, as previously noted, their study does not take endogeneity problems into consideration. This is a cause for concern about their empirical findings—as further explained in "Endogeneity" section—and which warrants the thorough investigation of the matter presented in this paper.

Endogeneity

A prerequisite for unbiased parameter estimates is the independence of the error term and independent variables (i.e., avoiding endogeneity). This is the focus of attention of much of the literature on the impacts of market access on productivity (e.g. Graham and Gibbons 2019). Yet, the topic has only recently received attention in non-parametric efficiency analysis (see Cazals et al. 2016; Santín and Sicilia 2017).

In the "Market Access Indicators" section, we distinguished between market access indicators that represent; (1) market potential and (2) current trade flows. The former represents features that are exogenously given from a port perspective, such as geographic location and economic density of both adjacent and more distant regions or countries. The latter should be considered endogenous as it hinges on shippers' and carriers' port choices: Although port choice is a key research topic in maritime economics alongside port efficiency, the two are currently separate research areas with little common ground (Rezaei et al. 2019). However, the comprehensive review by Moya and Valero (2017) illustrates the importance of port attributes such as cargo handling duration (i.e. crane productivity), intermodal and hinterland connections, and service frequency as determinants of port choice. This means that market access measures such as centrality or LSCI are vulnerable to a *simultaneous variable bias*, i.e., trade-flow based market access measure correlate with the regression residual (i.e. the efficiency term or unobserved port heterogeneity).

A conventional statistical approach to mitigate endogeneity is to identify suitable instrument variables (IVs) for endogenous regressors. Herein, we pursue the instrumental variable approach, noting that market potential indicators are valid instruments for endogenous market access indicators.

Methodology

Theoretical model

Our starting point is the semi-nonparametric StoNEZD model by Johnson and Kuosmanen (2012), where output $y \in \Re_+$ depends on a monotonic increasing and concave frontier production function $f(\mathbf{x})$ of input vector $\mathbf{x} \in \Re_+^M$ and a parametric function of market access indicators $\mathbf{z} \in \Re_+^K$. In this study, we provide three extensions to the StoNEZD approach. First, we assume a panel data of N ports indexed as $i = 1, \ldots, N$, observed over time periods $t = 1, \ldots, T$. In this setting, the model can be stated in logs as:

$$\ln y_{it} = \ln f(\mathbf{x}_{it}) + \left(\alpha + \boldsymbol{\delta}'\mathbf{z}_{it}\right) + \varepsilon_{it} \tag{2}$$

where ε is a composite error term that comprises random noise, efficiency and possibly unobservable heterogeneity. Note that we do not assume a priori any specific functional form for f. However, we allow the market access indicators $\mathbf{z}$ to shift the frontier production function without affecting its shape. Second, building upon Kumbhakar and Heshmati (1995) and Kumbhakar et al. (2014), we decompose the composite error term ε into the following components:

$$\varepsilon_{it} = \gamma_i + v_{it} - (\eta_i + u_{it}) \tag{3}$$

In this model, unobserved heterogeneity of ports and their operating environments is represented by the time-invariant term γ. The noise term v captures any other sources of random deviations such as measurement errors. Finally, a port can fail to achieve its maximum output due to inefficiency. More concretely, Eq. (3) draws a distinction between persistent inefficiency η and time-varying inefficiency u.

We utilize two competing efficiency models for the empirical analysis. The first specification by Kumbhakar and Heshmati (1995) does not control for unobserved port heterogeneity (i.e., assumes $\gamma = 0$ by construction). We refer to this as the *3 components* (3C) model in the following. The second specification due to Kumbhakar et al. (2014) considers unobserved heterogeneity. We refer to this as the *4 components* (4C) model.

Third, we relax the assumption that market access indicators $\mathbf{z}$ are uncorrelated with the composite error term. As accounted for in the "Endogeneity" section, some market access indicators are likely dependent on endogenous choices by the port management and can hence correlate with persistent efficiency and unobserved heterogeneity. To reliably estimate the effects of market access indicators on port efficiency, it is important to take endogeneity into account.

Estimation

Following Kumbhakar et al. (2014), we compute persistent and time-varying efficiencies based on stepwise procedures, starting from the nonparametric production function *f*, proceeding to the market access indicators, and finally decomposing the composite error term.

Step 1 Convex regression

In the first step, we solve the following nonlinear programming problem in GAMS.

$$\begin{aligned}
&\min \sum_{t=1}^{T} \sum_{i=1}^{N} \varepsilon_{it}^{2} \\
&\text{s.t.} \\
&\ln y_{it} = \ln \phi_{it} + \left(\alpha + \boldsymbol{\delta}' \boldsymbol{z}_{it}\right) + \varepsilon_{it}, \forall it \\
&\phi_{it} = \boldsymbol{\beta}'_{it} \mathbf{x}_{it}, \forall it \\
&\phi_{it} \leq \boldsymbol{\beta}'_{hs} \mathbf{x}_{it}, \forall it, hs \\
&\boldsymbol{\beta}_{it} \geq 0, \forall it
\end{aligned} \tag{4}$$

The optimal $\hat{\phi}_{it}$ are henceforth used as estimates of $f(\mathbf{x}_{it})$ for each port i and period t. Kuosmanen (2008) shows that any monotonic increasing and concave function $f(\mathbf{x})$ can be represented by a piece-wise linear function, characterized by the inequality constraints of problem (4). Coefficients $\boldsymbol{\beta}$ can be interpreted as the tangent hyperplanes of the underlying production function *f*. Note that formulation (4) imposes constant returns to scale, which is our preferred specification in the present application. Our data set is a panel data that includes only a small number of ports that vary considerably in size. Therefore, estimating the model under the variable returns to scale specification, one would effectively compare the smallest and the largest ports to their own performance in the other time periods. While we recognize the possibility of economies or diseconomies of scale, to facilitate inter-port efficiency comparison, we assess efficiency relative to the constant returns to scale benchmark. Therefore, our efficiency estimates encompass both technical and scale efficiencies, which is worth noting for the interpretation of the results.

It is also worth to note that we explicitly control for the market access indicators $\mathbf{z}$ when solving problem (4). This is the key difference to the popular two-stage DEA estimation of contextual variables (e.g. Simar and Wilson 2007), where the $\mathbf{z}$ variables are omitted from the first stage DEA estimation. This can cause problems similar to the omitted variable bias in the linear regression analysis (Johnson and Kuosmanen 2012).

Note from Eq. (4) that inputs $\mathbf{x}$ are not included in the same constraints as the composite error term. As a result, inputs $\mathbf{x}$ can correlate with the regression residuals. Analogous to the nonlinear regression, we only need to assume that $f(\mathbf{x}_{it})$ is uncorrelated with the composite error term ε_{it}.

Step 2 IV panel regression

Given $\hat{\phi}_{it}$ from Step 1, we apply standard fixed effects (FE) and random effects (RE) panel regression in the case of exogenous market access measures and IV panel regression in the case of potentially endogenous market access indicators. Specifically, we regress.

$$\ln y_{it} - \ln \hat{\phi}_{it} = \alpha + \boldsymbol{\delta}' \boldsymbol{z}_{it} + \gamma_i + \tilde{\varepsilon}_{it} \tag{5}$$

In other words, in Step 2 we re-estimate coefficients $\boldsymbol{\delta}$, but we also obtain the firm specific fixed or random effects γ_i at this stage. Note that $\tilde{\varepsilon}_{it}$ captures time-varying inefficiency and noise. When using instrumental variables for the market access measures, the coefficients $\boldsymbol{\delta}$ can change as we move from Step 1 to Step 2.

Step 3 Decomposing the composite error term

The purpose of this step is to break down the composite error term ε to its sub-components according to Eq. (3). This step can be implemented in several different ways, depending on how strong distributional assumptions one is willing to make. In this paper, the efficiency scores as derived as follows:

Persistent efficiencies

3C Calculate persistent efficiencies using the approach by Schmidt and Sickles (1984), i.e., by identifying the maximal fixed/random effect and calculating persistent efficiency as the difference between port-specific and the maximal fixed/random effects

4C Calculate persistent efficiency using the cross-sectional SFA model with half-normal efficiency term distribution and a constant term on the predicted fixed/random effects from Step 2. Time-varying efficiencies are predicted following Battese and Coelli (1988).

Time-varying efficiencies

3C For the model $\ln y_{it} - \ln \hat{\phi}_{it} - \hat{\boldsymbol{\delta}}' \boldsymbol{z}_{it} + \hat{\gamma}_i = \alpha + \tilde{\varepsilon}_{it}$, predict time-varying efficiencies using the cross-sectional SFA model with half-normal efficiency term distribution. Time-varying efficiencies are predicted following Battese and Coelli (1988).

4C Calculate time-varying efficiency using the cross-sectional SFA model with half-normal efficiency term distribution and a constant term on the predicted residual error term from Step 2. Time-varying efficiencies are predicted following Battese and Coelli (1988).

We implement Step 1 in GAMS, while the preceding calculations are executed in Stata using the package "frontier".

Monte Carlo simulation

The stepwise estimation procedure introduced in "Estimation" section relies on the assumption that possible endogeneity of the market access indicators does not affect the estimation of the production function f in Step 1. This seems reasonable because the identification of the nonparametric production function is based on Afriat's monotonicity and concavity constraints of Eq. (4), which makes it insensitive to endogeneity bias related to the **z** variables. To test this assumption, we use Monte Carlo simulation, where

Table 1 Results from Monte Carlo analysis: MSE

Correlation	0	0.2	0.4	0.6	0.8
Frontier $f(\mathbf{x}_{it})$	0.166	0.161	0.166	0.166	0.168
Market access $\boldsymbol{\delta}'\boldsymbol{z}_{it}$	3.958	5.271	7.481	10.024	13.185

the data generating process has been calibrated to the present application to Norwegian ports.

The Monte Carlo simulation consists of the several steps. First, applying the dataset presented in "Data" section, we compute the convex regression problem (4) (cf. Step 1 in "Estimation" section). We use the predicted $\hat{\phi}_{it}$ and $\hat{\boldsymbol{\delta}}$ as the "true" parameter values.

The random error term v_{it} is drawn from the normal distribution with mean 0 and standard deviation 0.15. We make the inefficiency term u correlated with one of the Harris measures of market access by using the formula by Wang and Schmidt (2002), specifically:

$$\gamma_i + u_{it} = \rho z_{kit} + w_{it}\sqrt{1-\rho^2} \tag{6}$$

where ρ is the correlation coefficient and w_{it} is a random number drawn from the uniform distribution over the interval [0.5,1]. We use 100 draws for each of the following correlation coefficients: 0; 0.2; 0.4; 0.6; 0.8. We then compute the pseudo-outputs, perturbing $\hat{\phi}_{it} + \hat{\boldsymbol{\delta}}'\boldsymbol{z}_{it}$ by the randomly drawn composite error term.

We compute problem (4) 500 times with the artificial data generated in Step 2. Then, we compute mean squared errors for the estimates of frontier $f(\mathbf{x}_{it})$ and the aggregate impact of market access $\boldsymbol{\delta}'\boldsymbol{z}_{it}$.

The results of the Monte Carlo exercise are presented in Table 1, which shows how the Mean Squared Error (MSE) of the estimated frontier and the market access impact develop as the correlation of the Harris measure and the error term gradually increases from zero up to 0.8. We see that the MSE of the market access increases due to the endogeneity bias. However, the MSE of the nonparametric frontier does not notably change. This confirms our a priori expectation about the insensitivity of the non-parametric production function to endogenous contextual variables.

Data

Content of the dataset

We analyze impacts of market access on intertemporal efficiencies of the 8 largest container ports in Norway; cf. Fig. 1. The five ports located on the east coast all belong to the Oslo fjord region, which is the most populated area in Norway. The three western ports, on the other hand, are not co-localized. In addition to the ports assessed in our investigation, smaller container ports in Norway and international ports in neighboring countries play a role in Norwegian container shipments. In particular, the port of Gothenburg in Sweden is important for shipment of goods to Norway with large freight volumes, inter alia due its strategic location and economics of scale and scope.

Fig. 1 Ports in southern Norway

Overall, access to markets is expected to be poorer in Western Norway compared to Eastern Norway.

Our sample consists of quarterly data per port from 2010 to 2016. Input and output variables are based on the dataset used in Rødseth et al. (2020), which has been extended with an additional year of data. We refer to this publication for details about the collection and cleaning of these data. Our production function specification includes one output (container throughput) and four input variables (i.e. quay length; port area; quay cranes; and cargo handling machines). We consider this a standard technology specification within the container terminal operations literature (e.g. Roy et al. 2020). Input variables are gathered from each of the ports under consideration, while container throughputs are obtained by processing source data of Statistic Norway's quarterly port statistic. We refer to Odeck and Schøyen (2020) for details about the classification and aggregation of cargo handling machines.

In this study, we have appended 5 new variables to the dataset:

Harris hinterland market potential measures onshore access to markets. As economic mass we apply hinterland employment by workplace and residence. Both variables are collected from Statistics Norway at zip code level. We measure friction by travel time. Note that previous studies do not find any indications of reverse causality of productivity from Norwegian road construction (Eliasson et al. 2015; Holmen 2022b).

Harris foreland market potential measures capability to reach foreign markets. As economic mass we apply trade volumes in twenty-foot equivalent units (TEUs) of foreign countries, obtained from UNCTAD port statistics. For each country, the largest trade partner port for Norway is used to proxy port location. Traveling frictions are measured by sea-distances between Norwegian and foreign ports. These data are obtained from *seadistances.org* and *classic.searoutes.com*.

Port LSCI builds on the ideas of Jia et al. (2017) and uses Statistics Norway's quarterly port statistics to derive connectivity indicators: (1) Number of distinct ships; (2) Total ship capacities in Gross Tonnage; (3) Maximal vessel size in Gross Tonnage; (4) Number of distinct flag states; and (5) Number of distinct ships with origin or destination abroad. We use the same weighting scheme as the original LSCI to aggregate the individual indices into a foreland market access score that ranges between 0 and 100, where 100 means that the port under consideration exhibits maximal foreland market access compared to the other ports in the sample.

Table 2 Summary statistics

Variables (per port per quarter level)	Obs	Mean	SD	Min	Max
Quay length (m)	224	417.8	228.2	140.0	875.0
Port area (1000 m^2)	224	64.9	37.7	10.0	140.0
Quay cranes (no)	224	2.0	1.1	0.0	4.0
Cargo handling machines (no)	224	6.2	6.0	2.0	24.0
Containers (TEUs)	224	16,610.1	13,612.0	1,009.0	57,751.0
Harris foreland measure	224	16.2	2.2	10.0	21.0
Harris hinterland measure	224	52.0	77.3	6.2	253.7
LSCI	224	67.0	25.1	7.0	100.0
Direct centrality, countries (no)	224	5.0	2.5	1.0	14.0
Direct centrality, ports (no)	224	13.9	7.3	1.0	32.0

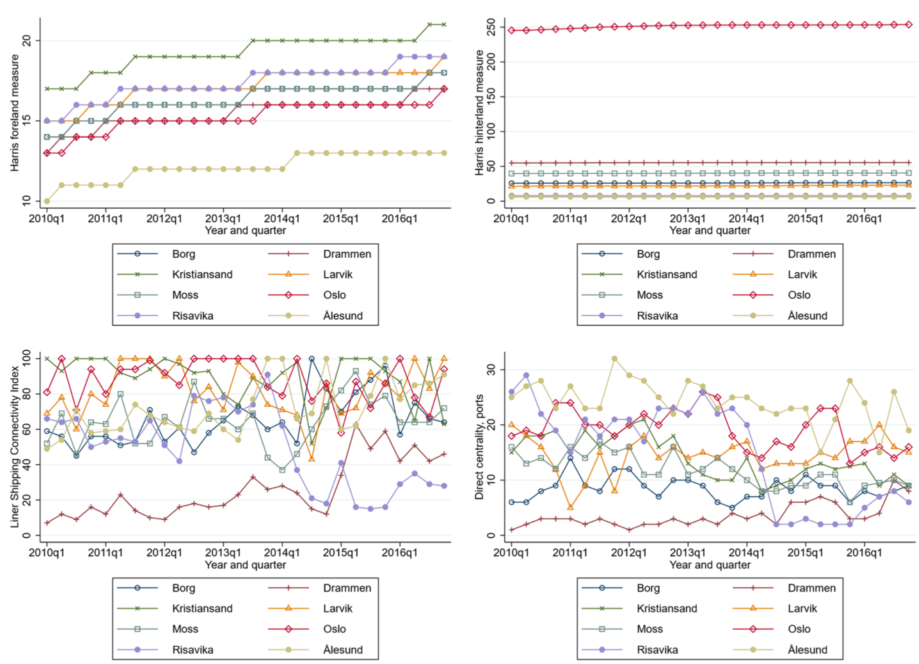

Fig. 2 Foreland and hinterland market access indicators

Two measures of direct centrality are derived based on Statistics Norway's quarterly port statistics: The distinct numbers of foreign port and country destinations per port and quarter.

Descriptive statistics

Summary statistics of the variables in the dataset are provided by Table 2.

Visualization of the intertemporal development of the market access indicators is presented by Fig. 2. The latter shows that market potential (i.e., Harris measures) is more persistent than actual trade flows.

Results

Regression analysis

Using the estimation algorithm outlined in the "Estimation" section, we estimate in total 16 different models, each distinguished regarding the following attributes:

Contextual variables (1) Base specification without contextual variables (applied as benchmark); (2) Harris measures; (3) LSCI; and (4) Direct centrality.

Unobservable intertemporal variations (1) Base specification without time controls; (2) Alternative specification with time trend and quarter dummies

Estimator (1) Standard OLS or IV estimators; (2) Panel data or panel data IV estimators

In the following, we label models without controls for unobservable intertemporal variations M1, while model specifications that include trend and quarter dummies are labeled M2.

First, we choose panel data estimator for implementing Step 2 of the efficiency estimation algorithms established in the "Estimation" section. We implement Hausman's (1978) specification test for all empirical models. Based thereon, we focus on the RE estimator, which we compare to conventional OLS or IV regression in the cases of endogenous market access measures.

Parameter estimates of contextual variables are reported by Table 3. Overall, it paints a positive picture of the impacts of market access measures on port efficiency. In some cases, the Harris foreland measure parameters are negative, but this can in part be explained by the inclusion of a time trend in the model. Figure 2 illustrates that the Harris foreland measure exhibits a strong and comparable growth trend for all ports, which makes it difficult to separate the effect of this measure from unobservable intertemporal variation.

The Harris hinterland measure is the only contextual variable that is robust to changes in model specification. The Harris foreland measure, LSCI, and direct centrality measures are statistically insignificant when individual heterogeneity, time trend, and quarter dummies are controlled for.

Efficiency scores

As outlined in the "Theoretical model" section, we estimate two sets of efficiency scores; i.e., for both the 3C and 4C efficiency models. In both cases, overall efficiency

Table 3 Results of regression analyses (Step 2 of efficiency estimation algorithm)

	Harris measures				LSCI				Direct centrality (DC)			
	OLS	**RE**	**OLS**	**RE**	**IV**	**IV-RE**	**IV**	**IV-RE**	**IV**	**IV-RE**	**IV**	**IV-RE**
Harris fl	−0.030***	0.036**	−0.050***	−0.025								
	(0.010)	(0.015)	(0.011)	(0.030)								
Harris hl	0.002***	0.003**	0.002***	0.002**								
	(0.000)	(0.001)	(0.000)	(0.001)								
LSCI					0.015***	0.027**	0.014***	0.014				
					(0.005)	(0.013)	(0.005)	(0.017)				
DC, country									0.105***	0.231	0.085***	0.119
									(0.022)	(0.254)	(0.025)	(0.312)
DC, port									0.037***	−0.066	0.062***	0.014
									(0.011)	(0.045)	(0.015)	(0.127)
Trend			0.012***	0.009**			0.004	0.004			0.022***	0.013
			(0.003)	(0.004)			(0.004)	(0.004)			(0.006)	(0.020)
q2			−0.031	−0.032			−0.068	−0.068			0.009	0.004
			(0.058)	(0.046)			(0.086)	(0.067)			(0.108)	(0.083)
q3			0.043	0.039			0.021	0.021			0.070	0.062
			(0.058)	(0.047)			(0.086)	(0.056)			(0.108)	(0.068)
q4			−0.002	−0.006			−0.072	−0.074			0.021	0.017
			(0.059)	(0.047)			(0.089)	(0.091)			(0.109)	(0.070)
α	−8.544***	−9.620***	−8.395***	−8.748***	−9.933***	−10.687***	−9.855***	−9.877***	−9.945***	−9.163***	−10.546***	−9.923***
	(0.166)	(0.272)	(0.166)	(0.460)	(0.316)	(0.879)	(0.298)	(1.048)	(0.179)	(0.759)	(0.300)	(1.423)
N	224	224	224	224	224	224	224	224	224	224	224	224

Standard errors in parentheses. Significance level: *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$

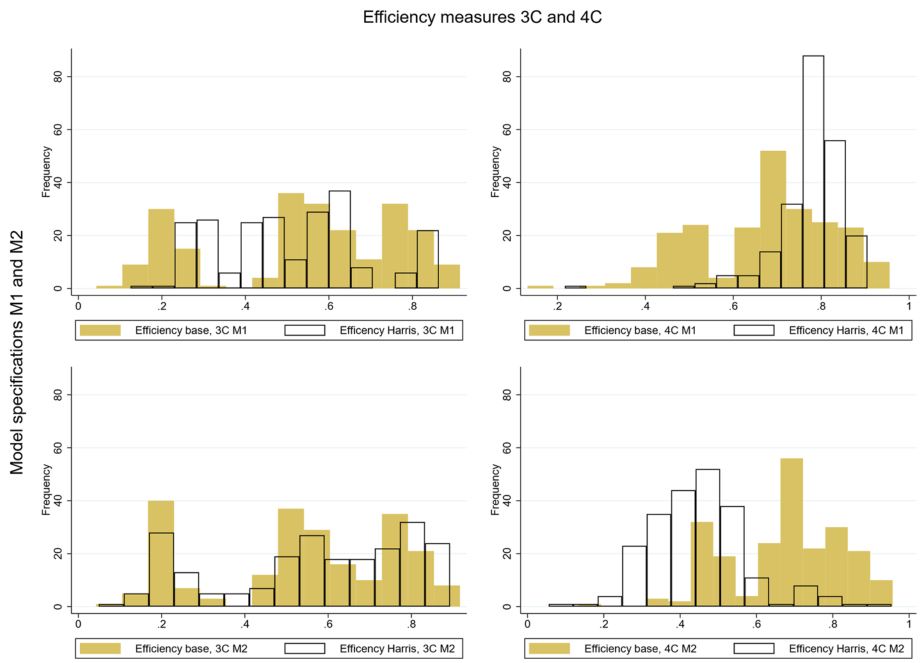

Fig. 3 Efficiency score distributions for base and Harris measure model specifications with (M2) and without (M1) controls for unobservable intertemporal variations and efficiency measures 3C and 4C

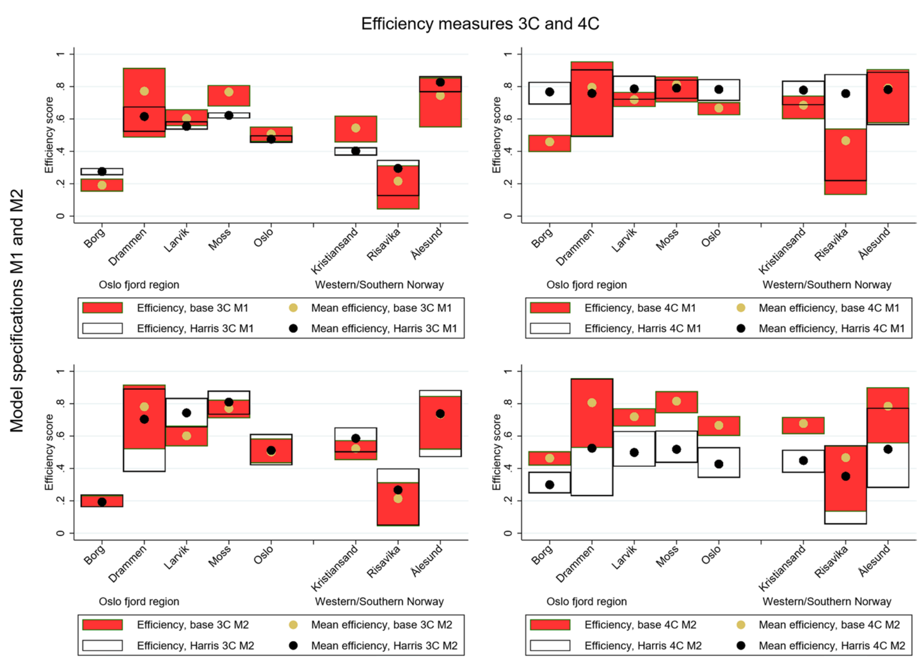

Fig. 4 Mean efficiencies and distributions per port for base and Harris measure model specifications with (M2) and without (M1) controls for unobservable intertemporal variations and efficiency measures 3C and 4C

comprises a persistent and time-varying component, while the latter also accounts for port heterogeneity.

Figure 3 illustrates that how efficiency is measured can impact the conclusion as to whether market access impacts port efficiency: For 3C, port efficiencies are slightly improved when including Harris measures into the model specification. For 4C, port efficiencies substantially improve relative to the base model when including Harris measures in specification M1. Yet, it deteriorates when including Harris measures in specification M2. This prevents us from drawing robust conclusions regarding how efficiency scores are affected by market access.

Figure 4 visualizes the means and distributions of efficiency scores per port for the base and Harris measure models. Considering the base specification, Borg and Risavika are found to be the most inefficient ports in the sample. For efficiency measure 4C,

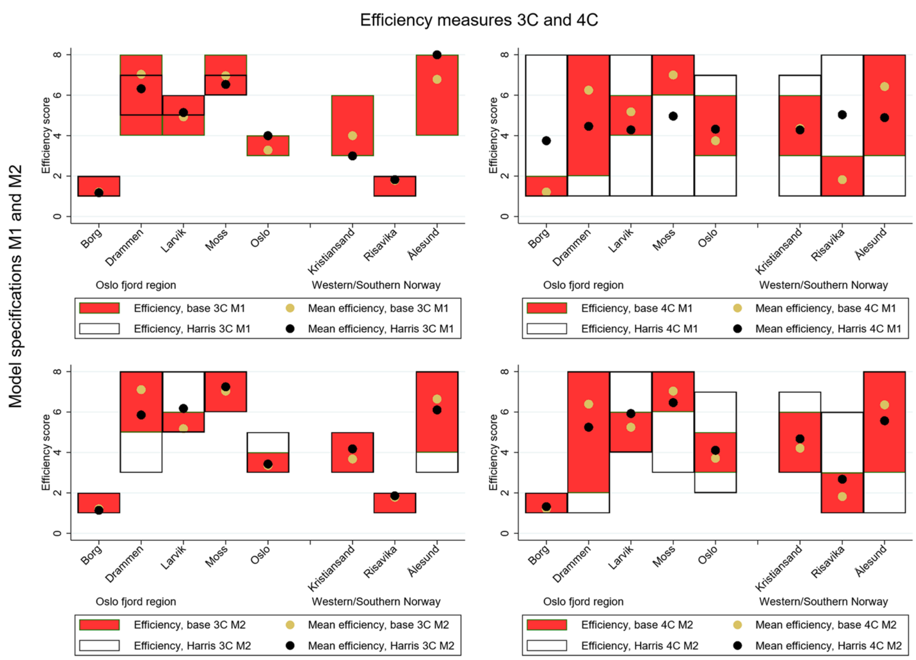

Fig. 5 Means and distributions of rankings per port for Harris measure model specifications with (M2) and without (M1) controls for unobservable intertemporal variations and efficiency measures 3C and 4C

Table 4 Kendall rank correlation

	Base model			
	3C M1	4C M1	3C M2	4C M2
Harris measure model				
3C M1	0.828			
4C M1		0.374		
3C M2			0.839	
4C M2				0.781

their efficiencies become more comparable to those of other ports when controlling for market access. Changes in efficiencies due to controlling for market access are less pronounced for the 3C measure, with notable exceptions of Moss and Kristiansand (efficiency deterioration) in M1 and Larvik (efficiency improvement) in M2. Note also that intra-port variations in efficiency are substantially reduced compared to the base model when incorporating market access measures in 3C M1.

It is noteworthy that Ålesund is among the best performing ports in the sample, despite being in Western Norway and thus subject to weaker hinterland market access than Eastern ports. Hence, market access may not be among the principle drivers of port efficiency.

We test whether the distributions of the base and Harris measure specifications are statistically different using the non-parametric Kolmogorov–Smirnov test. Except for the Harris measure under model M2 and efficiency model 3C, all efficiency score distributions calculated when including market access measures are found to be statistically significant from the efficiency score distributions of their corresponding base specifications.

We further consider whether the inclusion of market access indicators affects the ranking of ports. We study this both by calculating the ranking per quarter for the base and Harris measure model specifications (cf. Fig. 5) and by computing Kendall's rank correlation for the base and Harris measure model specifications (cf. Table 4). The latter takes

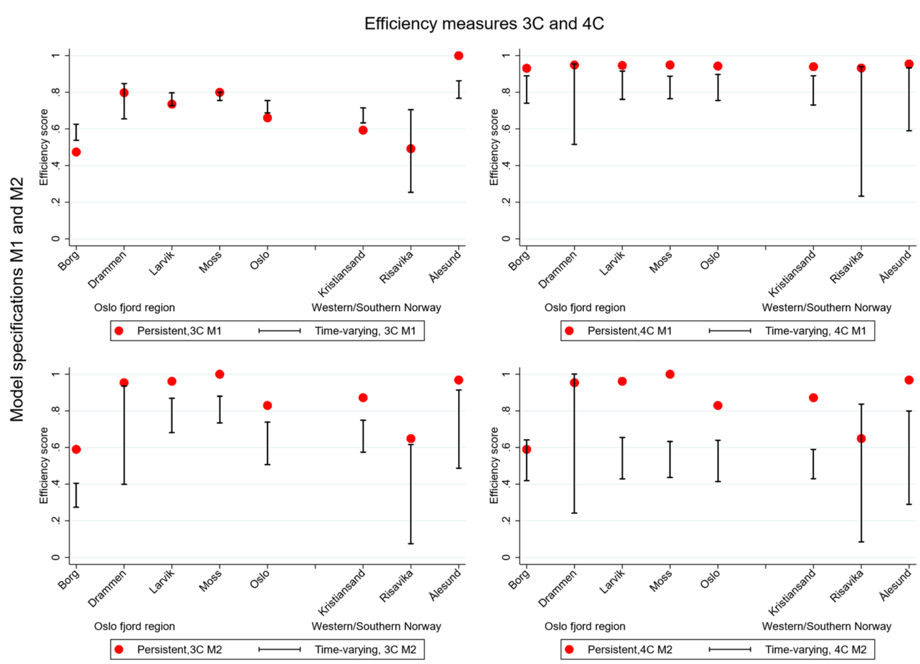

Fig. 6 Persistent and overall efficiencies (ranges) per port for Harris measure model specifications with (M2) and without (M1) controls for unobservable intertemporal variations and efficiency measures 3C and 4C

values between -1 and 1, where 1 indicates that the ranking of ports is identical across base and Harris measure models. We find that the rank correlations are high, except in the case of 4C M1. As shown by Fig. 5, introducing market access measures into this specification leads to much more volatile rankings than in the base model specification. This is also true for specification 4C M2.

Finally, Fig. 6 focuses on the decomposition of overall efficiencies into persistent and overall efficiencies. It shows that time-varying efficiency exhibits substantial intra-port variation for the period under consideration. It is also the main driver of inefficiency. This may be related to intertemporal variations in demand for maritime transport.

Robustness testing

In this sub-section, we implement robustness checks to evaluate if port size matters for the effect of market access on port efficiency. The motivation for doing this is because we estimate the port production function under constant returns to scale, which implies that efficiency scores might disentangle technical and scale efficiencies.

We implement the robustness check by classifying the ports into *large* (i.e., the Port of Oslo) and *small* ports[3] (i.e., the other ports), and to evaluate the interaction effect among the Harris fore- and hinterland measures and a port size dummy that takes the value 1 if Oslo, and 0 otherwise. The interaction effect offers statistical testing of the hypothesis that market access influences efficiencies of large and small Norwegian container ports asymmetrically.

Table 5 Results of robustness tests

	Harris measures			
	Orig	**Rob. test**	**Orig**	**Rob. test**
Harris fl	− 0.030***	− 0.029***	− 0.050***	− 0.048***
	(0.010)	(0.010)	(0.011)	(0.010)
Harris hl	0.002***	0.006***	0.002***	0.005***
	(0.000)	(0.001)	(0.000)	(0.001)
Size effect fl		0.004		− 0.087
		(0.074)		(0.075)
Size effect hl		− 0.003		0.002
		(0.005)		(0.005)
Other controls[a]	No	No	Yes	Yes
N	224	224	224	224

Orig. refers to models without port size interaction effects, while Rob. test refers to models with port size interaction effects. Standard errors in parentheses. Significance levels: *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$

[a] Other controls here refer to time trend and quarter dummies

[3] While the other ports are relative comparable in terms of throughput volume and handle on average between 6000 and 15,000 containers per quarter, the port of Oslo handles on average about 50,000 containers per quarter.

The results of this investigation is summarized by Table 5, which showcases that the effect of port size on efficiency effects of market access is negligible. The second and fourth columns of this table reproduce the original estimates from Table 3 for comparison, while the third and fifth columns present the robustness checks. The interaction effects (dubbed *Size effect fl* in the case of foreland and *Size effect hl* in the case of hinterland market access) are found statistically insignificant for both model specifications considered. The first-order effects of foreland and hinterland market access are also largely invariant to the inclusion of port size interaction effects, especially for the foreland market access measure.

Conclusions

In this paper, we investigate whether market access promotes container port productivity. Despite comprehensive investigations into this matter, unambiguous conclusions cannot be drawn from this study. Among others, selection of model specification and efficiency measure are shown to affect the results.

In our regression analyses with various market access controls, we find that hinterland market access has a significant positive correlation with port efficiency. However, our comparisons of models computed with and without market access indicators show that incorporating them may cause efficiencies to deteriorate as well as improve. Moreover, our findings robustly show that Ålesund—located in the more remote Western parts of Norway—is among the most productive ports in the sample. Kendall's correlation further shows that efficiency ranking of ports is only slightly affected by the inclusion of market access indicators for most of the model specifications considered. In contrast to the positive results of Tovar and Wall (2022), our comprehensive assessment suggests that the role of market access in determining port efficiency is uncertain. From a benefit–cost perspective, direct support to promote port productivity—e.g., by labor and management training or subsidizing investments in handling equipment—appears as a more economically sound approach to strengthen the position of maritime transports.

We stress that our results only apply to the Norwegian container ports under scrutiny, which are small and medium-sized ports that solely serve feeder vessels. Different conclusions could be obtained for a dataset comprising large international container ports. We leave this as a promising avenue for further research. We also encourage future research to explore more complex measures of market access and key external impacts that influence seaport performance, as highlighted by Rodrigue (2020). After all, port development and logistical routes are processes that lasts not only years, but decades of time, with various influences from trends and changes in economic and political environments.

Appendix: review of market access indicators and other variables in port efficiency studies

Table 6 provides a review of port efficiency studies, including their activity measures, connectivity and market access measures, measures for regionalization and competition, and other controls. The table relates to the literature reviews on market access indicators

Table 6 Review use of market access indicators and other variables in port efficiency studies

Study	Activity measures	Connectivity and market access measures	Regionalization and competition	Other controls
Bergantino and Musso (2011)	Regional GDP, employment and population, EU average (NUTS 3)	Access to main rail network (dummy)		
Bergantino et al. (2013)	Regional GDP, employment and population, EU average (NUTS 3)	Access to main rail network (dummy)		
Chang et al. (2018)	GDP of city closest to the port			Financial crisis; TEUs; emission control dummy
Chen et al. (2018)	National economic growth rate	Liner shipping connectivity index		Region
Cheon (2009)	Harris market potential (country GDP)			
Coto-Millán et al. (2016)	Percentage of foreign trade and regional GDP; Percentage of domestic trade within national GDP			Regulatory reforms (dummies)
de Oliveira and Cariou (2015)	Port city population	Liner shipping connectivity index	Herfindahl–Hirschman Index (distance-based)	Hub/gateway (dummy)
Ding et al. (2015)	Number of workers with bachelor's degree or higher	Number of shipping routes	Number of terminal operators	Domestic shipping lines; Registered capital
Ferreira et al. (2018)	Regional GDP per capita	European region dummy; Water depth		Port management model; Performance indicators
Gutiérrez et al. (2015)		Number of shipping companies; Number of shipping lines	Cluster (dummy)	Main port (dummy)
Huang et al. (2018)	Port city GDP; Proportion of middle and senior professionals	Number of routes; Berth depth; Hinterland traffic density		
Liu (1995)			Region dummy	Size dummy; Owner ship type dummies; Capital intensity
Niavis and Tsekeris (2012)	Per capita regional GDP; Regional population	Distance to Suez		Port area; Operator type (public/private)
Pérez et al. (2016)		Location dummy	Number of terminals per port (dummy)	Transshipment port dummy
Polyzos and Niavis (2013)	Port city population	Distance to main route Suez-Gibraltar		Port area

Table 6 (continued)

Study	Activity measures	Connectivity and market access measures	Regionalization and competition	Other controls
Schøyen et al. (2018)		Ice season dummy		Port authority type; service quality indicators (customs; logistics quality; infrastructure)
Serebrisky et al. (2016)	Per capita country income; country GDP	Liner shipping connectivity index; trade openness index		Landlord dummy; port specialization dummy; corruption index
Song and Liu (2019)	Regional per capita GDP; regional total fixed asset; FDI share of regional GDP; regional population density	Regional internet access (user share of regional population)		Freight milage divided by network size
Suárez-Alemán et al. (2016)	Country GDP growth	Liner shipping connectivity index; trade openness index; direct rail links		Transshipment port dummy; ship crane dummy
Tovar and Wall (2022)		Port liner shipping connectivity index		Output concentration; relative specialization
Wan et al. (2014)	Population within 250-miles from port	Number of class 1 railroad connections; On-dock rail facility; Metropolitan road congestion index	Number of operators; port scale of operation	
Wanke (2013)		Number of highway accesses; number of accessing channels; rivereine access dummy; railroad access dummy		Hinterland area; Administration type; cargo type dummy
Wanke and Barros (2015)		Number of highway accesses; number of accessing channels; rivereine access dummy; railroad access dummy		Hinterland area; Public private partnership dummy; cargo type dummy
Yan et al. (2009)	Country GDP; imports and exports	Water depth; number of liners calling	Number of operators and terminals	Port group; continental distribution
Yuen et al. (2013)	Region GDP within 500 km from port; average wage; population within 500 km from port	Distance to the nearest port; number of terminal operators at the city		Chinese ownership share
Ziran et al. (2017)	Total import and export; city GDP	Port city area; length of main arteries		Financial level; information level; industrialization level (indicators)

in the "Market access indicators" section and on contextual factors in the "Use of Market access indicators in port efficiency studies" section.

Abbreviations

AIS	Automatic Identification System
DEA	Data envelopment analysis
DC	Direct centrality
FE	Fixed effects
GAMS	General Algebraic Modelling System
GDP	Gross domestic product
HMP_i	Harris market potential of port i
IV	Instrumental variable
LSCI	Liner shipping connectivity index
M1	Efficiency score distributions without controls for unobservable intertemporal variations
M2	Efficiency score distributions with controls for unobservable intertemporal variations
OLS	Ordinary least squares
RE	Random effects
SFA	Stochastic Frontier Analysis
StoNEZD	Stochastic semi-Nonparametric Envelopment of Z variables Data
TEU	Twenty-foot equivalent unit
UNCTAD	United Nations Conference on Trade and Development
3C	3 Components model
4C	4 Components model

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Author contributions
KLR and RBH were primarily responsible for the research design, conceptualization, implementation of analysis and the initial writing of the manuscript. TK made substantial contributions to the conception and selections and application of method and analytical tool. KLR, RBH and HS performed the review of the literature on integration of a container port in the maritime transport network and performed the data gathering process by identifying and collecting data from primary and secondary data source. All authors contributed to interpreting the results and developing implications and conclusions. All authors read and approved the final manuscript.

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Availability of data and materials
The datasets generated and analysed during the study are not publicly available due to restrictions from Statistics Norway. The code is provided in the appendix. The dataset is available from the authors upon request.

Declarations

Competing interests
Authors declare having no financial and non-financial competing or conflict of interest.

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