Assessing the relative efficiency and productivity of Norwegian Seaport: A stochastic frontier Approach

James Odeck[1,2]* , Halvor Schøyen[3]

[1]Molde University College, P.O. Box 2110, NO-6402, Molde, Norway
[2] Norwegian University of Science and Technology, 7491 Trondheim, Norway

E-mail address: james.odeck@vegvesen.no

[3]Vestfold University College, P.O. Box 2243, NO-3103 Tønsberg, Norway

E-mail address: hs@hive.no

Abstract

This paper explores the efficiency, productivity and convergences/divergences in productivities among Norwegian seaports as compared to Nordic and UK seaports in the period 2002-2008. The rationale for the study is that seaports are constantly under pressure to improve their performances and, the decision makers and seaport managers need to know how seaports are performing relative to each other. The approach used is the econometric stochastic frontier analysis (SFA) to analyze efficiency and its subsequent Malmquist productivity index (MPI) to analyze productivity growth. Beta (β)- and Sigma(σ)-convergences are then used to infer the degrees of convergences or divergences in productivities. The data used includes Norwegian seaports and their comparable seaports in the Nordic countries and the UK. The results attests that: (1) the potential for efficiency improvement is large at about 20% on average, (2) there has been a total productivity regress of about 12%, (3) the productivity regress observed has been due to a regress in technical change at about 12% while efficiency change has remained unchanged and, (4) there is a strong indication of convergences among seaports with respect to productivities suggesting that seaports with initially lower indices progress faster than those with initially higher productivity indices. A major conclusion is that the Norwegian seaports perform as well as their international peers in the Nordic countries and the UK, and that over the years the productivity of seaports has converged even though productivities on average are a regress.

Keywords: Seaports; Convergences; Efficiency and Productivity; Stochastic Frontier Analysis (SFA).

* Corresponding author. Email: james.odeck@vegvesen.no

1. Introduction

The international literature on the performance of seaports has in the last decade recognized the importance of seaports' efficiency for a well-functioning supply chain and transportation systems in countries; see, for instance, UNTCAD (2008). Seaports are a vital link in the overall trading chain and consequently, seaports are an important contributor to any nation's international competiveness and the supply of transportation services. The contribution of seaport to international competitiveness has increased tremendously over the last decade irrespective of countries; see for instance Hung, Lu and Wang (2010). To attest this assertion in the Norwegian case, in the period 2002-2008 container flows over the Norwegian ports increased by a formidable 23%. Elsewhere apart from the case of Norway, these trends have led transportation and logistics scholars question whether seaports are as efficient as they should be i.e., whether there are potentials for efficiency improvements and whether seaports improve in productivities measured as a change in efficiency from one year to the other. Scholars have attempted to address this question by using frontier approaches to technical efficiency (TE) measurement where seaports are compared against each other as measured by the distance to a given frontier. The underlying rationale for this type of comparison is that poorly performing seaports can learn from their peers or best performers in order to increase efficiency and thereby improve supply chain and transport systems, which in turn increases seaport efficiency and productivity. Unfortunately, efficiency and productivity assessment of Norwegian seaports has not been forthcoming in the literature so we do not get to know how the Norwegian seaports perform relative to each and how they progress in productivities from one year to the other. Whilst, efficiency measurement reveals the best performers from which under-performers can learn from, productivity measurement has the additional advantage of identifying which components of productivity lead to progress or regress e.g., technical change and/or efficiency change refers to how seaports improve their efficiency from one year to the other while technological catch-up or change refers to how seaports are able to be technologically innovative in order to catch-up with the frontier and hence, be productive from one year to other. A third shortcoming in the literature of seaports irrespective of the case of Norway is that there is no study that has dealt with the issue of convergence or divergence in terms of productivity in the seaport industry. Convergence occurs if seaports that initially had lower efficiencies/productivities tend to increase their efficiencies/productivities at faster rates than seaports that were initially strong performers. If the opposite is true, that is, weak performers remain weak while strong performers increase their efficiencies/productivities; it would imply a divergence in performances. Using economic reasoning to explain convergence/divergence, seaports with low initial achievements have the potential to grow in efficiencies and productivities at a faster rate than seaports with initially high efficiencies and productivities because diminishing returns are not as strong as in those seaports that were initially high performers.

The aim of this paper is to explore the above discussed shortcomings in the literature of seaport efficiency. In particular, the paper investigates the following three issues: (1) the efficiency of Norwegian seaports as compared to other comparable seaports in the Nordic countries and the UK, (2) the productivity of Norwegian seaports as compared other comparable seaports in the Nordic countries and the UK and, (3) the existence of convergence/divergence with respect to productivity in the seaport industry and the roles that efficiency and technological catch-up plays in that respect. The data used are for the seaport production period 2002-2008. One particular issue to be noted in this analysis is that the original aim was to assess the efficiency and productivity of Norwegian seaports among themselves. However, because there are too few Norwegian seaports in total, the inclusion of comparable seaports in the Nordic countries and in the UK is to increase the discriminatory power in the analysis. The inclusion of other comparable international seaports has an additional advantage; it enables the comparison of the performance of Norwegian seaports relative to other international comparable seaports. The approach used to analyze efficiency of seaports is the stochastic frontier analysis (SFA) and its extension to Malmquist Productivity Indices (MPI) to analyze productivity. To analyze convergences/divergences in productivities, the well-known Beta (β)- and Sigma(σ)- convergences are used.

The rest of the paper is organized as follows. Section 2 provides a brief literature review, Section 3 describes the data and Section 4 briefly describes the methodology. The empirical results are presented in Section 5, and Section 6 provides concluding remarks.

2. Literature review

There are several studies that have addressed efficiency of seaports or container ports and terminals in the literature. There are basically two approaches to the estimation of efficiency frontier that have been used by authors; the stochastic frontier analysis (SFA) and the data envelopment analysis (DEA). The latter approach has gained popularity among scholars in the recent decades. The most thorough review and critical analysis of the major studies within seaport industry that have employed the DEA is found in Panayides et al. (2009). They highlighted some problems and limitations in the application of the DEA technique in the seaport context, particularly with respect to the specification of parameters, the sampling domain and the type of DEA to be applied. Concerning SFA, there is no particular literature that has thoroughly reviewed its applications in the seaport industry; although several authors have applied it in the seaport industry, see for instance Barros (2005); Coto-Millan et al. (2000); Cullinane et al. (2002); Cullinane and Song (2003); Estache et al. (2002); Liu (1995); Notteboom et al. (2000); Trujillo and Tovar (2007).

Rather than providing an account of individual studies that used frontier techniques i.e., DEA or SFA to assess efficiency, a compact way of summarizing the literature is through a table that indicates the authors, year of publication, method used and other relevant variables. From such a table, general and relevant observations from the literature can be made. Table 1 presents such a table where publications on seaport efficiency measurements were located through searches in several databases such as Ingenta, Science Direct, Routledge, Inderscience, and the Social Science Citation Index.

[INSERT TABLE 1]

Numerous observations can be made with respect to Table 1. First, it includes a total of 40 studies, where 29 and 11 used the DEA and the SFA approaches, respectively. This confirms the observation in many previous studies that the DEA is the most popular and most frequently used approach to efficiency measurement in the container port industry; see for instance Panayides et al. (2009). Secondly, the publication year of the studies indicate that DEA studies seem to be more current than the SFA studies, which confirms the recent popularity of DEA. In addition, cross-sectional data seems to be more frequently used in comparison to panel data, irrespective of the method used. Following this, the data used in the DEA cases are more recent than those used in the SFA cases. On average, the number of observations used does not seem to differ between the DEA and the SFA approaches, whereas the average efficiency scores are at 90 and 87 for DEA and SFA, respectively; indicating that the average DEA efficiency scores are higher than the SFA average scores. It is also observed that most of the published studies used data from Europe and Asia or both. The general conclusion that can be drawn from our review of the literature is that the DEA is the most popular approach, is more recent in applications across studies and produces higher efficiency scores in comparison to the SFA. However, there are two more observations from the literature: (1) The efficiency of Norwegian seaports have not been considered adequately, (2) few studies has considered the notion of productivity in the seaport industry and, (3) no study in the literature has considered convergence/divergence in productivities among seaports. This paper is thus a contribution to the literature in these respects.

3. Methodology

As shown in the literature above, there are basically two approaches to the measurement of efficiency that are commonly used in the literature of seaports; the Data Envelopment Analysis (DEA) and the Stochastic Frontier Analysis (SFA). These approaches are similar in the sense that they can both be used to evaluate efficiency of seaports from given frontier, but are dissimilar in the sense that the frontier from which efficiencies are measured are constructed differently. They both have advantages and disadvantages that have been exposed in the literature; see for instance O'Neill et al. (2008). Of these two approaches, we have chosen to use SFA because we need to explore elasticities and the inefficiency factors (noise) that impact ports' performance and these are better tackled by econometric approaches such as SFA (as compared to ones like DEA)[1]. Below, we briefly describe SFA and its connection to the Malmquist Productivty Indices (MPI).

Stochastic frontier approach (SFA)

The technology of port i in time period t used for producing output can be represented econometrically by the following general stochastic frontier function:

$$y_{it} = f(x_{it};\beta)e^{(\xi_{it}-\zeta_{it})}, \quad u_{it} = \xi_{it} - \zeta_{it} \; \textit{and} \; i = 1,2,3...,n . \qquad (1)$$

[1] We are aware that DEA has recently been developed to tackle noise by combining it with bootstrapping to ascertain confidence intervals; see for instance Simar and Wilson (2007). However, ascertaining production elasticities adequately still presents a problem.

where y_{it} denotes the output (e.g., container throughput) of the ith port; x_{it} represents the $(1 \times K)$ vector of the inputs (e.g., capital and labour); β is a $(K \times 1)$ vector of unknown parameters to be estimated; ξ_{it} is the systematic random error that accounts for measurement error and other factors not directly under the control of the port's management, e.g., the region or a country; and ζ_{it} is the asymmetric random that accounts for the non-negative random error component and measures technical inefficiency effects. In order to estimate u_{it}, one needs o impose a distribution form (e.g., half normal, truncated-normal, or gamma) on the asymmetric random component. We assume the truncated-normal distribution because it is the most frequently used in empirical applications and also because it is the one assumed in Coelli (1996), the software used in this paper. Thus, the systematic error variables ξ_{it} are assumed to be independently and identically distributed with mean zero and variance σ_{ξ}^{2}. The non-negative variables ζ_{it} are assumed to be independently and identically distributed truncations (at zero from below) the $N(\mu, \sigma_{\zeta}^{2})$ distribution. Furthermore, ξ_{it} and ζ_{it} are assumed to be independent of each other and also independent of the input vector x. The model without the technical inefficiency affects ζ_{it} results in an average frontier model. The variance parameters of the model are:

$$\sigma_u^2 = \sigma_\xi^2 + \sigma_\zeta^2, \qquad \gamma = \frac{\sigma_\zeta^2}{\sigma_\xi^2} \text{ and } 0 \le \gamma \le 1, \tag{2}$$

where γ is the variance of u.

The technical efficiency of port i can be estimated as:

$$TE_{it} = \frac{y_{it}}{y_{it}^{*}} = \frac{f(x_{it};\beta)e^{(\xi_{it}-\zeta_{it})}}{f(x_{it};\beta)e^{\xi_{it}}} = e^{-\zeta_{it}}, \text{ (i.e., } 0 \le TE \le 1). \quad (3)$$

Equation (3) states that the technical efficiency is in the interval [0, 1], where 1 implies 100 per cent efficiency. Estimates of the port-specific efficiency $e^{\zeta_{it}}$, as expressed in (3), depend upon the decomposition of $u_{it} = \xi_{it} - \zeta_{it}$ and can be derived from the conditional expectation of $e^{\zeta_{it}}$, given u_i. Suppressing time (*t*) and given the probability density functions of both ξ_i and ζ_i, standard integrals yield the measure of technical efficiency as (where Φ is the cumulative distribution function):

$$\begin{aligned} TE &= E[e^{\zeta_i} \mid u_i] \\ &= \left[\frac{1-\Phi\left\{\sigma_{\zeta}^{*} - (\mu_i^{*}/\sigma_{\zeta}^{*})\right\}}{1-\Phi(-\mu_i^{*}/\sigma_{\zeta}^{*})} \right] e^{-\mu_i^{*}+(1/2)\sigma_{i\zeta}^{*2}}, \end{aligned}$$

where (4)

$$\mu_i^{*} \equiv \frac{\mu\sigma_{\xi}^{2} - u_i\sigma_{\zeta}^{*}}{\sigma_{\xi}^{2} + \sigma_{\zeta}^{2}},$$

and

$$\sigma_{i\zeta}^{2} \equiv \frac{\sigma_{\zeta}^{2}\sigma_{\xi}^{2}}{\sigma_{\zeta}^{2} + \sigma_{\xi}^{2}}.$$

From the formulation above, technical inefficiency can be estimated as:

$$1 - E[e^{-\zeta_i} \mid u_i = \xi_i - \zeta_i]. \tag{5}$$

The port-specific efficiency index ($e^{\zeta_{it}}$) can be constructed using the results of equation (5). The mean technical efficiency of countries ($\overline{TE} = E[e^{-\zeta_i}]$) is obtained as:

$$\overline{TE} = \left[\frac{1 - \Phi\{\sigma_\zeta - (\mu / \sigma_\zeta)\}}{1 - \Phi(-\mu / \sigma_\zeta)} \right] e^{-\mu + (1/2)\sigma_\zeta^2}. \tag{6}$$

To incorporate further factors contributing to inefficiency, Coelli et al. (1998) have proposed a model in which the technical efficiency effects (ζ_{it} s) are defined as:

$$\zeta_{it} = Z_{it}\delta + W_{it} \ , \tag{7}$$

where Z_{it} is a vector of the explanatory variables associated with technical inefficiency effects, δ is a vector of unknown parameters to be estimated and the W_{it} are unobservable variables with the properties described.

The maximum likelihood estimates of the parameters of the stochastic frontier model are readily obtained using the computer program FRONTIER, version 4.1 (Coelli, XXX). The hypothesis that technical inefficiency effects are not random is expressed by H_0: $\gamma = 0$, where $\gamma = \sigma^2/\sigma_s^2$. Furthermore, the null hypothesis that the technical inefficiency effects are not influenced by the level of the explanatory variables in equation (1) is expressed by H_0: $\delta' = 0$, where δ' denotes the vector δ with the constant term δ_0 omitted, given that it is included in the expression $Z_{it}\delta$. Note that if $\gamma = 0$, then the model is equal to the traditional average response function that is efficiently estimated using ordinary least squares regression. The test statistic is calculated as:

$$LR = -2\{\ln[L(H_0)] - \ln[L(H_1)]\}, \qquad (8)$$

where L (H_0) and L (H_1) are values of the likelihood functions under the null and alternative hypotheses, H_0 and H_1, respectively. LR stands for likelihood-ratio statistics.

The Malmquist productivity index (MPI)

Next, productivity growth for an individual port from one year to another can be measured using the Malmquist Productivity Index (MPI) as improved efficiency relative to the benchmark frontier (the best performers). The Malmquist index for productivity growth is easily expressed by two adjacent SFA efficiency measures. For port i, the Malmquist index between time periods *t* and *t+1*, based on frontier (best performers) at time *t*, is calculated as:

$$M_t^i = \frac{TE_{t,t+1}^i}{TE_{t,t}^i}. \tag{9}$$

In equation (9), $TE_{t,t}^i$ and $TE_{t,t+1}^i$ are input technical efficiency scores for port *i* that relate observations from period *t* and *t+1*, respectively, to a period *t* technology (the best performer's benchmark). M_i^t measures the input productivity change between period *t* and period *t+1*. Productivity declines if $M_t^i < 1$, remains unchanged if $M_t^i = 1$ and improves if $M_t^i > 1$.

Note that a Malmquist index with a benchmark based on period *t+1* can, similarly, be written as:

$$M_{t+1}^i = \frac{TE_{t+1,t+1}^i}{TE_{t+1,t}^i}. \tag{10}$$

Therefore, to avoid arbitrariness in the choice of base period, Färe et al. (1994) proposed defining the input-output-oriented Malmquist productivity index as a geometric mean of (9) and (10):

$$M^{i} = \left[\frac{TE^{i}_{t,t+1}}{TE^{i}_{t,t}} \cdot \frac{TE^{i}_{t+1,t+1}}{TE^{i}_{t+1,t}} \right]^{0.5} . \qquad (11)$$

Moreover, the Malmquist index above can be divided into two mutually exclusive components that may help in clarifying reasons for efficiency or inefficiency as follows:

$$M^{i} = \frac{TE^{i}_{t+1,t+1}}{TE^{i}_{t,t}} \left[\frac{TE^{i}_{t,t+1}}{TE^{i}_{t+1,t+1}} \cdot \frac{TE^{i}_{t,t}}{TE^{i}_{t+1,t}} \right]^{0.5} = EC^{i} \cdot TC^{i}. \qquad (12)$$

The first component (EC^{i}) is known as the 'efficiency change.' It gives the relative change in efficiency between periods for port i, i.e., how port i has improved in efficiency relative to others on the frontier. The second component (TC^{i}) is known as the 'frontier productivity index or 'frontier shift' and shows the relative distance between the frontiers; essentially, it measures the change in frontiers between two periods. It is therefore sometimes referred to as the technical efficiency change (see Färe et al. ,1994). It follows that if the estimated value of M^{i} is larger (smaller) than 1, this indicates an improvement (deterioration) in productivity. A similar interpretation applies to the decomposed indexes.

Using equation (12), the efficiency change index (MC) for the SFA in two adjacent years, *t* and *s*, is calculated as ${}^{TE_{it}}\!/_{TE_{is}}$ in relation to the efficiency measurements described in equation (1). The technical change index (MF) between period *s* and *t* for a port can be calculated directly from the estimated parameters. One simply evaluates the partial derivatives of the production function with respect to time at a particular data point. It should be noted, however, that a non-neutral technical change may cause the technical change index to vary for different input vectors. Coelli et al. (1998) have suggested that the geometric mean be used to estimate the technical change index between adjacent time periods *s* and *t* as follows:

$$MF = \left\{ \left[1 + \frac{\partial f(x_{is}, s, \beta)}{\partial s} \right] \cdot \left[1 + \frac{\partial f(x_{it}, t, \beta)}{\partial t} \right] \right\}^{0.5}. \qquad (13)$$

Thus, through SFA, the indices for technical and efficiency change obtained are multiplied to obtain the total Malmquist productivity index.

Beta (β) and Sigma(γ) convergence/divergence

The next methodological issue is how to measure convergences or divergences in productivities. Barro and Sala-i-Martin (1995) and Sala-i-Martin (1996) draw a useful distinction between two types of convergence in productivity growth: σ-convergence and β- convergence. When the partial correlation between growth in income over time and its initial level is negative, there is β-convergence. When the dispersion of real per capita income (in our case, productivity) across a group of countries (in our, case ports) falls over time, there is σ-convergence. When any of these two types of convergences occurs, it is an indication that ports that initially were less productive grow faster in terms of productivity growth than those that were initially more productive; hence the term convergence in productivities. Consequently, if the opposite occur it will imply divergence in productivity growth. Intuitively, β-convergence is a necessary but not a sufficient condition for σ-convergence; β convergence does not guarantee the presence of σ convergence.

In this paper we examine the occurrence of β convergence by regressing the annual average growth rate of the Malmquist productivity indices (MPIs) against the natural logarithm of the initial level of the natural logs of the initial MPIs. Therefore, the general testable convergence equation is of the form:

$$g_i = \alpha + \gamma x_{i0} + \varepsilon_i, \qquad (14)$$

where g_i is the growth rate of the MPIs (productivity index, frontier shift index or efficiency change index) level of seaport i over the sample period, x_{i0} is the initial level of the corresponding productivity in the initial year for port i, α and γ are parameters to be estimated, and ε_i is the error term ($\varepsilon_i \approx iid(0, \sigma_\varepsilon^2)$). There is evidence of a process of convergence/divergence if γ is negative/positive, respectively, and statistically significant.

4. The Data

The primary source of data was the Containerization International Yearbook (CIY) and covered the period 2002-2008. The CIY has been referred to in the literature as the most reliable and comprehensive data available (for instance, see Wang and Cullinane (2006)). A primary requirement that guided the selection of all ports included in the study was that a sufficient percentage of all ports had to be Norwegian and that time series data for the period of interest (2002-2008) were available with seemingly reliable data. An advantage of using data from several years is that we can study productivity and Convergence/divergence as intended in the paper. A second requirement, given that there are not so many comparable Norwegian seaports, was that data was available for other comparable seaports in the region, e.g., other Nordic countries and the UK.

The container ports identified in CIY and included in this study were six Norwegian (Oslo, Borg, Moss, Larvik, Ålesund and Kristiansand); three Swedish (Gothenburg, Stockholm and Helsingborg); one Swedish-Danish shared port (Copenhagen/Malmo); three Danish (Århus, Aalborg and Fredricia); five Finnish (Helsinki Kotka, Turku, Raima and Hamina); one Icelandic (Reykjavik); and 5 UK ports (Southhampton, Liverpool, Tilbury, Immingham and Grangemouth). Thus, the data set included 24 container ports to be analyzed. As explained before, the reason for including Nordic and UK seaports in the data set and not just the Norwegian seaports are that (1) it increases the number of observations and thus leads to more reliable results, and; (2) they are gateway container ports and therefore comparable. It must be stressed here that in our data collection process, we compared the CIY data with those found on the websites of ports. Furthermore, we presented the CIY data to each port's administration for confirmation by phone, email and/or at meetings with the managers. The CIY input data for terminal area and equipment appeared to be imprecise, outdated or erroneous in many instances. Lessons learnt from the data collection process are that researchers need to counter-check the data that is derived from CIY or any other sources before use; otherwise, the results may not be unreliable. However, we warn that the CIY still offers the best point of departure concerning operational data and that counter-checking the data against the ports administration is what is required.

Next, the issue of which inputs and outputs to be used was considered.   Based on the literature review, container units (TEU) per port were identified as the appropriate output measure and are the most frequently used; see for instance Wang and Cullinane (2006). Input variables initially selected were berth length, quay cranes, terminal areas, number of yard gantry cranes, straddle carriers and container handling trucks. A preliminary test revealed that the coefficient of correlation between the number of quay cranes and terminal areas was too high at 0.87; hence, the number of quay cranes was excluded as an input variable in the final analysis. The summary statistics of the variables are given are given in Table 2.

[INSERT TABLE 2]

The table shows that there is a great variation in the magnitudes of variables among container ports, which attests to the fact that the data set contains ports of different sizes ranging from small to large.   Furthermore, berth length and terminal areas are both measured in meters. We aggregated these two measures to Berth length per terminal area; it is simply the ratio of berth length to terminal area. Because containers are handled at the berth and in the marshalling yards, this variable measures the degree to which the available ground is utilized. Finally, because there is a large difference between type of cranes at ports where some ports have zero number of a particular crane type, we aggregated all cranes into one input as number of machines (cargo handling machines); this aggregation has been used by other authors in the literature, see e.g., Cullinane et al (2002). This aggregation also solved an estimation problem since taking the log of zero as required in a translog model, is meaningless. Thus, the data set used in this analysis covers 6 periods (or 8 individual years) and contains 24 observations for each period or year and, one output and two inputs. Recall, however that, since we using a translog production function, there will be third input variable which is time.

5. Empirical results

In this section, we present the estimation results according to the objectives of the study described in section 1 and according to the methods described in described in section 3. Consequently, the results are presented in three parts as follows: (i) the results of the frontier estimation, (ii) the efficiency scores, (iii) productivity growth as measured by Malmquist productivity index and its decompositions into efficiency change and technological catch-up and, (iii) Beta and sigma convergence/divergence in productivities.

(i) The frontier estimation results

In the empirical version of the model described in section 3, we assumed a translog specification with a time trend providing the opportunity to characterize it in a more flexible form while assuming time invariant production function[1]as follows:

$$\ln y_{nt} = \kappa_0 + \sum_{i=1}^{k} \kappa_j \ln x_{int} + 0.5\sum_{i=1}^{k}\sum_{j=1}^{k} \kappa_{ij} x_{\text{int}} x_{jnt} + \sum_{i=1}^{k} \tau x_{\text{int}} t + \lambda_1 t + 0.5\lambda_{11} t^2 + \xi_{nt} - \zeta_{nt}, \quad (0)$$
$$n = 1,2...,24; t = 1,2...,8; k = 2,$$

where y_{nt} is the log of container throughput measured in TEU/year; x_{int} is the log of i-th input quantity(number of cargo handling machines and berth length/ terminal area); t is a time trend; ξ_{nt} is the error term that picks up whatever the model cannot explain; ζ_{nt} is the inefficiency term entered with a negative sign because inefficiency means less output; $\kappa_0, \kappa_{ij}, \tau, \lambda_1$ and λ_{11} represents the unknown parameters to estimated. The subscripts n and t index number of seaports and time periods respectively; while the superscript k index the number of input. As is common in this type of model the time trend, t, is used to approximate technical change. In the estimation procedure of this model, every series have been divided by their arithmetic means such that the first order parameters can be interpreted as elasticities. Remembering that the inefficiency term is represented by ζ_{nt}, this was specified as:

$$\zeta_{it} = \psi_0 + \psi_1 Z_{1it} + \psi_2 Z_{2it} + \psi_3 Z_{3it} + \psi_4 Z_{4it} + W_{it} \qquad (0)$$

Where Z_i represents country specific seaport variables i.e., whether the seaport is from Norway, Sweden or UK and whether the seaport is large or small as judged by mean deviation from TEU per year. Thus, there are 4 ψ parameters to be estimated. Equations 14 and 15 were estimated using the program FRONTIER (Coelli, 1996). The maximum likelihood estimates of the model are presented in Table 3.

[INSERT TABLE 3]

The signs of the first order coefficients which are elasticities are positive as expected; however, the elasticity estimate for berth length per terminal area is not significant while that for number of cargo handling machines is. The insignificant elasticity of berth length/ terminal area may be due to the fact that this variable has been historically determined among seaports; hence seaport managements have not been able to adjust it relative to what they produce. The estimated elasticities for machines and time are 0.68 and -0.12, respectively and are highly significant. The former indicates that an increase in the number of machines enhances technical efficiency significantly. The latter indicates that technical efficiency has tended to decrease over the years and significantly over the period 2002- 2008. This is a surprising result given that the model is a time invariant technical efficiency estimated for a period when seaports outputs increased tremendously. The second order coefficient show that this variable is highly significant indicating that technical efficiency, after all, increases for the very large seaports as measured with this variable whereas for the other variables, time included, the results are not significant.

The estimated coefficients in the inefficiency model are of interest in this study since they indicate how Norwegian seaports perform relative to other international and comparable seaports. The *Norway* coefficient is negative, which indicates that the Norwegian seaports are more technical efficient as compared to other; The *Swedish* and the *UK* coefficients indicates the same.

However, the coefficient for UK is the largest followed by the Norwegian and then Swedish; this indicates that the UK seaports performers better than all other seaports followed by the Norwegian seaports.

Next, both σ and γ parameters are both highly significant indicating that technical efficiency are not random and are influenced by the level of the explanatory variables. Generalized likelihood ratio test for the null hypotheses that the inefficiency effects are absent or that they have simpler distribution are presented in Table 4.

[INSERT TABLE 4]

The first null hypothesis, which specifies that the inefficiency effects are absent from the model is strongly rejected; the second hypothesis which specifies that the inefficiency effects are non-stochastic is rejected; the third hypothesis which specifies that there is no technical change is rejected and; the fourth model that specifies that Cobb-Douglas production function with no technical change is a better fit than the translog model used is also rejected at 5% significance level. There are several other tests that could be performed, however, the ones shown in Table 3 is a clear indication that the translog model chosen in this study is the most appropriate for the data set used in this study.

(ii) Efficiency scores

The results of the efficiency scores obtained across the whole period of study and by seaports ports are presented in table 5.

[INSERT TABLE 5]

The results show variations in efficiency scores across all years and across all seaports to the extent that: (1) the mean efficiency scores across all years is between 0.78 and 0.80 implying that the average seaport has the potential of increasing its efficiency by 20 to 22%

which in turn means that there is great potential for efficiency improvement in the seaport industry, (2) the standard variation indicates that there is a great deal of variation in performances among seaport; the distribution reported in the last part of the table show this to be case where only 2 to 3 seaports obtain scores above 0.95 and there is an even distribution for scores in the interval 0.5 to 0.95 and, (3) as observed in the frontier estimation, the UK ports of Liverpool, Tilbury, Immingham and Grangemouth are always on the upper part of the efficiency scale. It is also observed that some ports fluctuated, increased or decreased in efficiency scores over the years e.g., Oslo and Grangemouth while others are fairly stable over the years e.g., Gothenburg. For those that dropped, there are explanations to it. For the case of Oslo, a new Sjursøya Container Terminal (SCT) was opened in 2008. It was planned to replace the Filipstad Container Terminal (FCT). Due to terminal operational challenges, especially with regard to the handling and storage of empty containers, both SCT and FCT were in operation for most of 2008, and the operations at FCT were only terminated at the end of that year. Consequently, this circumstance increased Oslo's operational costs for 2008. Combined with a 3% decrease in annual container throughput from 2007 to 2008, these developments led to a reduction in Oslo's relative efficiency score from 0.83 in 2007 to 0.69 in 2008. Grangemouth container terminal was fully modernised in 2005 - 2006 when new cranes and more and container handling equipment were installed and IT systems were upgraded. That modernization led to increase in input without necessarily increasing output, hence efficiency dropped from about 0.94 to about 0.76.

A question that arises is whether the performance of Norwegian is better or worse than their international peers in the Nordic countries and the UK. We performed statistical tests to address this issue. We tested whether there are any significant differences in the annual efficiency scores between the Norwegian seaports as one group and the others as second group. We used the Mann-Whitney U test, the Kolmogorov-Smirnov test and the Median test to ensure that the results obtained conform to each other. Table 6 depicts the results of the statistical tests performed. The Mann-Whitney U test compares the distributions of the indices for each of the two groups and the Kolmogorov-Smirnov test gauge whether the two groups' underlying probability distributions differ. The null hypothesis in the Mann-Whitney U test and Kolmogorov–Smirnov tests are that the distribution of the mean indices values across the two groups are the same. The null hypothesis in the Median test is that the mean indices across the two port groups are identical. The statistical tests were conducted in SPSS Statistics 20. The test statistics with a high *p*-value across the different tests indicate there is no reason to believe there are differences in the mean efficiency scores between the two groups. The Median test statistics, which is significant just within the 5% level, shows that there are no significant differences in the mean efficiency scores between Norwegian ports and those of other countries in the sample. The Mann-Whitney U test shows that and the Kolmogorov–Smirnov tests are somewhat in contradiction, the mean value between them leads to the conclusion the distribution of the mean efficiency scores across the two groups may be different. Summing up, the mean efficiency scores between the two groups are not different; however the p-values are relatively low.

[INSERT TABLE 6]

(iii) Productivity growth

Next, the Malmquist productivity index as well as its EC and TC components were calculated for each seaport in the sample. The results are shown in Table 7.The tables shows the individual indices for each seaport by each period, averages for each individual seaport across periods, averages across seaports and the frequency distribution of indexes across seaports by each period and according to different levels of indices.

[INSERT TABLE 7]

Recall from section 3 that if the value of the Malmquist index or any of its components is less than 1, it implies regress between two adjacent time periods and if greater than 1 implies progress. To obtain the magnitude of progress/regress, the values are subtracted from 1. Consider first, the means across years and across seaports shown in the middle of the table. For the efficiency change index (EC), there is a fluctuation of indices around 1 and the grand mean across all periods and across seaports is at 1. The same picture emerges when the means of individual seaports across all periods is considered; the progress/regress are relatively small and the indices are around 1. What this means is that seaports have not improved or regressed with respect to efficiency change and this result is independent of which country the seaport belongs to (the Kruskal- Wallis test, the Median test and the Mann-Whitney test all produced insignificant results irrespective of groupings according to countries). Next, consider the technical change index (TC). There is a clear regress at about 12% (i.e. ((1-0.88) x 100)) and this result is also evident when one considers the means of individual seaport where there is a relatively small variation around 0.88. There is more to this observation: (1) the seaports have not been technical innovative in the period studied and the reason may be that technical progress occurred in the periods prior to this when the seaport industry across Europe was deregulated and, (2) the frontier estimation revealed that the technical efficiencies were negatively correlated to time; that correlation captured the technical change effect more as compared to efficiency change because the technical change is the partial derivatives of the production function with respect to time at a particular data point. Finally, consider the Malmquist productivity index (M) which by convention is a multiplication of EC and TC. The grand mean result is not surprising and shows a regress at about 12% indicating that its development is solely explained by regress in technical change since efficiency change index has more or less remained unchanged. Thus, the conclusion is that seaports studied regressed in productivities for the reason that ports have not been innovative enough in the period studied; notwithstanding these developments are similar across seaports and across countries in the sample.

As in the previous section, it is of interest to know the productivity performance of Norwegian seaports as compared other international peers. As for the efficiency scores we checked whether there are any statistically significant differences in the productivity indices EC, TC and M, between the Norwegian seaports as one group and the others as second group. We applied the Mann-Whitney U test and the Kolmogorov-Smirnov test to measure whether the two groups' underlying probability distributions differ. The null hypothesis in the Mann-Whitney and Kolmogorov–Smirnov tests are that the distribution of the mean indices values across the two groups are identical. The null hypothesis in the median test is that the mean indices across the two port groups are identical. Results are presented in Table 8. The test statistics, with a very high *p*-value across the methods, shows that there are no significant differences in ECs, TCs and Ms. Hence, there are no reasons to suspect that the productivity indices are different between the Norwegian seaports and the other sampled ports.

[INSERT TABLE 8]

(iii) Convergences in productivity growth

The next question to be addressed is whether convergences occur in the seaport industry. This question is highly relevant because, no study has addressed such convergences in the literature of seaport productivity and because the seaport industry is growing quickly in terms of container units (TEU) handled, which indicates that seaports are of vital importance for well-functioning transportation services and supply chains.

The results of the β -convergence test is reported in Table 9. The results show that, while -convergence cannot be confirmed to occur at any significant level with respect to EC, MPI and TC, -convergences have occurred at 5 and 10% significance levels respectively. To infer the existence of σ -convergence, the productivity indices in the initial period are plotted against productivities in the final period as a percentage of deviation from the cross sectional mean. We used a Gaussian kernel function and set the bandwidth selection criterion to be the minimisation of the asymptotic mean integrated square error. Fig.1 shows the density estimation of the productivity levels (as a percentage of deviations from the cross-sectional mean) for EC, TC and MPI. Panel (a) indicates that the cross-sectional dispersion of EC has decreased, and the mode of distribution in the final period is lower than in the initial period. Panel (b) shows that the dispersion for TC has increased, and the mode is lower than in the initial period. Panel (c) shows that the dispersion of MPI has decreased, and the mode is lower than in the initial period. Thus, there is a clear indication of convergence in EC and MPI, while for the TC; there is an indication of divergence. The latter result implies that nations that were technically innovative initially experience a faster growth rate than those countries that were less innovative initially.

[INSERT TABLE 9]

6. Concluding remarks

In this paper we have examined the efficiency, productivity and convergence of Norwegian seaports. In addition to the Norwegian ones we incorporated in the data set other comparable seaports located in other Nordic countries and the UK. This has made it possible to measure the general performance of the Norwegian seaports and how they perform relative to other comparable seaports. The methodological contribution of this study is that it is the first in the literature of seaport efficiency and productivity measurements dealing with the issue of convergence or divergence in terms of productivity. The main empirical contribution of this study is that it is the first to consider SFA-based productivity indices of Norwegian seaports.

The framework for analysing efficiency and productivity has been SFA and Malmquist indices. For assessing convergence/divergence, Beta (β)- and Sigma(σ)-convergences were used to infer the degrees of convergences or divergences in efficiencies and productivities. We derived some interesting results as follows: Firstly, there is a potential for efficiency improvement among the sampled Norwegian seaports at 22%. For all 24 the seaports in the sample the potentials are at 20% on average. Thus, there seems to be a great potential for efficiency improvement in the seaport industry. Secondly, there has been a total productivity regress among the Norwegian seaports at about 13%. For all sampled seaports the productivity regressed of about 12% on average. Thirdly, the productivity regress observed has been due to a regress in technical change at about 13% for the Norwegian seaports and a regress of about 12% on average for all 24 seaports. Fourthly, efficiency change has remained unchanged for the Norwegian seaports and improved with 1% on average for the foreign seaports. All over, among the sampled ports, the efficiency change in the period 2002-2008 was zero. Fifthly, there is a strong indication of convergences among seaports with respect to productivities, suggesting that seaports with initially lower indices progress faster than those with initially higher productivity indices.

The grand conclusion is that seaports studied regressed in productivities for the reason that seaports have not been innovative enough in the period studied; notwithstanding these developments are similar across seaports and across countries in the sample. A further conclusion is that the Norwegian seaports perform as well as their international peers in the Nordic countries and the UK, and that over the years the productivity of seaports has converged even though productivities on average are a regress. Observing the impact of each productivity indices on productivity estimates and their convergences has great managerial and policy implications. The differentiation into productivity indices is informative in that it helps to identify the source of productivity change. E.g. it would be a waste of management focus, effort and resources if a seaport or a container terminal which already makes efficient use of its existing production facilities, instead explains its inferior productivity to efficiency deficiencies, and erroneously postpones a technological investment program.

However, the offered efficiency and productivity indices should not be interpreted uncritically, as there may exist noise in the data and there may be external factors that were not included in the study. Future areas of potential research are to discover qualitative internal factors for inefficiency and productivity change, and to identify possible external factors (e.g. differences in ownership and governance structures) that may impact efficiency, productivity and their convergences.

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8. **References**

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Tables and Figures

Table 1: Literature review

Author(s)	Publication year	Dataset	Basic model	Data type	year of data	Average TE-Score	Number of observations
I. Non -Parametric DEA frontiers							
Roll and Hayuth (1993)	1993	Hypothetical data for 20 ports	DEA-CCR	Hypothetical	-	-	20
Martinez-Budria et al. (1999)	1999	26 Spanish ports (1993–1997)	DEA-BCC	Panel	1993-1997	0.833	26
Tongzon (2001)	2001	4 Australian plus 12 international container ports (1996)	CCR	cross-sectional	1996	0.594	16
Itoh (2002)	2002	8 Japanese ports (1990–1999)	DEA-Window-CCR	cross-sectional	90	0.710	240
Barros (2003)	2003	5 Portuguese seaports (1999–2000)	CCR	cross-sectional	1999	1.000	5
Barros and Athanassiou (2004)	2004	2 Greek and 4 Portuguese seaports(1998–2000)	CCR	panel	1998-2000	0.865	18
Park and De (2004)	2004	11 Korean seaports (1999)	CCR	cross-sectional	2001	0.669	11
Cullinane et al. (2004)	2004	25 of 30 largest container ports in the world (1992–1999)	DEA-window (CCR)	Panel	1992-1999	0.722	506
Cullinane et al. (2005a)	2005	25 of the 30 largest container ports plus 5 mainland China (1992–1999)	DEA-CCR		1992	0.689	30
Cullinane et al. (2005b)	2005				2001		
Min and Park(2005)	2005	11 Korean terminals	DEA CCR-window	panel	1999-2002	0.921	68
Wang and Cullinane (2006)	2006	104 European container terminals(2003)	CCR	cross-sectional	2003	0.430	29
Rios and Maçada (2006)	2006	23 MERCOSUR container terminals(2002–2004)	DEA-BCC	cross-sectional	2002	0.783	23
Barros (2006)	2006	24 Italian port authorities (2002–2003)	DEA-CCR,	Panel	2002-2003	0.763	48
Cullinane et al. (2006)	2006	25 international container ports	CCR	cross-sectional	2001	0.580	25
Al-Eraqui et al. (2010)	2010	22 seaports in the East Africa and the Middle East(2000–2005)	BCC - window	panel	2002-2005	0.770	198
Al-Eraqui et al. (2007)	2007	22 Seaports in the Middle East and East Africa	CCR	cross-sectional	2001	0.786	22
Hung et al(2010)	2010	31 container ports in Asia-Pacific region	BCC	cross-sectional	2003	0.563	31
Wu et al(2010)	2010	77 global contianer ports	CCR	cross-sectional	2003	0.563	77
Kamble et al.(2010)	2010	12 India ports	BCC	cross-sectional	2010	0.844	12
Ablanedo-Rosas and Ruiz-Torres	2009	29 Mexican coastal ports	BCC	cross-sectional	2009	0.453	29
Cullinane and Wang(2010)	2009	25 leading container ports	BCC- Window	panel	1992-1999	0.785	506
Lin and Tseng(2007)	2007	10 Container ports in Asia-Pacific region	CCR	cross-sectional	1998	0.830	10
Munisamy and Singh(2011)	2011	69 major asian containers	CCR	cross-sectional	2007	0.340	34
So et al(2007)	2007	19 major container ports in Northeastern Asia	CCR	cross-sectional	2004	0.633	19
NG and LEE(2007)	2007	8 malaysian seaports	CCR	cross-sectional	2005	0.886	6
Simões and Marques(2010)	2010	41 European seaports	CCR	cross-sectional	2005	0.425	41
Wu and Liang(2009)	2009	77 world container ports	BCC	cross-sectional	2007	0.667	77
Min and park(2008)	2008	11 Korean terminals	BCC-window	panel	1999-2002	0.922	396
Bichou(2011)	2011	10 international terminals	CCR	panel	2002-2008	0.697	10
					Average DEA	**0.704**	
II. Parametric stochastic frontiers							
Liu (1995)	1995	panel data of 28 commercial UK ports 1983-1990	Translog production function	Panel	1983-1990	0.780	224
Coto-Milla n, *et al.* (2000)	2000	panel data of 27 Spanish ports from 1985-1989	Translog cost function	Panel	1985-1989	0.328	135
Notteboom et al.(2000)	2000	36 European container terminals suplemented with 4 asian terminals	Bayesian Stochastic with Cobb-Douglas production function	Cross-sectional	1994	0.769	38
Estache, *et al.* (2002)	2002	panel data of 13 Mexican port authorities 1996-1999	Cobb-Douglas and Translog production function	Panel	1996-1999	0.550	52
Cullinane, *et al.* (2002)	2002	Cross-sectional and panel data of 15 Asian container ports 1989-1998.	Cobb-Douglas production function	Panel	1989-1998	0.719	150
Cullinane, & Song. (2003)	2003	Cross-sectional and panel data from 5 Korean and UK container terminals	Cobb-Douglas cost function	Cross-sectional	1978-1996	0.631	65
Cullinane, *et al* . (2006)	2006	Cross-sectional data of 74 European container port with 2002 data	Cobb-Douglas production function	Cross-sectional	2002	0.530	74
Barros (2005)	2005	Panel data of 10 Portuguese port authorities, 1990-2000	Translog cost function	Panel	1990-2000	0.396	20
Tongzon & Heng. (2005)	2005	cross-sectional data of 25 container ports/terminals, 1999	Cobb-Douglas production function	Cross-sectional	1999	0.866	25
Trujillo, & Tovar (2007)	2007	Cross-sectional data of 22 European port authorities 2002	Cobb-Douglas distance (production) function	Cross-sectional	2002	0.587	22
Gonzalez, & Trujillo (2008)	2008	Panel data of 5 Spanish port authorities, including 17 ports 1990-2002	Translog distance (production) function	Panel	1990-2002	0.919	65
					Average SFA	**0.643**	
Overall average TE						**0.688**	

Table 2: Summary values of variables, Averages (2002-2008)

	Inputs					Output
Variable name	Berth length	Terminal area	Yard gantry cranes	Straddle carriers	Container handling trucks	Container throughput
Unit of measurement	m	m^2	Number	Number	Number	TEU/year
Average	875.49	290100.80	0.46	12.20	9.59	278192.60
Max	2100.00	1060000.00	5.00	90.00	40.00	1869806.00
Min	75.00	11000.00	0.00	0.00	0.00	10560.00
S.D.	590.82	272809.10	1.22	22.01	8.14	347310.42

Table 3: Maximum-likelihood estimates of the translog stochastic production of seaports

Name of variable	Parameters	Coeffient	Standard error	t-ratio
(1) Determinants of frontier				
Constant	κ_0	0.243	0.018	13.780
Berth length/terminal area	κ_1	0.234	0.278	0.840
No. of machines	κ_2	0.689	0.315	2.190
Time	λ_1	-0.123	0.046	-2.690
Berth length/terminal area^2	κ_{11}	-0.287	0.117	-2.460
Berth length/terminal area x No. Machines	κ_{12}	0.241	0.165	1.460
Berth length/terminal area x Time	τ_1	0.066	0.018	3.710
No. of machines^2	κ_{22}	-0.245	0.128	-1.910
No. of machines x time	τ_2	-0.019	0.011	-1.730
Time^2	λ_{11}	-0.001	0.005	-0.280
(2) Inefficiency model				
constant	Ψ	0.300	0.072	4.140
Norway(=1; 0 otherwise)	Ψ_1	-0.190	0.093	-2.040
Sweden(=1; 0 otherwise)	Ψ_2	-0.080	0.097	-0.830
UK(=1; 0 otherwise)	Ψ_3	-0.699	0.279	-2.510
Small(=1 if TEU/year less than average, 0 otherwise)	Ψ_4	-0.420	0.153	-2.750
Sigma-squared	σ^2	-2.607	0.283	-9.210
Gamma	γ	3.510	0.587	5.980
Log likelihood function		75.627		

Null hypotheses	Loglikelihood	Test Statistics	Critical Value	Decision
No inefficiency in the model (H0: $\gamma=\Psi_0=\ldots\Psi_4=0$)	54.4	41.2	8.71	Reject
Inefficiency effects are not stochastic (H0: $\gamma=0$)	34	82	3.84	Reject
No Technical Change (H_0: $\gamma=\kappa_3=\kappa_{13}=\kappa_{23}=\kappa_{33}$)	64	22	8.71	Reject
Cobb -Douglas production function with no technical (H_0: $\kappa_{ij} = 0$; $\kappa_3=0$ and $\Psi_0=..\Psi_4=0$)	46	58	6.48	Reject

Table 4: Tests of hypotheses for parameter of the inefficiency frontier model

Table 5: Results of efficiency scores by year, seaports and distribution of scores

Seaport	2002	2003	2004	2005	2006	2007	2008
Oslo	0.921	0.792	0.823	0.793	0.788	0.826	0.694
Borg	0.807	0.833	0.846	0.870	0.865	0.702	0.744
Moss	0.781	0.803	0.830	0.871	0.810	0.826	0.798
Larvik	0.747	0.712	0.754	0.760	0.668	0.737	0.759
Ålesund	0.948	0.949	0.943	0.924	0.700	0.754	0.757
Kristiansand	0.560	0.597	0.632	0.637	0.643	0.737	0.755
Gothenburg	0.978	0.953	0.964	0.968	0.972	0.962	0.955
Stockholm	0.781	0.732	0.707	0.730	0.593	0.623	0.571
Helsingborg	0.595	0.614	0.766	0.794	0.921	0.978	0.943
Copen/Malmo	0.674	0.609	0.632	0.659	0.684	0.706	0.720
Aarhus	0.767	0.777	0.925	0.931	0.724	0.706	0.677
Aalborg	0.626	0.539	0.540	0.581	0.586	0.565	0.569
Fredericia	0.568	0.592	0.702	0.596	0.732	0.814	0.915
Helsinki	0.892	0.923	0.916	0.858	0.798	0.767	0.744
Kotka	0.798	0.651	0.693	0.714	0.764	0.789	0.813
Turku	0.514	0.468	0.447	0.406	0.440	0.457	0.465
Rauma	0.767	0.815	0.839	0.803	0.930	0.942	0.946
Hamina	0.929	0.948	0.931	0.930	0.930	0.957	0.924
Reykjavik	0.875	0.891	0.923	0.947	0.942	0.925	0.897
Southampton	0.969	0.975	0.966	0.954	0.966	0.980	0.963
Liverpool	0.870	0.880	0.887	0.896	0.916	0.945	0.959
Tilbury	0.906	0.895	0.919	0.922	0.904	0.921	0.924
Immingham	0.858	0.793	0.947	0.960	0.946	0.942	0.970
Grangemouth	0.951	0.974	0.984	0.938	0.763	0.745	0.746
Mean	0.795	0.780	0.813	0.810	0.791	0.804	0.800
S.D	0.141	0.152	0.147	0.149	0.143	0.140	0.142
Min	0.514	0.468	0.447	0.406	0.440	0.457	0.465
Max	0.978	0.975	0.984	0.968	0.972	0.980	0.970
Frequency distribution(%)							
<30	0	0	0	0	0	0	0
31-50	0	1	1	1	1	1	1
51-70	6	6	4	4	6	2	4
71-80	6	5	4	5	6	9	8
81-90	5	6	5	5	2	3	2
91-95	4	3	7	6	7	5	5
96-100	3	3	3	3	2	4	4

Table 6: Non-parametric statistical tests on the differences in efficiency scores between Norwegian and the other seaports. The *p*-values are in parenthesis.

	Efficiency	
	Norwegian	Others
Period	2002-2008	2002-2008
Number of ports	6	18
Number of observations	$7 \cdot 6 = 42$	$7 \cdot 18 = 126$
Mean	0.78	0.81
Variance	0.0087	0.0241
Test for differences		
Mann-Whitney U Test	retain the null hypotesis	
	(0.055)	
Kolmogorov-Smirnov	reject the null hypotesis	
	(0.000)	
Median	retain the null hypotesis	
	(0.050)	

Table 7: The Malmquist productivity index and its component

	Efficiency change (EC)							Technical change (TC)							Malmquist Productivty index (M)						
Port	**2002/2003**	**2003/2004**	**2004/2005**	**2005/2006**	**2006/2007**	**2007/2008**	**Mean**	**2002/2003**	**2003/2004**	**2004/2005**	**2005/2006**	**2006/2007**	**2007/2008**	**Mean**	**2002/2003**	**2003/2004**	**2004/2005**	**2005/2006**	**2006/2007**	**2007/2008**	**Mean**
Oslo	0.86	1.04	0.96	0.99	1.05	0.84	0.96	0.87	0.87	0.87	0.88	0.88	0.88	0.87	0.75	0.90	0.84	0.87	0.92	0.74	0.84
Borg	1.03	1.02	1.03	0.99	0.81	1.06	0.99	0.86	0.86	0.88	0.88	0.86	0.86	0.87	0.89	0.88	0.91	0.88	0.70	0.91	0.86
Moss	1.03	1.03	1.05	0.93	1.02	0.97	1.00	0.90	0.91	0.92	0.92	0.90	0.89	0.91	0.92	0.94	0.96	0.86	0.92	0.86	0.91
Larvik	0.95	1.06	1.01	0.88	1.10	1.03	1.01	0.87	0.87	0.88	0.88	0.88	0.88	0.88	0.83	0.92	0.88	0.77	0.97	0.90	0.88
Ålesund	1.00	0.99	0.98	0.76	1.08	1.00	0.97	0.88	0.88	0.88	0.87	0.87	0.87	0.87	0.88	0.87	0.86	0.66	0.93	0.87	0.85
Kristiansand	1.07	1.06	1.01	1.01	1.15	1.02	1.05	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.91	0.90	0.86	0.86	0.97	0.87	0.89
Gothenburg	0.97	1.01	1.00	1.00	0.99	0.99	1.00	0.89	0.88	0.88	0.88	0.87	0.87	0.88	0.86	0.89	0.88	0.88	0.86	0.87	0.87
Stockholm	0.94	0.97	1.03	0.81	1.05	0.92	0.95	0.90	0.90	0.89	0.89	0.89	0.89	0.89	0.84	0.86	0.92	0.72	0.93	0.81	0.85
Helsingborg	1.03	1.25	1.04	1.16	1.06	0.96	1.08	0.87	0.86	0.86	0.86	0.86	0.86	0.86	0.89	1.08	0.89	1.00	0.91	0.83	0.93
Copen/Malmo	0.90	1.04	1.04	1.04	1.03	1.02	1.01	0.85	0.86	0.86	0.85	0.85	0.85	0.85	0.77	0.89	0.89	0.89	0.88	0.87	0.86
Aarhus	1.01	1.19	1.01	0.78	0.97	0.96	0.99	0.90	0.90	0.90	0.89	0.87	0.87	0.89	0.91	1.07	0.90	0.69	0.85	0.83	0.88
Aalborg	0.86	1.00	1.07	1.01	0.96	1.01	0.99	0.88	0.88	0.87	0.87	0.87	0.87	0.87	0.76	0.88	0.94	0.88	0.84	0.88	0.86
Fredericia	1.04	1.19	0.85	1.23	1.11	1.12	1.09	0.87	0.87	0.87	0.87	0.86	0.86	0.87	0.91	1.03	0.74	1.06	0.96	0.97	0.94
Helsinki	1.03	0.99	0.94	0.93	0.96	0.97	0.97	0.90	0.90	0.90	0.90	0.89	0.88	0.90	0.93	0.89	0.84	0.84	0.86	0.86	0.87
Kotka	0.82	1.06	1.03	1.07	1.03	1.03	1.01	0.90	0.90	0.89	0.89	0.88	0.88	0.89	0.74	0.96	0.92	0.95	0.91	0.90	0.90
Turku	0.91	0.96	0.91	1.08	1.04	1.02	0.99	0.87	0.87	0.87	0.87	0.86	0.86	0.87	0.79	0.83	0.79	0.94	0.90	0.88	0.85
Rauma	1.06	1.03	0.96	1.16	1.01	1.00	1.04	0.86	0.86	0.85	0.85	0.85	0.85	0.85	0.91	0.88	0.82	0.99	0.86	0.86	0.89
Hamina	1.02	0.98	1.00	1.00	1.03	0.97	1.00	0.91	0.91	0.90	0.89	0.89	0.88	0.89	0.93	0.89	0.90	0.89	0.91	0.85	0.89
Reykjavik	1.02	1.04	1.03	0.99	0.98	0.97	1.00	0.88	0.88	0.87	0.88	0.88	0.88	0.88	0.89	0.91	0.90	0.87	0.86	0.85	0.88
Southampton	1.01	0.99	0.99	1.01	1.02	0.98	1.00	0.88	0.88	0.88	0.87	0.88	0.88	0.88	0.89	0.87	0.86	0.89	0.89	0.86	0.88
Liverpool	1.01	1.01	1.01	1.02	1.03	1.01	1.02	0.89	0.89	0.89	0.88	0.88	0.88	0.89	0.90	0.89	0.89	0.91	0.91	0.90	0.90
Tilbury	0.99	1.03	1.00	0.98	1.02	1.00	1.00	0.87	0.87	0.87	0.86	0.86	0.86	0.87	0.86	0.89	0.87	0.85	0.88	0.86	0.87
Immingham	0.92	1.19	1.01	0.99	1.00	1.03	1.02	0.95	0.94	0.93	0.92	0.91	0.89	0.92	0.88	1.13	0.94	0.91	0.90	0.92	0.95
Grangemouth	1.02	1.01	0.95	0.81	0.98	1.00	0.96	0.83	0.86	0.89	0.89	0.89	0.89	0.87	0.85	0.87	0.85	0.72	0.87	0.89	0.84
Mean	0.98	1.05	1.00	0.99	1.02	1.00	1.00	0.88	0.88	0.88	0.88	0.87	0.87	0.88	0.86	0.92	0.88	0.86	0.89	0.87	0.88
S.D	0.07	0.08	0.05	0.12	0.06	0.05	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.06	0.08	0.05	0.10	0.05	0.04	0.03
Min	0.82	0.96	0.85	0.76	0.81	0.84	0.95	0.83	0.85	0.85	0.85	0.85	0.85	0.85	0.74	0.83	0.74	0.66	0.70	0.74	0.84
Max	1.07	1.25	1.07	1.23	1.15	1.12	1.09	0.95	0.94	0.93	0.92	0.91	0.89	0.92	0.93	1.13	0.96	1.06	0.97	0.97	0.95
Frequency distribution(%)										Numbet of ports											
<30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50-70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
70-80	0	0	0	2	0	0	0	0	0	0	0	0	0	0	5	0	2	3	1	1	0
80-90	3	0	1	3	1	1	0	19	20	21	22	22	24	22	12	15	15	12	11	18	20
90-95	4	0	2	2	0	1	0	5	4	3	2	2	0	2	7	4	6	3	9	4	4
95-100	3	6	6	6	7	8	12	0	0	0	0	0	0	0	0	1	1	3	3	1	0
100-120	14	17	15	10	16	14	12	0	0	0	0	0	0	0	0	4	0	1	0	0	0
120-150	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
150-200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

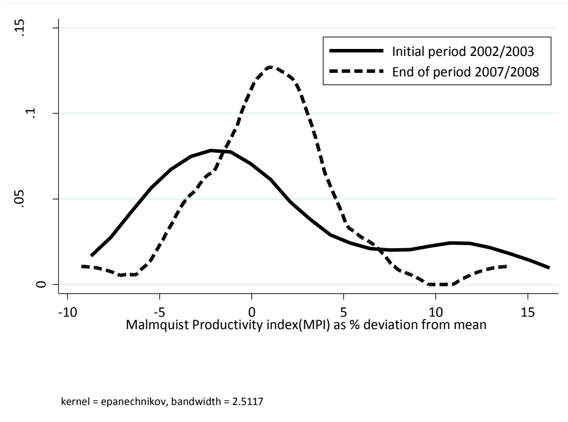
Table 8: Non-parametric statistical tests on the differences in MPI indices between Norwegian and the other seaports. *p*-values are in parenthesis.

	Efficiency change (EC)		**Technical change (TC)**		**Malmquist Productivity index (M)**	
	Norwegian	Others	Norwegian	Others	Norwegian	Others
Period	2002-2008	2002-2008	2002-2008	2002-2008	2002-2008	2002-2008
Number of ports	6	18	6	18	6	18
Number of observations	$6 \cdot 6 = 36$	$6 \cdot 18 = 108$	$6 \cdot 6 = 36$	$6 \cdot 18 = 108$	$6 \cdot 6 = 36$	$6 \cdot 18 = 108$
Mean	1.00	1.01	0.87	0.88	0.87	0.88
Variance	0.0065	0.0058	0.0003	0.0004	0.005	0.0045
Test for differences						
Mann-Whitney U Test	retain the null hypotesis		retain the null hypotesis		retain the null hypotesis	
	(0.719)		(0.164)		(0.879)	
Kolmogorov-Smirnov	retain the null hypotesis		retain the null hypotesis		retain the null hypotesis	
	(0.893)		(0.087)		(0.893)	
Median	retain the null hypotesis		retain the null hypotesis		retain the null hypotesis	
	(0.847)		(0.847)		(0.564)	

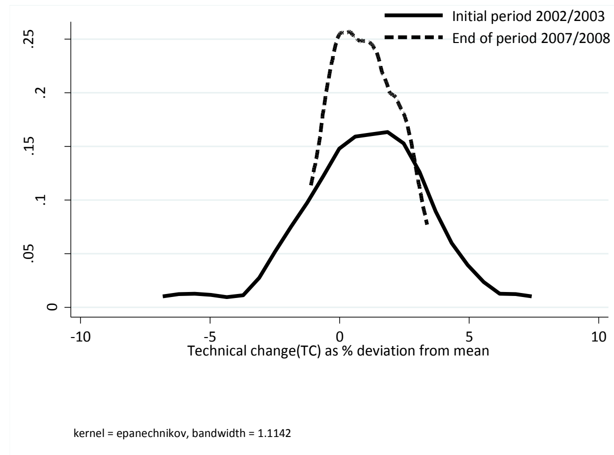
Table 9: The β convergence/divergence results

	Coefficient	Standard error	t-value	P-value
Total Malmquist productivity index(MI)	0.212	0.104	2.030	0.082
Constant	0.750	0.236	3.180	0.015
R-squared	0.160			
Technical Change (TC)	0.559	0.183	3.050	0.008
Constant	0.207	0.141	1.460	0.164
R-squared	0.646			
Efficiency change(EC)	0.075	0.172	0.440	0.676
Contant	0.331	0.244	1.360	0.217
R-squared	0.008			

Figure 1: Distributions of productivity levels and σ -convergence

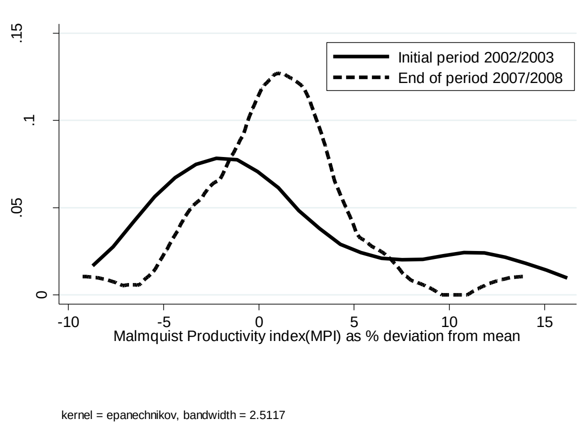


(a)



(b)

(c)



[1] Time varying efficiency could be assumed, however, it would restrict all the technical efficiency of all ports to follow the same trend direction, i.e., either all increasing or decreasing over time which is unlikely to be valid in many instances.