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Abstract

This paper uses three different Malmquist Productivity Index (MPI) decompositions to measure Greek seaports' productivity for the time period 2006-2010. In addition bootstrap techniques are applied in order for confidence intervals of the MPIs and their components to be constructed and therefore to verify if the indicated changes are significant in a statistical sense. Finally, a second stage nonparametric analysis has been applied identifying the effect of seaports' size on their productivity levels. The results reveal that the number of terminals is a crucial determinant of seaports' productivity levels. In addition it appears that the high length of Greek seaports has a negative influence on their productivity levels over the years.

Keywords: Malmquist productivity index; bootstrap approach; nonparametric analysis; Greek seaports.

JEL Codes: C6; D24; L91.

1. Introduction

Various research papers have been devoted to the examination of the efficiency in the transport sector. Various approaches from simple performance indicators to Total Factor Productivity (TFP), Stochastic Frontier Approach (SFA), Data Envelopment Analysis (DEA) and Free Disposal Hull (FDH) models have been used in every transport sector like public transit, railways, airports, airlines and seaports. According to Gillen and Lall (1997), this growing interest has been motivated by the need to investigate the results of deregulation, privatization and commercialization.

Seaports play a significant role in the world trade and development (Tongzon, 2001). The assessment of seaport efficiency is of extreme importance because of the increasing competition they face (Cullinane et al., 2006) which in turn creates the need for better utilization of the available resources. Seaports are complex entities which combine sea and land operations. Cullinane et al. (2002) identify two types of ports, the comprehensive port which provides all the services and landlord port which provides only the basic services. They have analyzed a port function matrix which is an alternative way to distinct the types of seaports according to the services provided.

Econometric models, SFA and DEA have been used to assess the efficiency of seaports. In their study, Roll and Hayuth (1993) apply a DEA model to measure the efficiency of twenty seaports. Tongzon (2001) investigates the efficiency of sixteen international seaports. The author utilizes a DEA model and uses land, labor, capital and delay time as inputs and cargo and ship working rate as outputs. The later is used as a measure of quality. Bonilla et al. (2002) employ DEA in order to measure the commodities traffic efficiency of the seaports in Spain. Commodities traffic efficiency refers to the time the product needs to reach the final costumer. Barros (2003) utilizes

DEA in Portuguese seaports and finds that the reform made by the authorities does not fulfil the targets.

Similarly, Barros and Athanassiou (2004) compared the efficiency of seaports in Portugal and Greece and provided benchmarks. They have used labor and capital as inputs and ships, freight, cargo and containers as outputs. Cullinane et al. (2004) used a DEA window analysis in order to achieve more robust results. Estache et al. (2004) applied the Malmquist Productivity Index (MPI) to examine if seaport liberalization was a success in Mexico. The results verify the success of the reforms made. Finally, Cullinane et al. (2006) studied the top twenty ports in 2001 by using DEA and SFA. Additionally they have used the SFA approach and found that the size of the port is related to its efficiency levels. Manzano et al. (2008) employ an econometric model and argue that efficiency tends to rise when the autonomy of seaport rises. Gonzales and Trujillo (2008) apply a translog distance function in the top Spain seaports and find that the reforms made in seaport industry had a positive effect on their technological change.

In contrast to those studies our paper measures seaports productivity by applying for the first time three different decompositions as has been introduced by several authors (Färe et al., 1994a; 1994b; Ray and Desli, 1997; Gilbert and Wilson, 1998; Simar and Wilson, 1998a; Zofio and Lovell, 1998; Wheelock and Wilson, 1999). As well the inference approach introduced by Simar and Wislon (1999) is also applied in order to construct confidence intervals for Malmquist productivity indices and their decompositions. Finally, a second stage analysis is carried out by applying nonparametric regression approaches aiming to establish how the size of the examined seaports has affected their productivity levels over the examined period.

The paper is structured as follows. Section two presents a brief literature of the efficiency based studies and the different models applied to measure the efficiency and productivity of transport units. Moreover, section 3 discusses the proposed methodology, whereas section four presents the data and our empirical. Finally, the last section concludes the paper.

2. Literature review

In public transit industry, the government may consider two alternative scenarios to reduce cost, such as privatization or the improvement of management (Chu et al., 1992). Based on Hatry's (1980) argument that efficiency and effectiveness should be examined separately in public organizations, Chu et al. (1992) constructed DEA models, one for efficiency and one for effectiveness, in order to assist public agencies to monitor and improve their management. While efficiency refers to the technical efficiency, effectiveness refers to the ability to use the outputs to fulfil the managerial targets (Hatry, 1980). Chu et al. (1992) use various expenses as inputs and vehicle hours of service as output for their efficiency model. For the effectiveness model the authors use as inputs the output of the previous model along with some exogenous variables such as population density and as outputs on their effectiveness model they use the number of passenger trips.

Several studies apply DEA approach which is suitable for multiple input-output cases. Chang and Kao (1992) study the efficiency of five bus firms in Taipei using as inputs capital, labor and fuel and as outputs vehicle kilometers, revenue and the number of bus trips. The authors find that private firms achieve better scores than public-owned firms. Nolan (1996) and Karlaftis (2003) employ the same variables as Chang and Kao (1992) at US bus transit. The aforementioned variables are also used along with other variables by Kerstens (1996) who applies a DEA model at French bus sector and finds that small firms have increasing while larger firms have decreasing returns to scale.

Obeng (1994) by using labor, fuel and fleet size as inputs and vehicle miles as output finds that technical efficiency decreases with the size of the firm. Viton (1998) applies DEA and Malmquist productivity index to examine the efficiency of US bus transit and finds that there is a slight improvement in productivity over time. Cowie and Asenova (1999) examined the British bus sector after deregulation and privatization and found high levels of inefficiency. Odeck (2008) applied a DEA and Malmquist productivity index to examine the effect of mergers on the efficiency of the Norwegian public bus sector finding evidence that mergers boost efficiency. In a different study, Nozick et al. (1998) point out the problem of traffic congestion and analyze a DEA model to investigate which travel demand management policy deals with traffic congestion problem more effectively.

However, it must be emphasized that the majority of the studies in the literature using various methodologies and approaches have concentrated in airline industry. Oum and You (1998) used a translog variable cost function to assess the competitiveness of the twenty two top airlines in the world, whereas Assaf (2009) applied SFA investigating if US airlines are in crisis. The results indicate a decline in efficiency scores. Schefczyk (1993) investigated the operational efficiency of fifteen airlines using a DEA model and found that high operational performance is a leading determinant of high profitability. Moreover, Peck et al. (1998) applied DEA to examine the strategies of aircraft maintenance, whereas Capobianco and Fernandez (2004) used a DEA model to examine the airline capital structure.

Scheraga (2004) examined the airline industry on the eve of the terrorist attack of September 11th 2001. The author investigated thirty eight airlines around the globe and concludes that the events had an effect not only on US airlines but also on other major airlines. Moreover, Scheraga (2004) argues that airline carriers need to have financial mobility in order to survive any unexpected event like a terrorist attack. The author for the analysis has used a DEA model with available ton-kilometers, operating costs and non-flight assets as inputs and revenue passenger and non-passenger kilometers as outputs. Finally, Chiou and Chen (2006) applied a DEA model to measure the cost efficiency, cost effectiveness and service effectiveness of fifteen Taiwanese airlines.

Greer (2006) utilizes labor, fuels and seating capacity in a DEA model to produce seat miles as the only output. The author investigates fourteen US airlines and finds that low-cost carriers achieve better scores in technical efficiency. These findings are verified by Barbot et al. (2008) for international airlines. Greer (2008, 2009) applies the same DEA model with Greer (2006) in US airlines. Greer (2008) also utilizes a Malmquist productivity index and finds a significant improvement in productivity over time. Greer (2009) uses a tobit regression in a second stage to study the driver factors of efficiency. The findings indicate that average aircraft size, average stage length and hubbing of the flights are significant factors while labor unions are an insignificant factor. Barros and Peypoch (2009) in their study found that demographics are an important factor for airline efficiency, while Quellette et al. (2010) noted the significance of deregulation. Merkert and Hensher (2011) underline the importance of aircraft size and the number of aircraft types on efficiency. They argue that firms with large and few aircraft families achieve better efficiency scores in terms of technical, allocative and cost efficiency.

A number of studies have also examined the efficiency of the airports which are considered as a determinant factor for the economic development (Sarkis, 2000). According to Adler and Berechman (2001) there are several factors an airline needs to address in order to choose an airport including delays, runway capacity, costs and traffic control. Parker (1999) examined the efficiency of British Aircraft Authority before and after privatization and found that privatization had no impact on efficiency. Parker (1999) used a DEA model with capital, labor, non-labor and capital costs as inputs and passengers, cargo and mail as outputs.

Sarkis (2000) investigates the efficiency of forty four US airports by utilizing a DEA model with operational costs, labor, gates and runaways as inputs and operational revenue, passengers, cargo and general aviation movements as outputs. He argues that hub airports and airports which are not in a snow belt are generally more efficient. Adler and Golany (2001) developed a DEA model to determine which airports are more likely to become the main gateway for airline companies. Commenting on the DEA studies Adler and Berechman (2001) addressed the importance of a quality variable in a DEA model for airports. Finally, Sarkis and Talluri (2004) employed the same model with Sarkis (2000) and provided benchmarks for inefficient airports whereas, Barros (2008) used SFA to investigate the efficiency of Portuguese airports and reported that capital, prices, sales to planes, sales to passengers and aeronautical fee are the main determinant factors of efficiency.

3. Methodology

3.1 Malmquist productivity index and its main decompositions

Following Färe et al. (1994a) a multiple input and a multiple output at time $t\left(\mathbf{V}^t\right)$ can be defined as:

$$\mathbf{V}^t = \left\{\left(\mathbf{x}^t, \mathbf{y}^t\right) : \mathbf{x}^t \text{ can produce } \mathbf{y}^t\right\}, t = 1, \ldots, T \tag{1}$$

where at time t the input vector is indicated as $\mathbf{x}^t = \left(x_1^t, \ldots, x_M^t\right) \in \Re_+^M$ and the output vector is indicated as $\mathbf{y}^t = \left(y_1^t, \ldots, y_N^t\right) \in \Re_+^N$. Then the output sets with respect to V^t can be defined as:

$$\mathbf{P}^t\left(\mathbf{x}^t\right) = \left\{\mathbf{y}^t : \left(\mathbf{y}^t, \mathbf{x}^t \in \mathbf{V}^t\right)\right\}, t = 1, \ldots, T \tag{2}$$

Additionally we assume that the output sets satisfy strong disposability, convexity and they are bounded and closed.

Following Shephard (1970) production technology can be defined by an output distance function as:

$$\begin{aligned} D^t\left(\mathbf{x}^t, \mathbf{y}^t\right) &= \inf\left\{\varphi : \left(\mathbf{y}^t / \varphi\right) \in \mathrm{b}\mathbf{P}^t\left(\mathbf{x}^t\right)\right\}, t = 1, \ldots, T \\ &= \left(\sup\left\{\varphi : \left(\mathbf{y}^t / \varphi\right) \in \mathbf{P}^t\left(\mathbf{x}^t\right)\right\}\right)^{-1}, t = 1, \ldots, T \end{aligned} \tag{3}$$

where $\varphi \in (0,1]$ and $D^t\left(\mathbf{x}^t, \mathbf{y}^t\right) \leq 1$ if and only if $\mathbf{y}^t\left(\mathbf{P}^t\left(\mathbf{x}^t\right)\right)$. According to Färe et al. (1994b) the given inputs $\mathbf{x}^t$ are defined as the maximum proportional expansion of the outputs $\mathbf{y}^t$. The value of $D^t\left(\mathbf{x}^t, \mathbf{y}^t\right)$ is given by $\left\|\mathbf{y}^t\right\| / \left\|\mathbf{y}_k^t\right\|$, where $\mathbf{y}_k^t \in \mathrm{Isoq}\mathbf{P}^t\left(\mathbf{x}^t\right) = \left\{\mathbf{y}^t : \mathbf{y}^t \in \mathbf{P}^t\left(\mathbf{x}^t\right), \varphi\mathbf{y}^t \notin \mathbf{P}^t\left(\mathbf{x}^t\right), \varphi > 1\right\}$ and is the frontier output. If $D^t\left(\mathbf{x}^t, \mathbf{y}^t\right) = 1$ then the production is technically efficient.

In addition we need to define the distance function in different period and in order to define Malmquist productivity index. This can be obtained similarly as:

$$D^{t+1}\left(\mathbf{x}^t,\mathbf{y}^t\right)=\inf\left\{\varphi:\left(\mathbf{y}^t/\varphi\right)\in\mathbf{P}^{t+1}\left(\mathbf{x}^t\right)\right\},t=1,...,T \tag{4}$$

According to Caves et al. (1982) the output oriented Malmquist productivity index can be written as[1]:

$$M_C^t\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)=\frac{D_C^t\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)}{D_C^t\left(\mathbf{x}^t,\mathbf{y}^t\right)} \tag{5}$$

The geometric mean of the Malmquist productivity index can be defined as:

$$\begin{aligned}M_C\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)&=\left\{\left[M_C^t\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)\times M_C^{t+1}\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)\right]\right\}^{1/2}\\&=\left[\frac{D_C^t\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)}{D_C^t\left(\mathbf{x}^t,\mathbf{y}^t\right)}\times\frac{D_C^{t+1}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)}{D_C^{t+1}\left(\mathbf{x}^t,\mathbf{y}^t\right)}\right]^{1/2}\end{aligned} \tag{6}$$

$M_C\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)$ can take the values >1 (productivity growth), $=1$ (stagnation) or <1 (decline) between the periods t and $t+1$. As explained by Grosskopf (2003, p. 462) the Malmquist productivity index defined in (6) is linked to the average product notion since the distance functions are calculated under the assumption of constant returns to scale (CRS).

The initial decomposition of the index was provided by Färe et al. (1994a) as:

$$\begin{aligned}M_C\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)&=\frac{D_C^{t+1}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)}{D_C^t\left(\mathbf{x}^t,\mathbf{y}^t\right)}\times\left\{\left[\frac{D_C^t\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)}{D_C^{t+1}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)}\times\frac{D_C^t\left(\mathbf{x}^t,\mathbf{y}^t\right)}{D_C^{t+1}\left(\mathbf{x}^t,\mathbf{y}^t\right)}\right]\right\}^{1/2}\\&=\mathrm{TE}\Delta_C\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)\times\mathrm{T}\Delta_C\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)\end{aligned} \tag{7}$$

In equation (7) 'TEΔ' measures technical efficiency change on the best practice whereas 'TΔ' measures the geometric mean of the magnitude of technical change. However the decomposition was made under the constant returns to scale (CRS)

[1] In the Malmquist productivity index decompositions we excluded the subscript 'o' from our notation since we are using the general definition of the output distance function. In addition the subscript 'C' indicates the technology of distance functions, which is calculated under assumption of constant returns to scale (CRS), whereas the subscript 'V' indicates calculation under the assumption of variable returns to scale (VRS).

assumption and best practice technologies may exhibit variable returns to scale (VRS) technologies. Even though this decomposition is widely used by researchers to measure productivity changes as suggested by Lovell (2003, p 443) this index measures inappropriately productivity since their productivity change measure is inappropriately defined on the best practice technologies, and in addition the scale effect component is missing.

Therefore Färe et al. (1994b) redefined $\mathrm{TE}\Delta_C\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)$ as:

$$\begin{aligned}\mathrm{TE}\Delta_C\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right) &= \left[\frac{D_V^{t+1}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)}{D_V^t\left(\mathbf{x}^t,\mathbf{y}^t\right)}\right]\times\left\{\frac{D_C^{t+1}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)/D_V^{t+1}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)}{D_C^t\left(\mathbf{x}^t,\mathbf{y}^t\right)/D_V^t\left(\mathbf{x}^t,\mathbf{y}^t\right)}\right\} \\ &= \mathrm{TE}\Delta_V\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)\times\left[\frac{SE^{t+1}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)}{SE^t\left(\mathbf{x}^t,\mathbf{y}^t\right)}\right] \\ &= \mathrm{TE}\Delta_V\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)\times SE\Delta\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)\end{aligned} \tag{8}$$

As can be realized from (8) $\mathrm{TE}\Delta_V$ measures under the VRS assumption the technical efficiency change whereas $SE\Delta$ measures the change in scale efficiency between the two periods. Therefore the Malmquist productivity index will take the form of:

$$\begin{aligned}M_C\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right) &= \mathrm{TE}\Delta_V\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)\times SE\Delta\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right) \\ &\quad\times \mathrm{T}\Delta_C\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)\end{aligned} \tag{9}$$

However Ray and Desli (1997) provided a different decomposition of Malmquist productivity index[2]:

$$\begin{aligned}M_C\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right) &= \mathrm{TE}\Delta_V\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)\times S\Delta\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right) \\ &\quad\times \mathrm{T}\Delta_V\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)\end{aligned} \tag{10}$$

where:

[2] For an extensive analysis regarding the decompositions of Malmquist productivity index see Lovell (2003) and Grosskopf (2003).

$$\mathrm{TE}\Delta_V\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)=\frac{D_V^{t+1}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)}{D_V^{t}\left(\mathbf{x}^{t},\mathbf{y}^{t}\right)},$$

$$\mathrm{T}\Delta_V\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)=\left[\frac{D_V^{t}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)}{D_V^{t+1}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)}\times\frac{D_V^{t}\left(\mathbf{x}^{t},\mathbf{y}^{t}\right)}{D_V^{t+1}\left(\mathbf{x}^{t},\mathbf{y}^{t}\right)}\right]^{1/2}$$

Then the 'scale change factor $S\Delta$ was decomposed as:

$$\begin{aligned}&S\Delta\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)\\&=\left\{\left[\frac{D_C^{t}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)/D_V^{t}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)}{D_C^{t}\left(\mathbf{x}^{t},\mathbf{y}^{t}\right)/D_V^{t}\left(\mathbf{x}^{t},\mathbf{y}^{t}\right)}\right]\times\left[\frac{D_C^{t+1}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)/D_V^{t+1}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)}{D_C^{t+1}\left(\mathbf{x}^{t},\mathbf{y}^{t}\right)/D_V^{t+1}\left(\mathbf{x}^{t},\mathbf{y}^{t}\right)}\right]\right\}^{1/2}\\&=\left[\frac{SE^{t}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)}{SE^{t}\left(\mathbf{x}^{t},\mathbf{y}^{t}\right)}\times\frac{SE^{t+1}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)}{SE^{t+1}\left(\mathbf{x}^{t},\mathbf{y}^{t}\right)}\right]^{1/2}\end{aligned}\qquad(11).$$

Finally, a third decomposition has been provided by several authors (Gilbert and Wilson, 1998; Simar and Wilson, 1998a; Zofio and Lovell, 1998; Wheelock and Wilson, 1999) defined as:

$$\begin{aligned}M_C\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)&=\mathrm{TE}\Delta_V\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)\times SE\Delta\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)\\&\quad\times\mathrm{T}\Delta_V\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)\times S\mathrm{BT}\Delta\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)\end{aligned}\qquad(12).$$

Whereas $\mathrm{TE}\Delta$ and $\mathrm{T}\Delta$ are the same as Ray and Desli (1997) definition in (10). Moreover, $SE\Delta$ is defined as Färe et al. (1994b) decomposition in (8) and the final component $S\mathrm{BT}\Delta$ is the scale bias of technical change and can be defined as:

$$\begin{aligned}S\mathrm{BT}\Delta\left(\mathbf{x}^t,\mathbf{y}^t,\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)&=\left\{\left[\frac{D_C^{t}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)/D_V^{t}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)}{D_C^{t+1}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)/D_V^{t+1}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)}\right]\right.\\&\quad\left.\times\left[\frac{D_C^{t}\left(\mathbf{x}^{t},\mathbf{y}^{t}\right)/D_V^{t}\left(\mathbf{x}^{t},\mathbf{y}^{t}\right)}{D_C^{t+1}\left(\mathbf{x}^{t},\mathbf{y}^{t}\right)/D_V^{t+1}\left(\mathbf{x}^{t},\mathbf{y}^{t}\right)}\right]\right\}^{1/2}\end{aligned}\qquad(13).$$

According to Lovell (2003, p.456) if scale efficiencies are different from the two technologies, then a scale bias exhibits in technical scale component.

3.2 Computing Malmquist productivity index using Data Envelopment Analysis (DEA)

Having $s=1,...,S$ seaports the frontier technology using data envelopment analysis (DEA) methodology can be defined as:

$$\begin{aligned}
\mathbf{V}^{t} = \Big\{\left(\mathbf{x}^{t},\mathbf{y}^{t}\right): y_{n}^{t} \le \sum_{s=1}^{S} \omega^{s,t} y_{n}^{s,t} \qquad & n=1,...,N \\
\sum_{s=1}^{S} \omega^{s,t} x_{m}^{s,t} \le x_{m}^{t} \qquad & m=1,...,M \\
\omega^{s,t} \ge 0 \qquad & s=1,...,S\Big\}
\end{aligned} \tag{14}$$

where $\omega^{s,t}$ indicates the intensity variable. In addition if $\sum \omega^{s,t}=1$ is added in (14) then the efficiency is calculated under the assumption of variable returns to scale. As analysed previously in order to calculate the Malmquist productivity index and its components four distance functions are needed to be calculated for $D^{t}\left(\mathbf{x}^{t},\mathbf{y}^{t}\right)$, $D^{t+1}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)$, $D^{t}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)$ and $D^{t+1}\left(\mathbf{x}^{t},\mathbf{y}^{t}\right)$ following the linear programming as in Färe et al. (1994b).

Let (s') be a seaport, and then the four output distance functions reciprocal to Farell's (1957) output-based technical efficiency measurements can be calculated as:

$$\begin{aligned}
&\left(D^{t}\left(\mathbf{x}^{s',t},\mathbf{y}^{s',t}\right)\right)^{-1} = \max \varphi^{s'} \\
&\text{st}\sum_{s=1}^{S} \omega^{s,t} y_{n}^{s,t} \ge \varphi^{s'} y_{n}^{s',t} \qquad n=1,...,N \\
&\sum_{s=1}^{S} \omega^{s,t} x_{m}^{s,t} = x_{m}^{s',t} \qquad m=1,...,M \\
&\omega^{s,t} \ge 0 \qquad s=1,...,S
\end{aligned} \tag{15}$$

$$\left(D^t\left(\mathbf{x}^{s',t+1},\mathbf{y}^{s',t+1}\right)\right)^{-1} = \max\varphi^{s'}$$
$$\begin{aligned} &\text{st}\sum_{s=1}^{S}\omega^{s,t}y_n^{s,t} \geq \varphi^{s'}y_n^{s',t+1} && n=1,\ldots,N \\ &\sum_{s=1}^{S}\omega^{s,t}x_m^{s,t} = x_m^{s',t+1} && m=1,\ldots,M \\ &\omega^{s,t}\geq 0 && s=1,\ldots,S \end{aligned} \qquad (16).$$

As such the distances $D^{t+1}\left(\mathbf{x}^{t},\mathbf{y}^{t}\right)$ and $D^{t+1}\left(\mathbf{x}^{t+1},\mathbf{y}^{t+1}\right)$ can be calculated accordingly by changing $t+1$ with t and additionally the variable returns to scale can be imposed by adding to the above linear programming problems the $\sum\omega^{s,t}=1$ restriction.

Moreover, according to Simar and Wilson (1998b, 1999, 2000a, 2000b) the proposed bootstrap approach for constructing confidence interval for Malmquist productivity indexes and their decompositions can be applied. The aim of the following procedure is to estimate the population distribution of the Malmquist index (component) and thus to make possible to test hypotheses regarding the true parameter value (Hoff, 2006).

Letting M_s^I be the 'true' unknown index, $\hat{M}_s^I$ be the DEA estimate of index as indicated previously and ${}^{*}M_{s,b}^I$ to be the bootstrap estimates of the index as calculated following Simar and Wilson (1999), then the basic assumption for constructing the confidence intervals is that the distribution of $\hat{M}_s^I - M_s^I$ can be approximated by the distribution of ${}^{*}M_{s,b}^I - \hat{M}_s^I$. Therefore the values b_α and α_α can define the $\left(1-\alpha\right)$ confidence interval as:

$$\Pr\left(b_{s,a} \leq \hat{M}_s^I - M_s^I \leq \alpha_{s,\alpha}\right) = 1-\alpha \qquad (17)$$

and can be approximated from the bootstrap values $\hat{b}_\alpha$ and $\hat{\alpha}_\alpha$ as:

$$\Pr\left(\hat{b}_{s,a} \leq {}^{*}M^{I}_{s,b} - \hat{M}^{I}_{s} \leq \hat{\alpha}_{s,\alpha} \right) = 1-\alpha \tag{18}$$

Then the bootstrap estimate of the $(1-\alpha)$ confidence interval for the *s*th Malmqusit index or its component can be given by:

$$\hat{M}^{I}_{s} - \hat{\alpha}_{s,\alpha} \leq M^{I}_{s} \leq \hat{M}^{I}_{s} - \hat{b}_{s,a} \tag{19}$$

In this way for the *s*th seaport can be said that the Malmquist index (or/and its component) is significantly different from unity at $\alpha\%$ level if (19) does not include the value 1.

3.3 Determine the effect of seaport size on its productivity levels

Finally, a local linear estimator is applied in order to reveal the effect of seaport size on their obtained Malmquist productivity index and its components. Following Fan (1992, 1993) the local linear kernel model will have the form of:

$$y_i = \alpha + \beta'(X_i - x) + e_i \tag{20}$$

given that y_i can be seaport's i productivity measure (or its component) let X_i be the variable(s) that determine seaport's size, then by using the $X_i - x$ instead of X_i the intercept equals to $E(y_i | X_i = x)$. If we fit the linear regression through the observations $|X_i - x| \leq h$ this can be written as:

$$\min_{\alpha,\beta} \sum_{i=1}^{n} \left(y_i - \alpha - \beta'(|X_i - x|)\right)^2 I\left(\|X_i - x\| \leq h\right) \tag{21}$$

or setting $\phi_i = \begin{pmatrix} 1 \\ |X_i - x| \end{pmatrix}$ then we have the explicit expression of:

$$\begin{pmatrix}\hat{\alpha}(x)\\ \hat{\beta}(x)\end{pmatrix} = \left(\sum_{i=1}^{n} I(\|X_i - x\| \le h)\phi_i\phi_i'\right)^{-1}\left(\sum_{i=1}^{n} I(\|X_i - x\| \le h)\phi_i y_i\right)$$
$$= \left(\sum_{i=1}^{n} \mathrm{K}\left(H^{-1}(|X_i - x|)\right)\phi_i\phi_i'\right)^{-1}\left(\sum_{i=1}^{n} \mathrm{K}\left(H^{-1}(|X_i - x|)\right)\phi_i y_i\right) \tag{22}$$

In equation (22) $\mathrm{K}(.)$ represents the kernel function and h the bandwidth (or smoothing parameter) calculated by the least squares cross-validation data driven method as suggested by Li and Racine (2004)[3].

4. Data and empirical analysis

Our analysis is applied on the main Greek seaports for the time period 2006-2010 as has been reported by the Greek Seaport Authorities[4]. In addition for the construction of output distance functions two inputs and two outputs has been used. As described in table 1 the inputs used are total assets and number of employees and the outputs are number of passengers travelled and tonnes of merchandise. Moreover in order to examine how seaports' sizes influence their productivity levels two variables have been used as a proxy of seaport size (i.e. seaports' length and the number of terminals)[5].

Table 1 about here

In addition to table1, table 2 provides the average values of the MPI and its components following the three decompositions made over the examined time period. Looking at the average values of productivity (MPI) over the years we can conclude that only the time period of 2007-2008 the Greek seaports have been unproductive. But it must be mentioned that MPI index records the average product notion since it is

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[3]The selection of bandwidth h is very critical for our nonparametric regression analysis because when $h \to \infty$ (i.e. the smoothing is increased) the local linear estimator collapses to OLS regression of y_i on X_i.

[4] Access to statistics regarding the main Greek seaports can be obtained from: http://www.elime.gr/index.php/2011-09-16-07-14-33

[5] All the data can be accessed from Eurostat at http://epp.eurostat.ec.europa.eu/portal/page/portal/transport/data/database and from the Hellenic Statistical Authority at: http://www.statistics.gr/portal/page/portal/ESYE.

measured under the assumption of constant returns to scale (equation 6). However as has been suggested by Grosskopf (2003) the "true" underline technology can also exhibit variable returns to scale.

Table 1: Descriptive statistics of the variables

	Total Assets (in €)	*Number of employees*	*Number of passengers traveled*	*Tonnes of merchandise*
		2006		
Mean	50190011.583	199.083	2000303.833	3736001.583
Std	78842850.283	445.542	3120408.019	6770485.700
Min	1596429.000	5.000	129684.000	113933.000
Max	241181543.000	1523.000	11539254.000	19948271.000
		2007		
Mean	50290232.333	205.667	2019547.500	4185224.667
Std	82463851.080	467.873	2975557.478	7032124.616
Min	1365263.000	8.000	150202.000	114375.000
Max	272169456.000	1605.000	11062987.000	20121916.000
		2008		
Mean	53654117.750	210.250	2012360.917	3085928.167
Std	88763745.384	483.465	3005180.250	4959441.547
Min	1254527.000	8.000	163502.000	104140.000
Max	299885833.000	1671.000	11079057.000	16041842.000
		2009		
Mean	52936507.833	210.583	1979997.750	2981004.417
Std	108141820.797	478.797	2840453.979	4972125.658
Min	1123535.000	9.000	158179.000	76547.000
Max	375507622.000	1649.000	10444943.000	14963214.000
		2010		
Mean	54644019.500	180.083	1879955.000	3072681.583
Std	113278351.788	405.858	2610951.953	5212150.891
Min	1179818.000	8.000	100875.000	25645.000
Max	392661710.000	1396.000	9598418.000	16127224.000
	Seaport length (in metres)	*Number of terminals*		
Mean	2966.083	4.000		
Std	1951.295	2.000		
Min	1050.000	1.000		
Max	7140.000	6.000		

Table 2 provides the 95% lower (LB) and upper (UB) confidence intervals bounds as has been introduced by Simar and Wilson's (1999) bootstrap methodology. In addition table 2 provides seaports' technical change under the assumption of constant ($T\Delta_{CRS}$) and variable ($T\Delta_{VRS}$) returns to scale. The technical change under the constant returns to scale hypothesis ($T\Delta_{CRS}$) has been used in the decomposition provided by Färe et al. (1994a, 1994b) measuring the geometric mean of the magnitudes of Greek seaports technical change along rays (equations 7-9) through different periods (i.e. t+1 and t).

As can be realized this measure does not correspond to the best practice technologies therefore as Färe et al. (1994b) explained two other components must be introduced. These are the technical efficiency change ($TE\Delta_{VRS}$ measured under best practice technology) and the change in scale efficiency ($SE\Delta$). The results reveal that during the periods 2007-2008 and 2008-2009 Greek seaports have increased technical efficiency change (above 1) and decreased their scale efficiency change (i.e. below 1). In addition when looking at the results for $T\Delta_{CRS}$ we realize that seaports technical progress has been improved during the period of 2007-2008. But it must be noted that according to Lovell (2003) $T\Delta_{CRS}$ does not capture correctly the shift in seaports' frontier since it is calculated under the constant returns to scale.

Under the decomposition introduced by Ray and Desli (1997) seaports' technical progress is measured correctly by the factor $T\Delta_{VRS}$. The results reveal that Greek seaports have experienced technical progress under the periods 2006-2007 and 2009-2010 and not as reported by the $T\Delta_{CRS}$ during the period 2007-2008. According to Lovell (2003) and Grosskopf (2003) the MPI under the best practice technology is the product of $T\Delta_{VRS}$ and $TE\Delta_{VRS}$.

In addition a component or a 'residual' component (Grosskopf, 2003, p.466) is missing in order for the MPI under the VRS technology to be equal to the MPI given by the ratio of average product (i.e. under the assumption of CRS-as in our case). This component has been calculated by Ray and Desli (1997) and is the contribution of scale economies ($S\Delta$), which measures seaports' positive impact of expansion when having non-constant returns to scale (i.e. when SΔ >1). Therefore SΔ reflects the contribution of scale economies on seaports' productivity under the VRS technologies between two periods (equation 11). Thus the results reveal a positive contribution of scale economies to seaports' productivity levels for the periods of 2006-2007, 2008-2009 and 2009-2010.

Table 2: Descriptive per period statistics of Malmquist index, components and 95% bootstrap confidence intervals

min	**0.893**	*0.207*	*1.003*	**0.567**	*0.044*	*0.718*	**0.980**	*0.931*	*1.058*
max	**1.904**	*1.433*	*2.789*	**1.218**	*1.117*	*1.674*	**1.183**	*1.036*	*1.600*

	MPI	*LB*	*UB*	**TΔ$_{CRS}$**	*LB*	*UB*	**TΔ$_{VRS}$**	*LB*	*UB*	**TEΔ$_{VRS}$**	*LB*	*UB*
						2006-2007						
mean	**1.038**	*0.930*	*1.11*	**0.939**	*0.668*	*1.259*	**1.069**	*0.854*	*1.471*	**0.912**	*0.22*	*1.098*
std	**0.314**	*0.238*	*0.411*	**0.251**	*0.245*	*0.364*	**0.336**	*0.309*	*0.492*	**0.164**	*0.152*	*0.287*
min	**0.672**	*0.557*	*0.675*	**0.645**	*0.366*	*0.852*	**0.592**	*0.404*	*0.728*	**0.517**	*0.144*	*0.720*
max	**1.870**	*1.300*	*2.299*	**1.561**	*1.349*	*2.169*	**1.661**	*1.438*	*2.348*	**1.045**	*0.678*	*1.341*
						2007-2008						
mean	**0.889**	*0.824*	*0.949*	**1.053**	*0.658*	*1.538*	**0.886**	*0.499*	*1.293*	**1.015**	*0.015*	*1.368*
std	**0.258**	*0.257*	*0.267*	**0.214**	*0.174*	*0.324*	**0.122**	*0.082*	*0.204*	**0.261**	*0.186*	*0.350*
min	**0.451**	*0.416*	*0.452*	**0.788**	*0.424*	*1.147*	**0.647**	*0.228*	*0.865*	**0.416**	*0.109*	*0.505*
max	**1.497**	*1.416*	*1.545*	**1.497**	*0.933*	*2.255*	**1.070**	*0.722*	*1.652*	**1.622**	*0.804*	*2.076*
						2008-2009						
mean	**1.019**	*0.920*	*1.108*	**0.969**	*0.409*	*1.212*	**0.948**	*0.404*	*1.154*	**1.054**	*0.722*	*1.452*
std	**0.324**	*0.268*	*0.440*	**0.075**	*0.032*	*0.111*	**0.086**	*0.011*	*0.146*	**0.218**	*0.142*	*0.314*
min	**0.755**	*0.677*	*0.757*	**0.857**	*0.289*	*1.043*	**0.825**	*0.207*	*0.902*	**0.830**	*0.483*	*1.140*
max	**1.836**	*1.472*	*2.268*	**1.084**	*0.616*	*1.407*	**1.076**	*0.552*	*1.379*	**1.677**	*1.355*	*2.366*
						2009-2010						
mean	**1.021**	*0.957*	*1.080*	**0.865**	*0.561*	*1.148*	**1.035**	*0.831*	*1.371*	**0.977**	*0.444*	*1.165*
std	**0.246**	*0.225*	*0.261*	**0.141**	*0.136*	*0.211*	**0.149**	*0.019*	*0.231*	**0.122**	*0.101*	*0.184*
min	**0.546**	*0.515*	*0.596*	**0.612**	*0.021*	*0.843*	**0.749**	*0.380*	*0.972*	**0.663**	*0.116*	*0.757*
max	**1.505**	*1.288*	*1.618*	**1.172**	*1.024*	*1.656*	**1.249**	*1.043*	*1.685*	**1.205**	*0.666*	*1.549*

	SEΔ	*LB*	*UB*	**SBTΔ**	*LB*	*UB*	**SΔ**	*LB*	*UB*
					2006-2007				
mean	**1.263**	*0.789*	*1.647*	**0.919**	*0.563*	*1.115*	**1.158**	*1.071*	*1.429*
std	**0.354**	*0.262*	*0.577*	**0.170**	*0.062*	*0.190*	**0.338**	*0.317*	*0.692*
min	**1.000**	*0.309*	*1.062*	**0.520**	*0.019*	*0.663*	**0.953**	*0.929*	*0.981*
max	**2.017**	*1.212*	*2.852*	**1.198**	*1.050*	*1.437*	**2.196**	*2.087*	*3.501*
					2007-2008				
mean	**0.871**	*0.369*	*1.140*	**1.172**	*0.505*	*1.555*	**0.954**	*0.877*	*1.022*
std	**0.215**	*0.161*	*0.245*	**0.313**	*0.197*	*0.607*	**0.108**	*0.037*	*0.195*
min	**0.442**	*0.292*	*0.621*	**0.898**	*0.510*	*0.934*	**0.765**	*0.375*	*0.786*
max	**1.245**	*1.017*	*1.536*	**2.083**	*0.970*	*3.168*	**1.118**	*1.057*	*1.430*
					2008-2009				
mean	**0.996**	*0.526*	*1.252*	**1.024**	*0.674*	*1.306*	**1.012**	*0.958*	*1.137*
std	**0.211**	*0.170*	*0.366*	**0.084**	*0.010*	*0.191*	**0.188**	*0.162*	*0.421*
min	**0.760**	*0.064*	*0.985*	**0.902**	*0.275*	*1.047*	**0.846**	*0.530*	*0.946*
max	**1.61**	*0.930*	*2.277*	**1.182**	*0.983*	*1.644*	**1.536**	*1.426*	*2.356*
					2009-2010				
mean	**1.228**	*0.817*	*1.593*	**0.881**	*0.598*	*1.069*	**1.060**	*1.044*	*1.200*
std	**0.303**	*0.135*	*0.566*	**0.182**	*0.054*	*0.266*	**0.056**	*0.029*	*0.145*

Finally, a similar scale bias component (SBTΔ) has been introduced by several authors (Gilbert and Wilson, 1998; Simar and Wilson, 1998a; Zofio and Lovell, 1998; Wheelock and Wilson, 1999) and represents the changes of seaports' scale efficiencies between two periods (see equation 12-13). Therefore, if there are differences between the scale efficiencies between two periods then seaports' technical change ($T\Delta_{VRS}$) exhibits a scale bias. According to Lovell (2003, p. 456) it measures the shift in seaports' technical optimal scale between two period technologies and can contribute to or detract from productivity growth. The results reveal such contribution to seaports' productivity growth for the periods 2007-2008 and 2008-2009.

Table 3 provides the average values of MPI index and its components as has been presented previously following the three decompositions. It also provides the results obtained following the bootstrap procedure by Simar and Wilson (1999) presented previously. Therefore, in the case of MPI it is reported that the seaport Igoumenitsa Port Authority S.A. is productive over the years with an average productivity of 1.172. The asterisks indicate that the value obtained is statistically significant at 95% different from unity, following the bootstrap procedure presented previously.

Furthermore, statistically significant differences from unity are reported for the seaports of Volos Port Authority S.A., Lavrion Port Authority S.A., Piraeus Port Authority S.A and Rafinas Port Authority S.A. However, as can be realised these ports have reported to be unproductive over the time period of 2006-2010. In addition all the rest of the seaports are reported to have statistically insignificant productivity values at 95% indicating overall neutral productivity behaviour over the examined period. The $T\Delta_{CRS}$ under calculated under the Färe et al. (1994a, 1994b) decomposition reveals a statistical significant decline of Greek seaports technical progress under the examined period.

More specifically the ports of Volos Port Authority S.A., Eleusis Port Authority S.A., Iraklion Port Authority S.A., Thessaloniki Port Authority S.A., Kavala Central Port Authority S.A., Corfu Port Authority S.A., Lavrion Port Authority S.A., Piraeus Port Authority S.A. and Rafinas Port Authority S.A. are reported to have statistically significant $T\Delta_{CRS}$ values below unity indicating that they had a decrease on their technical change (under the assumption of CRS) over the years. However, when we account for the best practice technologies (i.e. under the assumption of VRS- $T\Delta_{VRS}$) the results reveal that five seaports have reported a decline and one seaport an incline of their technical progress over the years.

Under the decompositions of Ray and Desli (1997) and several authors (Gilbert and Wilson, 1998; Simar and Wilson, 1998a; Zofio and Lovell, 1998; Wheelock and Wilson, 1999) the seaports with a decrease on their technical change are Alexandroupolis Port Authority S.A., Eleusis Port Authority S.A., Corfu Port Authority S.A., Piraeus Port Authority S.A. and Rafinas Port Authority S.A. But the seaport of Igoumenitsa Port Authority S.A. is the only seaport reporting an increase of its technical change over the examined period. Moreover, as it is reported three seaports have decreased their technical efficiency change ($TE\Delta_{VRS}$) over the years. Under all the decompositions presented previously the seaports of Volos Port Authority S.A., Lavrion Port Authority S.A. and Patras Port Authority S.A. have decreased their technical efficiency change over the years, whereas the rest of the seaports are reporting to have a stagnated technical efficiency change level.

Furthermore, under the decompositions of several authors (Färe et al., 1994b; Gilbert and Wilson, 1998; Simar and Wilson, 1998a; Zofio and Lovell, 1998;

Wheelock and Wilson, 1999) five seaports have reported positive change on their scale efficiency (SEΔ) levels and three seaports a negative change. Following again the bootstrap approach by Simar and Wilson (1999) the seaports with a positive scale efficiency change are Volos Port Authority S.A., Iraklion Port Authority S.A., Thessaloniki Port Authority S.A., Kavala Central Port Authority S.A. and Lavrion Port Authority S.A. Similarly the ports with the negative change on SEΔ are Alexandroupolis Port Authority S.A., Piraeus Port Authority S.A. and Rafinas Port Authority S.A.

Moreover, the SBTΔ factor according to Lovell (2003) represents the scale bias of seaports' technical change over the years. It appears that four ports have values below unity with 95% statistical significance, indicating that the shift in their technically optimal scales has been detracted from their productivity growth. The seaports with a reported scale bias are Igoumenitsa Port Authority S.A., Iraklion Port Authority S.A., Thessaloniki Port Authority S.A. and Kavala Central Port Authority S.A. Finally, under the decomposition provided by Ray and Desli (1997) the scale change factor (SΔ) indicates that only in the case of Lavrion Port Authority S.A. a statistically significant positive contribution (1.327) of seaport's scale economies on its productivity levels over the examined periods has been obtained. For all the other seaports it appears that their scale economies have a neutral effect on their productivity levels.

Following Li et al. (2009) we apply a test of equality density functions defined over the MPI and its components between the examined periods. Additionally we have bootstrap methods for obtaining the statistic's null distribution and the least squares cross-validation method in order to smooth the MPI and its components as analytically described in Li et al. (2009). Under the null hypothesis the two distributions examined are equal, whereas under the alternative the two distributions examined are not equal.

Table 3: Average values of Malmquist productivity index and its decomposition components

Seaports	MPI	$T\Delta_{CRS}$	$TE\Delta_{VRS}$	$SE\Delta$	$T\Delta_{VRS}$	$SBT\Delta$	$S\Delta$
Alexandroupolis Port Authority S.A.	0.984	1.000	1.000	0.973**	0.985**	0.999	1.046
Volos Port Authority S.A.	0.950**	0.940**	0.985**	1.324**	1.051	1.070	1.034
Eleusis Port Authority S.A.	0.962	0.923**	1.009	1.038	0.928**	1.021	1.006
Igoumenitsa Port Authority S.A.	1.172**	1.095	1.000	1.049	1.132**	0.969**	1.016
Iraklion Port Authority S.A.	1.168	0.986**	1.046	1.125**	1.023	0.964**	1.074
Thessaloniki Port Authority S.A.	1.018	0.936**	1.000	1.137**	1.000	0.953**	1.016
Kavala Central Port Authority S.A.	1.078	0.964**	1.033	1.114**	1.082	0.933**	0.998
Corfu Port Authority S.A.	0.984	0.984**	1.000	1.000	0.970**	1.015	1.015
Lavrion Port Authority S.A.	0.868**	0.838**	0.890**	1.304**	0.841	1.007	1.327**
Patras Port Authority S.A.	1.001	1.027	0.913**	1.070	1.025	1.001	1.066
Piraeus Port Authority S.A.	0.831**	0.895**	1.000	0.951**	0.907**	0.996	0.909
Rafinas Port Authority S.A.	0.883**	0.893**	1.000	0.989**	0.871**	1.059	1.047

*The "**" indicate that the index is significantly different from unity at the 5% level*

Table 4 presents the results of the test obtained and the asterisks indicate the bootstrap *p-value* obtained under 1%, 5% and 10% significance levels. As it appears for the case of MPI we can realise that we cannot reject the null hypothesis of equality of seaports' MPI distributions over the years. The same result applies also for the technical efficiency change ($TE\Delta_{VRS}$), which indicates that seaports have the same $TE\Delta_{VRS}$ distribution over the years. In addition with the results revealed previously we can assume that over the years the policies' imposed to the Greek seaports had insignificant effect on their productivity and efficiency change levels.

In a similar manner it can be observed from the results presented in table 4 that few are the cases where the distributions are not equal between the examined periods. For instance when looking at the $T\Delta_{VR}$ we can realise that the distributions are not equal between the periods of 2006-07 and 2007-08, also between the 2008-09 and 2009-10 and finally between 2007-08 and 2009-10, implying that seaports' technical progress between those periods have changed. Similar results for rejecting the null hypothesis at different statistical levels of significance are reported for some cases of SΔ, SBTΔ, $TΔ_{CRS}$ and SEΔ.

Table 4: Consistent density equality test for Malmquist productivity index and its components over the examined periods

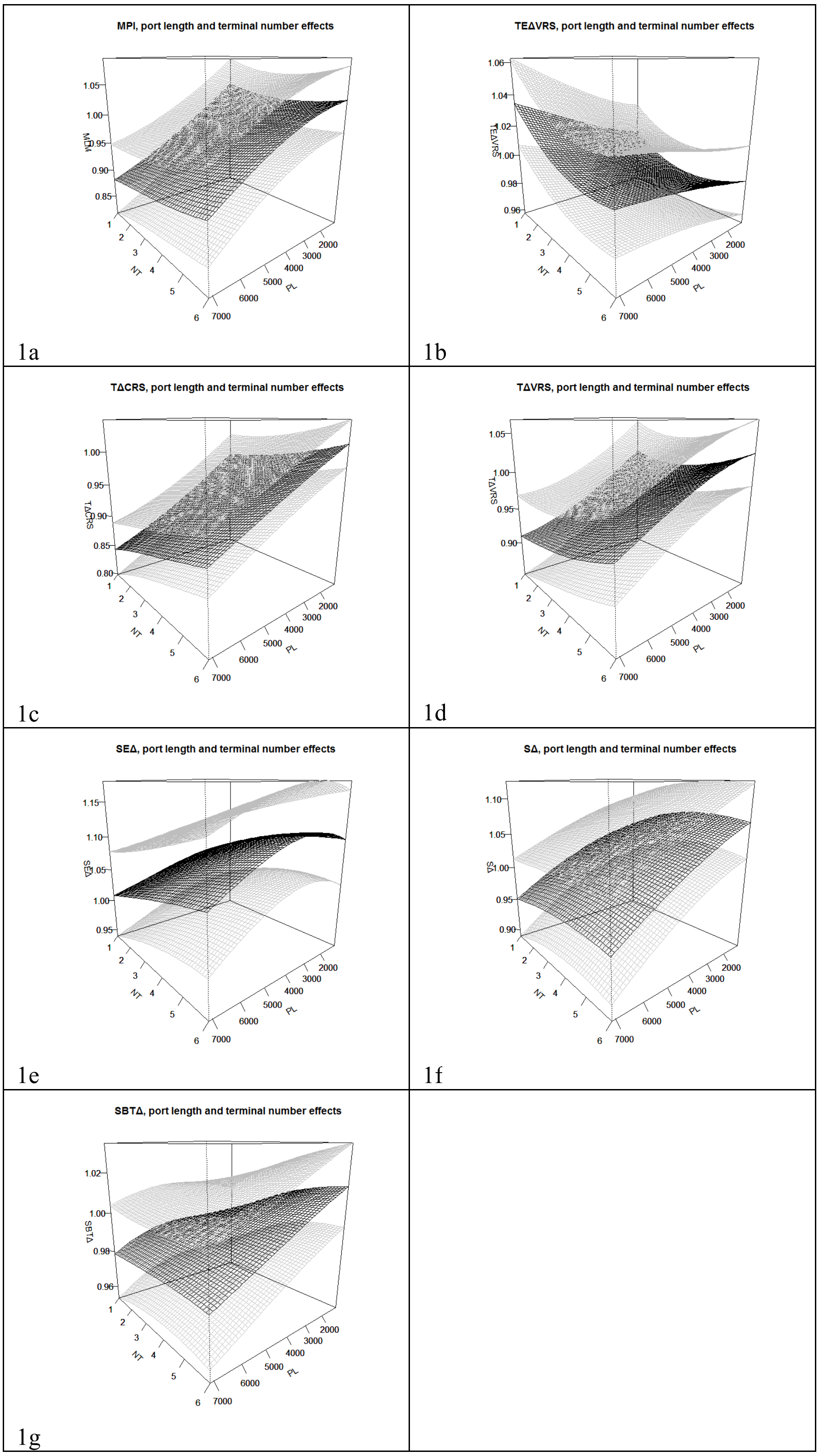
MPI				**$TEΔ_{VRS}$**			
Years	*2007-08*	*2008-09*	*2009-10*	***Years***	*2007-08*	*2008-09*	*2009-10*
2006-07	0.212	0.670	0.040	*2006-07*	-2.434	-1.202	-0.960
2007-08		0.167	0.170	*2007-08*		0.412	2.090
2008-09			0.002	*2008-09*			1.310
$TΔ_{CRS}$				**$TΔ_{VRS}$**			
Years	*2007-08*	*2008-09*	*2009-10*	***Years***	*2007-08*	*2008-09*	*2009-10*
2006-07	0.430	2.711*	0.696	*2006-07*	1.056***	1.749	0.412
2007-08		1.622	0.739*	*2007-08*		1.252	1.059*
2008-09			1.083*	*2008-09*			2.785***
SEΔ				**SΔ**			
Years	*2007-08*	*2008-09*	*2009-10*	***Years***	*2007-08*	*2008-09*	*2009-10*
2006-07	0.195	-0.357	-0.959	*2006-07*	2.724	1.870	4.547
2007-08		-0.196	0.926*	*2007-08*		-1.252	2.376*
2008-09			0.818*	*2008-09*			3.658*
SBTΔ							
Years	*2007-08*	*2008-09*	*2009-10*				
2006-07	-0.115*	1.708	-0.249				
2007-08		3.089	1.706				
2008-09			0.827*				

**** p-value < 0.001., ** p-value < 0.05; * p-value < 0.1*

Moreover, as presented previously we apply a local linear kernel regression in order to see how the size of seaports affected their productivity levels and their components. As a proxy of size we have used in our analysis two variables (seaport length-PL and the number of terminals-NB). Figure 1 presents graphically the combined effect[6] of these two variables on the obtained productivity measures and its components. As can be observed the effect of seaports' length (PL) is negative on

[6] In addition figure 1 presents the variability bounds of pointwise error bars using asymptotic standard error formulas (Hayfield and Racine, 2008).

Figure 1: The effects of seaports length (PL) and number of terminals (NB) on their productivity levels



their obtained productivity levels (i.e. when seaport's length increases its productivity decreases). The same effect appears also in the case of seaports' technical progress (both for CRS and VRS case), scale efficiency change, scale bias and for scale change factor. However a positive effect of seaports' length on its technical efficiency change is observed.

Finally, when examining the effect of number of terminals on seaports' productivity over the examined periods, a positive effect for MPI, TΔ (both for CRS and VRS case) and for SEΔ is recorded. As well it appears that seaports' number of terminals has a neutral effect on seaports' SΔ and SBTΔ levels. At the same time, it is observed that seaports' terminal number has a negative effect on their technical efficiency change over the years. As a general result we can interpret the findings that number of terminals within a seaport is more important than seaport's absolute length.

5. Conclusion

The paper contributes to the existing literature in two distinct ways. First and in respect to methodologies applied, to our knowledge is the first study applying three different decompositions of Malmquist productivity indexes as has been introduced by several authors (Färe et al., 1994a; 1994b; Ray and Desli, 1997; Gilbert and Wilson, 1998; Simar and Wilson, 1998a; Zofio and Lovell, 1998; Wheelock and Wilson, 1999). In addition we apply the bootstrap approach (Simar and Wilson, 1999) on the obtained MPI and its components in order to verify if the indicated changes are significant in a statistical sense or if there are products of sampling noise.

The second contribution of the paper lies on the application of a real case study in the case of Greek seaports. The productivity and its components are calculated for the period of 2006-2010 and in a second stage analysis using a local linear kernel model the effect of their sizes on the obtained productivity levels is calculated. The results reveal that there are several productivity disparities among the Greek seaports.

Under different decompositions it appears that the Greek seaports suffered from stagnation of technological progress over the years. At the same time, the empirical findings from these different decompositions indicate that Greek seaports' scale effects have caused their productivity to decrease over the years. Finally, the second stage nonparametric analysis revealed that Greek seaports' length has a negative effect on their productivity growth, whereas the number of terminals has a positive effect.

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