# Efficiency and productivity changes in Greek airports during the crisis years 2010-2014

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**Abstract**

The aim of this study is to evaluate the operating efficiency and productivity changes of the Greek airports, during the first years of the severe economic crisis in Greece (2010-2014), by using two methods: Data Envelopment Analysis (DEA) and Malmquist Productivity index (MPI). Findings have shown that, despite the dramatic effects of the economic crisis on the socio-economic life of the country, overall airport efficiency and productivity improved, mainly due to exogenous factors such as international tourism growth. The MPI reveals that over the period of the study, airports have experienced an annual average increase in total factor productivity (TFP) of 0.9% (an increase of 3.6% over the examined period). On examining the components of this productivity change, it becomes evident that this is due to the combination of both positive (a slight progress) annual average technology change (0.5%) and technical efficiency change (0.4%). The results also indicate that 65.8% of airports have an increase in average TFP during the period 2010–2014, ranging between 0.4% and 20%. However, as Greek airports operate at poor levels of efficiency, there is still considerable space for improvements in most of the airports.

*Keywords*: Greek Airports, Airport Performance, Economic Crisis, Tourism, DEA, Malmquist index

## 1. Introduction

Since May 2010, “Greece has been receiving financial support from Euro Area Member States and the International Monetary Fund (IMF) to cope with its financial difficulties and economic challenges. This support comes in the form of economic adjustment programs, which include measures to support the Greek government’s efforts to address economic imbalances, tackle social challenges, and pave the way for sustainable economic growth and job creation” (EU, 2016). In an effort to meet economic reform targets, the Greek Government invited on March of 2013 private investors to submit offers for the concession of the right to use, operate, manage and exploit 14 out of the 38 Regional Airports owned by the Greek State (Hellenic Republic Asset

Development Fund-HRADF-2013)[1]. In December 2015 HRADF and a consortium comprising of the German group Fraport and Slentel (a unit of the Greek Kopelouzos energy group) signed an agreement for the concession of 14 regional airports. This was ratified by the Greek Parliament in June 2016. The privatization is still in progress and is expected to be finalized in autumn 2016.

Over the years, Greek airports have been owned and managed by the Greek Government through the supervision of the Hellenic Civil Aviation Authority (HCAA-YPA in Greek), which is a public authority under the Ministry for Infrastructure, Transport and Networks. HCAA was established in 1926 and its mission was the organization, development, and control of the country's air transport infrastructure, as well as the research concerning the overall air transport policy. Despite changes that occurred due to Greece entering the EU in 1981, the Greek state has been solely responsible for the maintenance, development and management of Greek airports, with the exception of the new Athens International Airport (AIA) which became the country's first international airport under private management in 1995.

Greece´s geomorphology includes 80% mountainous terrain and about 1400 islands, of which about 227 are inhabited and vary greatly in size, population, and development. Due to the insular specificity, Greece has an impressively large number of airports relating to its size: 39 airports used for civil aviation in total country area of 131,957 sq. km whereas Spain, for instance, has only 50 airports in a total area of 505,951 sq. km (Eurostat, 2015). As a result, air transport is a critical factor both for the social coherence and economic development of the country. It is characteristic that only in 2014 the air transport sector accounted for 807 million Euros of Greek national generated income, recording a 15,7% increase of its contribution over the years of 2010-2014 (ELSTAT, 2015).

More than its direct importance for the country´s development, air transport remains simultaneously the main catalyst for tourism, one of the main production sectors of the country. "Tourism, both for business and leisure purposes, makes a large contribution to the Greek economy, with foreign

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1 The concession process grouped Greek airports into 2 clusters: Cluster A includes the airports of Thessaloniki, Corfu, Chania, Kefalonia, Zakynthos, Aktion and Kavala and Cluster B includes the airports of Rhodes, Kos, Samos, Mitilini, Mykonos, Santorini, and Skiathos. Three of the 14 airports are located on the mainland (Thessaloniki, Aktio and Kavala) while the rest serve insular destinations.

visitors contributing over €10.2 billion in the Greek economy each year. Over 70% of these visitors arrive by air, so passengers who arrive by air probably spend around €7.5 billion in Greece" (Oxford Economics, 2011). World Travel & Tourism Council (WTTC, 2015) economic data for 2015 estimated a 7,6% direct contribution of tourism to Greek GDP (at market prices) and a total (direct, indirect and induced) contribution of 18,5% of the National GDP. Similar tendencies apply in respect to tourism's contribution to generated employment which, by the end of 2015 accounted for 23% of the country's total (direct and indirect) generated jobs.

Greek tourism endeavours to maintain its pace in a globalized market. In 2015, just the number of international arrivals numbered more than 22 million, which is more than double the country's population, not including cruising passengers and economic immigrants. During the study period, international arrivals increased by a spectacular 46,5%, ranging from 15 million in 2010 to 22 million in 2014 (Eurostat, 2015). The ratio of tourist arrivals to population was 2.2 in 2014, compared to 1.23 for Spain, 0.77 for Italy, 0.71 for Portugal, and 0.47 for Turkey (compiled by authors based on World Bank accessed through Quandl, 2015).

HCAA data for the period 2010-2014 shows an increase of 16% on the total number of arrivals by air. It is important to underline that this increase is mainly the result of incoming tourists both on scheduled and charter flights. At the same time, Greek domestic traffic decreased by 3% over the same period, mainly reflecting the effects of the economic crisis. So the trends of increasing international tourism flows went in parallel to restricted domestic mobility to tourism accommodation establishments (Eurostat, 2015).

As the above mentioned figures indicate, air transport sector has the potential to strongly contribute directly and indirectly to the economic performance of the country. Until airports privatization is fully implemented, all 38 Greek airports are owned and centrally managed by the HCAA. As a result, they all apply the same policies concerning user charges and, at the same time, they lack commercial strategy and management, as would be applied by business decision making units (DMUs) (Fragoudaki and Giokas, 2016). Following the privatization, HCAA will retain its role as regulator of aeronautical services and provider of air-traffic control services as well as the manager of the remaining airports.

As in the global aviation industry the role of airports has changed, “from places where airplanes land and take off and where passengers and cargo are handled, airports are transformed from simple public utilities into business entities that successfully operate in an increasingly competitive environment” (Oxford Economics, 2008), it is necessary for Greek airports to change their orientation and develop a commercial strategy taking into account the changing external environment. Within this context, this paper aims to evaluate the operating efficiency and productivity changes of the Greek airports during the first five years (2010-2014) of the severe economic crisis in Greece.

The analysis considers all 38 Greek airports currently open to civil aviation, excluding Athens International Airport. According to HCAA (2015) there are three categories of airports: Category I includes 15 “international airports”, including Athens International Airport; Category II includes 26 “national airports”, that also accommodate international traffic, and Category III includes four “municipal airports”. Despite this historical classification, many airports are designated “points of entry and exit”, and as such, all but eight airports accommodate both domestic and international traffic depending on tour operator demand. Out of these, 28 are island-based and only 10 are located on the mainland. Finally, 12 of these airports are of mixed civil and military use.

Following this introductory section on the current state and contribution of Greek airports during the first years of economic crisis, Section 2 summarizes literature applications of Data Envelopment Analysis (DEA) and Malmquist Productivity Index on airport performance. After a short presentation of the methodology in Section 3, Section 4 presents the data and discusses the empirical results derived by applying this methodology. Summary and concluding remarks are presented in Section 5.

## 2. Literature Review: Airport performance analysis using DEA and Malmquist Index

The assessment of relative competitive position and the value of continuous performance appraisal are focal points of airport managers. “Investors and bankers that are interested in airport privatization want to use benchmarking techniques to identify possible business opportunities” (Graham, 2005). As a result, various studies have utilized a variety of techniques for airport benchmarking (Ibid).

Data Envelopment Analysis (DEA) has been applied in many studies aiming to analyze the efficiency of airports around the world. Malmquist index on the other hand has been used to examine productivity changes over time. A number of studies using those methodologies are presented here. DEA was used by Sarkis (2000) to evaluate the operational efficiencies of 44 major US airports and put forward that airlines tend to favor more efficient airports. Martin and Roman (2001) used DEA to measure the efficiency of Spanish airports prior to privatization. Fernandes and Pacheco (2002) used DEA to analyze the capacity of 35 domestic Brazilian airports in order to monitor which of them were efficient in terms of passenger processing and use of airport resources. Yoshida and Fujimoto (2004) used DEA to measure the relative efficiency of Japanese airports and discuss the criticism whether there is any over-investment in Japanese regional airports. Barros and Dieke (2007) analyzed the financial and operational performance of Italian airports with panel data for 2001–2003, aiming to examine the relative roles of dimension, managerial status, and workload unit (WLU) in determining the proximity of airports to the frontier of best practices. Wei and Hongshan (2010) used DEA to compare the productivity of ten airports around the Yangtze River Delta, considering both desirable and undesirable outputs, such as delays, and arguing that there may be a balance between quantity and quality of outputs. Barros (2008) also used DEA, for examining the technical efficiency of airports in Argentina, and analyzed the results in the context of economic crisis during the period 2003-2007. Despite the crisis the eight efficient airports maintained their efficiency during this crisis period. At the same time "major airports were largely immune to the economic crisis, small regional airports emerge as more sensitive".

Barros and Weber (2009) used DEA to estimate the Malmquist input based index of total factor productivity for 27 UK airports during the 2000/1 to 2004/05. Productivity change was factored into an index of efficiency change and an index of technological change, which was further decomposed into indices that measure the bias in the production of outputs, the bias in the employment of inputs and the magnitude of the shift of the production frontier. Study findings highlighted that UK airports experienced average decrease in productivity during the study period, becoming less efficient and facing technological regress. At the same time no clear relationship emerged between ownership and productivity improvement or regulation. Gitto and Mancuso (2012) used DEA to evaluate the impact of regulatory reforms on the technical efficiency of 28 Italian airports during 2000–2006; their analysis utilizes two models, operations and monetary, to analyze management's exploitation of aeronautical and non-aeronautical business. Wanke (2013) employed a DEA approach to measure the efficiency of Brazilian airports, studying physical infrastructure and aircraft operations followed by flight consolidation efficiency in terms of traffic volumes. Chang et al. (2013), used DEA to examine the technical efficiency of 41 Chinese airports and then regressed on environmental factors assessing whether geographical characteristics and service strategies influence the performance of Chinese airports. Most recent studies include those of Merkert and Mangia (2014), who studied the cost efficiency of 35 Italian and 46 Norwegian airports over time, applying a DEA approach to evaluate the role of competition (both from other airports and from surface transport) as a key determinant for efficiency. Millan et al. (2014) applied DEA to analyze the efficiency and productivity of 35 Spanish airports using panel data for the period 2009-2011. Results showed that during those crisis years Spanish airports experienced a dramatic productivity regress due to the reduction of their technological change component. Also it was shown that airport size had a positive impact on the technical and scale efficiency and the presence of low cost carriers had positively affected the scale efficiency of airports where they were present.

DEA has been used in the three studies on Greek airports performance. Tsekeris (2011) used DEA to compare the performance of Greek airports, considering their relative technical efficiencies and examining determining factors such as seasonality, location, size, and operating characteristics, for example, operating hours. Also Psaraki-Kalouptsidi and Kalakou (2011) used DEA to assess the efficiency of Greek airports for the period 2004–2007 and assessed the efficiency of Greek airports first by evaluating airside and landside infrastructure and then by analyzing economic efficiency. Fragoudaki and Giokas (2016) applied DEA in conjunction with a Tobit censored regression model to measure the relative efficiency of Greek airports and the determining factors. Original and bootstrap efficiency measurements showed that, in general, there is considerable space for improvements in most of the Greek airports. Further analysis into the relationship between the efficiency scores and the factors that may affect airport efficiency indicated that island location, connectivity and hotel infrastructure in the area were significant factors affecting airport efficiency.

Malmquist productivity index was used by Chow and Fung (2012) to measure productivity changes in 30 airports in Greater China during the period 2000-2006. Study findings showed that on average productivity of airports increased by 10.3% annually over this period. The Malmquist productivity index analysis showed that the most salient progress was observed in regional airports rather than the major international hubs. In addition, changes in overall productivity were mostly explained by technical change. Ahn and Min (2014) used DEA intended for dynamic benchmarking and Malmquist productivity index built on a time series analysis to evaluate the comparative efficiencies of major international airports for a multi-year period 2006-2011. The study findings indicated that the productivity of an airport was influenced by exogenous factors such as technological advances and shifts in Government policies rather that endogenous factors such as improvements in managerial practices. In turns of the Malmquist productivity index that is that the productivity of an airport was influenced by a technical change index (TCI) rather than a technical efficiency change index (TECI).

Abbott (2015) studied the efficiency performance of New Zealand's airports in the context of structural reform. Malmquist Data Envelopment Analysis was used in the first part of his study to estimate the productivity change of the country's three largest airports over the period 1991/92 and 2011/12. It is noted that partial productivity measures were also used to reinforce the analysis. DEA in a two stage process was used in the second part of his study to determine the impact of type of ownership and scale economies on efficiency levels. Findings highlighted that larger airports were more efficient than smaller ones and that jointly owned airports were less efficient. Overall the efficiency and productivity of the three largest airports had improved over time. This was also reflected on the partial productivity measures which included labor and capital productivity indicators. Extended literature review on airport efficiency using DEA and Malmquist index can be viewed in Ahn and Min (2014).

## 3. Methodology

### 3.1 Data Envelopment Analysis

Before applying the proposed methodology to the actual problem, this section presents the basic characteristics of DEA and Malmquist Productivity Index. Since the proposed models are well established and extensively applied in the literature, their discussion is limited in this paper. A brief description of the used models is outlined.

DEA is a non-parametric mathematical programming technique developed by Charnes et al. (1978), which is based on an efficiency concept originally introduced by Farrell 1957. The technique is used to estimate the relative efficiency of homogenous Decision Making Units (DMUs) within a data set by constructing efficiency frontiers. Such DMU's (here airports) are homogenous units that utilize multiple inputs to produce multiple outputs. Any unit on the frontier is considered 100% efficient and the units positioned below the frontier are considered inefficient (less than 100%

efficient). Various mathematical forms of DEA model have been suggested in the literature (Cooper et al. (2007); Cook and Seiford (2009), since the efficiency concept was first proposed by Farrell (1957). The most popular, among them are the CCR and BCC models. CCR is the original model o DEA. The original mathematical model of DEA by Charnes et al.(1978), known as CCR model assumes constant returns to scale (CRS) relationship between inputs and outputs, while the BCC model introduced by Banker et al. (1984) is used under the assumption of variable returns to scale (VRS).

The initial CCR output – oriented model (in envelopment form), can be stated as follows:

$$
\begin{aligned}
&\mathrm{Max}\,\theta_0 + \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+\right)\\
&\text{subject to}\\
&\sum_{j=1}^{n}\lambda_j x_{ij} + s_i^- = x_{i0} \quad , \qquad i = 1,2,\ldots, m; \qquad\qquad (1)\\
&\sum_{j=1}^{n}\lambda_j y_{rj} - s_r^+ = \theta_0 y_{r0} \ , \qquad r = 1,2,\ldots.. s;\\
&\lambda_j \, , s_i^- , s_r^+ \geq 0 \, , \forall \ j, \ j = 1,2,\ldots n \ ; 0 < \varepsilon <<< 1.
\end{aligned}
$$

Where: m is the number of inputs, s is the number of outputs and n is the number of airports (DMUs) used in the evaluation; $\theta_0$ is the radial efficiency factor showing the proportional increase in output levels of the airport 0; $\lambda_j$ is the intensity factor showing the contribution of airport j in the derivation of the efficiency of airport 0; $x_{ij}$ is the amount of the ith input used by the jth airport; $y_{rj}$ is the amount of the r output produced by the jth airport; $\varepsilon$ is a small positive number to ensure that the inputs and the output have at least some weighting in the efficiency measure; and $s_i^-$ , $s_r^+$ are input and output slack variables

The efficiency rating of the "0" airport is given by the index $z_0^* = 1/\theta_0^*$, where $\theta_0^*$ is the optimal value of the $\theta_0$ . Airports which $z_0^* = 1$ are characterized as relative efficient or benchmark airports, while airports for which $z_0^* < 1$ are lie inside the frontier and characterized as inefficient.

Note that the above original model (CCR) uses CRS, as pointed out previously. Banker et al. (1984) extended the above original model to account for the existence of VRS. The VRS model (known as BCC model) can be obtained through the addition of a convexity constraint to model (1) requiring that the multipliers $\lambda_j$ add up to 1 $\left(\sum_{j=1}^{n}\lambda_j = 1\right)$. In this study, the airports were analyzed using output oriented BCC model.

## 3.2 Malmquist Productivity Index

The approach is standard and is detailed in Coelli et al. (1998), and therefore only a short description is provided here. In order to measure productivity changes of each airport over the period 2010-2015, the Malmquist productivity index (MPI) was used. MPI as a concept has been influenced by early work done by Malmquist (1953), has been introduced as a theoretical index by Caves et al. (1982), and became more popular as an empirical index by Fare et al. (1994a). The Malmquist index evaluates the productivity change of a unit (here an airport) between two time periods, by calculating the ratio of the distance function for each year relative to a common technology. On the assumption that the airport seeks to maximize output for a given level of input (i.e. an output-oriented approach), Fare et al.(1994a), using the period t+1 benchmark technology, defined the output- oriented MPI between period t and period t+1 (base period), as follows:

$$MPI_0^{t+1} = \frac{d_0^{t+1}(y_{t+1}, x_{t+1})}{d_0^{t+1}(y_t, x_t)} \qquad (2)$$

Where the subscript "0" indicates the unit under evaluation, ($y_{t+1}$, $x_{t+1}$) is the most recent production point, ($y_t$, $x_t$) is the earlier production point, $d_0^t(y_{t+1}, x_{t+1})$ and $d_0^t(y_t, x_t)$ are the distance functions for unit "0" observed at time t+1 and t, respectively.

Using period t-technology the MPI is as follows:

$$MPI_0^{t} = \frac{d_0^{t}(y_{t+1}, x_{t+1})}{d_0^{t}(y_t, x_t)} \qquad (3)$$

To avoid the need to choose arbitrarily one of the two technologies, the $MPI_0$ can be defined as a geometric mean of the two indices, evaluated with respect to period t and period t+1 technologies (Fare et.al, 1994a) as follows:

$$MPI_0 = \left[ \frac{d_0^t(y_{t+1}, x_{t+1})}{d_0^t(y_t, x_t)} \, x \, \frac{d_0^{t+1}(y_{t+1}, x_{t+1})}{d_0^{t+1}(y_t, x_t)} \right]^{1/2} \qquad (4)$$

Fare et al. (1994a) further suggested that this index can be decomposed further into two components: one describing the change in technical efficiency (EC) over the two periods (i.e. whether or not the airport is getting closer to its efficiency frontier over time) and another reflecting the technological change (TC) (i.e. whether or not the frontier is shifting out over time).

$$MPI_0 = \underbrace{\frac{d_0^{t+1}(y_{t+1}, x_{t+1})}{d_0^t(y_t, x_t)}}_{Efficiency\ \text{change (EC)}} \underbrace{\left[ \frac{d_0^t(y_{t+1}, x_{t+1})}{d_0^{t+1}(y_{t+1}, x_{t+1})} x \frac{d_0^t(y_t, x_t)}{d_0^{t+1}(y_t, x_t)} \right]^{1/2}}_{\text{Technological Change (TC)}} \quad (5)$$

In the analysis so far, constant returns to scale (CRS) have been assumed. The approach can be further extended by decomposing the efficiency change (technical efficiency change) into scale efficiency and pure technical efficiency components. Assuming that the production technology is subject to VRS, Fare et al. (1994b), relaxed the CRS assumption allowing VRS, while Ray and Desli (1997) measure technical change by the ratio of VRS distance functions.

The computation of MPI requires the solution of output-distance functions in two separate periods t and t+1, which can be estimated via DEA technologies, as described above (Charnes et al, 1978; Fare et al., 1994a; Coelli, et al., 1998). A value of $MPI_0$ greater than one indicates progress in the total factor productivity change, $MPI_0$ equal to one indicates no change in the total factor productivity, while $MPI_0$ less than one indicates productivity decline of the unit “0” from period t to t+1. The same applies for all the other components.

## 4. Data and Empirical results

### 4.1 Data

DEA application requires the use of measures as inputs and outputs. Restrictions on data availability led to selecting airport operational measures only, as financial and other qualitative data were not publicly available. As a result, we selected three airport infrastructure measures such as runway length in meters (Input 1), apron size in square meters (Input 2) and passenger terminal size in square meters (Input 3). As outputs we selected annual data for total aircraft movements, total numbers passengers and tons of cargo handled, which we converted to Work Load Units (WLUs).

Runway length (Input 1) is the key infrastructure characteristic, determining the size of aircraft which can land at each airport. This plays a key role at Greek airports, particularly those on smaller islands, where potential incoming international flights are restricted. Thessaloniki Airport, is the only airport in the study group with two runways. In this case, the length of the two runways was added up, (Yoshida and Fujimoto, 2004). Apron size (Input 2), in square meters, reflects the number of aircraft parking positions, depending on the size of aircraft, and together with the runway length determines the nature of airside traffic which can be handled by an airport in a specific time. Greece, as an incoming tourism receiving country faces high seasonality. During the summer period, congestion is common in apron, particularly on the islands, when non-scheduled flights arrive outside agreed times. Terminal size (Input 3), in square meters, reflects the ability of the airport to handle flows of passengers in a certain time, taking into consideration necessary processes and also safety and quality standards. Due to very high seasonality and inadequate infrastructure, problems of long queues in and out of the terminal are quite common particularly on certain islands. "Delays and queues grow throughout the various systems in terminals to the point that service capacity fails to meet demand. This situation may also occur as a result of seasonal demand variations, which make it difficult to ascertain a facility's absolute capacity" (Fernandes and Pacheco, 2002). It is well known that the problem of very high seasonality poses difficult dilemmas regarding investments for infrastructure, which proves to be inadequate in the peak summer period and seriously underutilized and costly in the winter months. In the case of Greek airports, decisions regarding infrastructure development are the result of HCAA forecasts and studies and government decisions.

The number of aircraft movements was used as the first output (Output 1). This figure reflects the volume of airside operations and the actual use of airport infrastructure. As the second output we selected the total number of passengers combined with total tons of cargo handled to reflect traffic work load at each airport. Work load unit (WLU) which represents one passenger (departing or arriving) or 100 kg of freight (inbound or outbound) is a widely used aggregate measure (Airports Council International-ACI, 2012) and has been suggested by a number of studies (Doganis, 1992; Graham, 2005; Merkert et al., 2012; ACI, 2012). All figures used refer to total traffic including domestic and international (scheduled and non-scheduled).

### 4.2 Empirical Results

Table 1 below presents the Pearson correlation coefficients of used inputs and outputs in order to test whether they are isotonic. As shown in Table 1, the inputs – outputs used in our analysis are all positively correlated and therefore isotonic. Consequently, they are justified to be included in our model (Lu and Hung, 2011; Wanke, 2012).

**Table 1. Pearson Correlation coefficients between inputs and outputs**

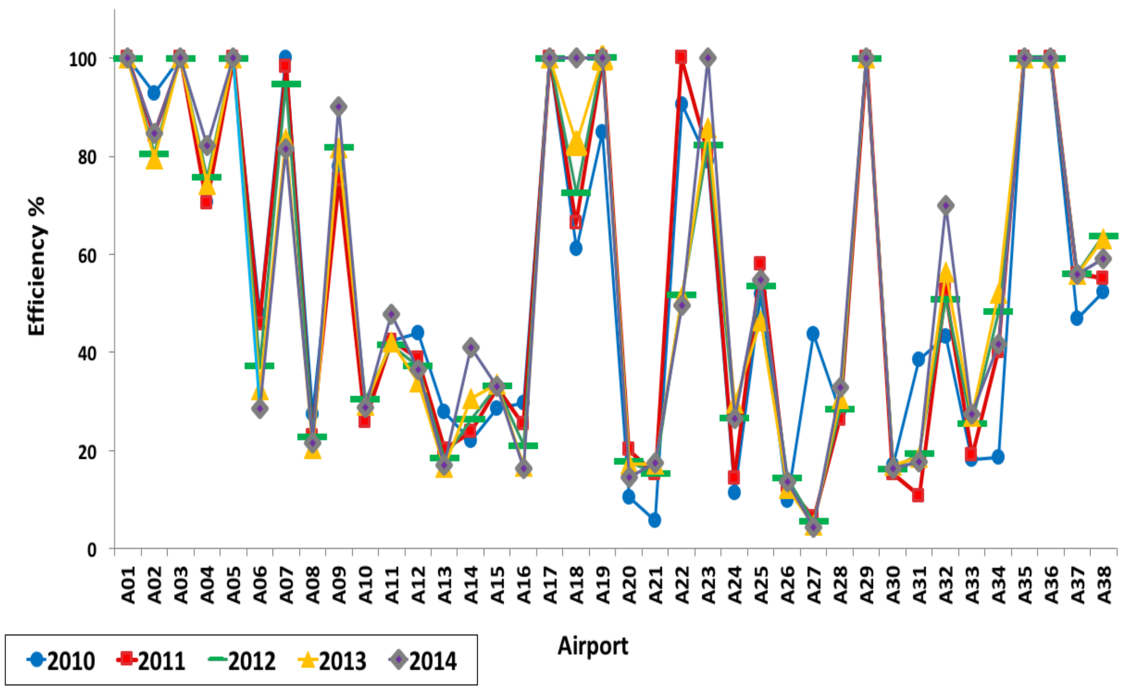
| Inputs/Outputs | O1 | O2 |
|---|---|---|
| I1 | 0.57 | 0.54 |
| I2 | 0.88 | 0.85 |
| I3 | 0.87 | 0.89 |

Table 2 and Figure 1 give some representative results from the application of DEA and allow us to draw interesting conclusions: Looking at the efficiency scores, it is noted that the number of efficient airports is 8 airports in 2010 then increases to 9 in 2011, falls to 8 in 2012 and 2013 and then increases to 10 airports in 2014.

**Table 2. Descriptive statistics of the ratio of relative efficiency (%) for the years 2010-2014**

| Year | 2010 | 2011 | 2012 | 2013 | 2014 | 2010-2014 |
|---|---|---|---|---|---|---|
| Average | 53.99 | 54.06 | 53.95 | 53.79 | 55.57 | 54.27 |
| StDev | 32.83 | 33.99 | 32.54 | 32.66 | 34.08 | 32.51 |
| Median | 45.51 | 49.18 | 49.62 | 48.94 | 48.74 | 48.11 |
| Min | 5.82 | 6.30 | 5.56 | 4.92 | 4.48 | 12.60 |
| 1st Quartile | 27.83 | 23.10 | 25.72 | 27.61 | 26.84 | 23.14 |
| 3rd Quartile | 89.16 | 94.8 | 82.22 | 83.41 | 97.50 | 85.20 |
| No. of eff. Airports | 8 | 9 | 8 | 8 | 10 | 7 |
| Coef. of Var.%. | 60.81 | 62.87 | 60.31 | 60.72 | 61.32 | 59.91 |

The average efficiency ratio is stable close to 54% in the study period, peaking at 55.6% in 2014. That is, the level of technical efficiency of the Greek airports on average appears to be not satisfactory. The sudden rise in the average efficiency (even a slight) in 2014 is also obvious from the number of fully efficient airports, which was 10 in 2014, the highest of the study period.




Note: Airports' names corresponding to numbers above are shown in Appendix.

**Fig.1.** Efficiency Ratings of the airports for the period 2010-2014.

The first conclusion from the analysis is that no regular trend or variation in efficiency of Greek airports is observed during the period 2010-2014.

Seven airports (A01, A03, A05, A17, A29, A35, A36) exhibit the highest level of efficiency and maintain this throughout the whole period (2010-2014). Those are: Thessaloniki, Heraklio, Kos, Chios, Paros, Kastelorizo and Kasos. This finding coincides with Barros's (2008) findings, where efficient airports in Argentina maintained their efficiency throughout the crisis period. Five airports (A07, A18, A19, A22, A23), are inefficient for at least one year of the period under investigation. Two of them with high efficiency level (>90% in 2010) in the beginning of this period, airports A07 and A22, have a significant decrease in their efficiency from 100% and 90.6% efficiency in 2010 to 81.5% and 49.6 % in 2014, respectively %. The dramatic drop in efficiency at A22 airport (Karpathos) probably reflects the considerable increase in Terminal size in 2012. On the other hand, Mytilini (A07), faced a considerable (-9.15%) decrease in passenger traffic during this period. The other three airports of this group A18, A19, A23 are the only airports of this sample that have significant increase in their efficiency from 61.2%, 84.9% and 79.1% in 2010 to 100% in 2014, respectively. It is highlighted that those airports are Mykonos, Skiathos and Santorini, three of the most popular tourist destinations, which had a significant increase in passenger numbers. Passengers handled at those cosmopolitan island airports increased by 80.7%, 36.84% and 63.37% respectively between 2014 and 2010. Twenty six airports (A02, A04, A06, A08 - A16, A20, A21, A24 - A28, A30 - A34, A37, A38) are inefficient over the whole study period. Five of them, however, (A06, A08, A16, A27, A31) present a ratio of technical efficiency which is well below 50% for all the years, and their efficiency tends to decrease significantly year over year. Quite the reverse is the case for the A04, A09, A32 and A34 airports (Kerkyra, Chania, Naxos and Ikaria) which have enhanced their efficiency, while the remaining airports present a stable efficiency. The most inefficient airports were A20, A21, A26, A27 and A30) which had the lowest efficiency ratio (less than 21%) in all years. Namely those are : Kozani, Kastoria, Skyros (island), Nea Aghialos and Syros (island). Noticeable is the deterioration of the efficiency of the A27 (Nea Aghialos) which from the 18th position in 2010 dropped to last position the following years. A huge development in Terminal capacity, realized in anticipation of very optimistic traffic forecasts is most probably the factor underlying this.

The main conclusion from Fig.1 is that a large proportion of the airports have no significant change in their efficiency during the study period. Even though there are some differences between the efficiency ratios, as explained before, the results seem to agree well that airports are characterized either by a low or a high ratio of efficiency. Noteworthy changes in efficiency were mainly triggered by exogenous factors such as significant traffic increase or dramatic increase in infrastructure. However in cases of very low efficiency not even substantial traffic increase was enough to improve efficiency.

The analysis is further extended using the Malmquist TFP analysis in order to determine whether the total productivity of individual airports is improving or deteriorating over the study period (2010–2014). In order to generate the Malmquist estimates, we used DEAP 2.1, developed by Coelli (1996).

As we mentioned in previous section, an airport could increase its productivity by using its existing technology and inputs more efficiently (i.e. producing more of same products), which is termed as efficiency change (EC) (or catch-up). On the other hand, an airport could also increase its productivity if it adopts innovations, diffusions or technological improvements (i.e. developments of new products, processes and technologies of their operations), which is referred as Technological change (TC) (or frontier shift). Therefore, for each airport, the total factor productivity change

(TFPC) is the product of technological change and efficiency change; the latter is also divided into pure (PEC) and scale efficiency (SEC) change to investigate the scale effects, in other words how close an airport is to its most efficient scale size. It is noted that a value of TFP index, which is greater than one, implies progress in productivity, a value of the index equal to one implies no change, while a value of the index that is less than one indicates regress in productivity. The same applies for all the other components. Table 3 below presents the descriptive statistics for productivity growth rates and its components.

**Table 3. Total Factor Productivity index and its components for the period 2010-14**

| | TFP | EC | TC | PEC | SEC |
|---|---|---|---|---|---|
| Mean (geom.) | 1.009 | 1.004 | 1.005 | 1.006 | 0.998 |
| Average | 1.016 | 1.013 | 1.006 | 1.014 | 0.999 |
| StDev* | 0.115 | 0.126 | 0.039 | 0.127 | 0.030 |
| Median | 1.025 | 1.011 | 1.007 | 1.008 | 1.0 |
| Max | 1.2 | 1.272 | 1.067 | 1.317 | 1.106 |
| Min | 0.586 | 0.568 | 0.91 | 0.566 | 0.936 |
| Q1 | 0.971 | 0.972 | 0.983 | 0.980 | 0.983 |
| Q3 | 1.081 | 1.069 | 1.035 | 1.057 | 1.004 |
| CV% | 11.4 | 12.4 | 3.8 | 12.5 | 3.0 |
| % <1 | 34.2 | 36.8 | 44.7 | 29.0 | 47.4 |
| % =1 | 0 | 13.2 | 0 | 18.4 | 18.4 |
| % >1 | 65.8 | 50.0 | 55.3 | 52.6 | 34.2 |
| Period | | | | | |
| 2010/11 | 0.952 | 0.994 | 0.957 | 0.988 | 1.006 |
| 2011/12 | 0.992 | 0.995 | 0.997 | 1.027 | 0.969 |
| 2012/13 | 1.013 | 0.984 | 1.029 | 0.988 | 0.996 |
| 2013/14 | 1.084 | 1.043 | 1.039 | 1.020 | 1.023 |

*StDev=standard deviation, Q1, Q3=1st and 3rd quartile, CV%=coefficient of variation

The empirical results indicate that the mean annual total factor productivity growth was marginally positive at 0.9% during the study period. This reflects that the average airport productivity level in 2014 was 103.6 % of that of 2010, an increase of 3.6% over the examined period. When examining the components of this productivity change (0.9%), it becomes evident that this is due to the combination of both positive (very slightly) annual average technology change (0.5%) and technical efficiency change (0.4%). Furthermore, the increase in technical efficiency is due mainly to the pure efficiency change that increased 0.6% annually since the other component (scale change) decreased by an annual average rate of 0.2%. The year-to-year changes show that both TFP index and technology follow a similar pattern for the examined period, whereas technical efficiency follows a different pattern. TFP and technology show an increasing trend, reaching its peak in 2013-14. The results show that airport productivity grew at the rate of 4.8% annually in the period from 2012 to 2014, at a faster rate from 2013 to 2014 (8.4%) that did from 2012 to 2013 (1.3%) and decreased in the period from 2010 to 2012 (-2.8%). During the two consecutive years (2012 -2013 and 2013-2014), airports experienced technological progress for both periods (TC >1) and became more efficient (EC>1) only for one period (from 2013 to 2014). In the other two periods (2010 to 2011, 2011 to 2012), average airport efficiency and technology declined (EC & TC < 1). At the end of 2014, 25 airports out of 38 (65.8%) had, on average, a higher productivity level than in 2010, and the remaining 13 airports (34.2%) had a lower productivity level than in 2010. More specifically, the findings suggest that 65.8% of airports have an increase in average TFP during the period 2010–2014, ranging between 0.4% and 20%. Overall, the breakdown of total productivity changes of Greek airports into the change in efficiency gain (EC) and technical progress (TC) showed mixed results. The positive change in TFP (i.e. Malmquist changes are greater than 1), in 7 airports (out of 25) suggest that there is an improvement in technology, in 10 in technical efficiency and in the remaining 8 airports that change is due both to technical efficiency and technology. These results show that there might be a diffusion of best-practice technology in the management. On the other hand, the regress in terms of TFP who have registered the remaining 34.2% of the airports during the same period, ranges between –1.3% and –41.4%. This finding suggests that, for those airports, best-practice technology in the management has not been used, or that it was poor technology which needed to be up. Since the median (1.025) is higher than the geometric mean (1.009), this suggests that the majority of Greek airports operated above the average total productivity, whereas the coefficient of variation of 11.4% suggests that there is low dispersion in airports' total productivity. Analysis of Total Factor Productivity Index and its components is presented on Table 4.

**Table 4. Airport TFP index and its components 2010-2014 (average)**

| a/a | EC | TC | PEC | SEC | TFP | a/a | EC | TC | PEC | SEC | TFP |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A01 | 0.999 | 1.010 | 1.000 | 0.999 | 1.009 (23) | A20 | 1.133 | 1.005 | 1.089 | 1.041 | 1.139 (4) |
| A02 | 0.972 | 1.036 | 0.977 | 0.995 | 1.007 (24) | A21 | 1.272 | 0.943 | 1.317 | 0.966 | 1.200 (1) |
| A03 | 1.000 | 1.030 | 1.000 | 1.000 | 1.030 (19) | A22 | 0.844 | 1.025 | 0.860 | 0.981 | 0.865 (35) |
| A04 | 1.039 | 1.040 | 1.039 | 1.000 | 1.080 (11) | A23 | 1.064 | 1.042 | 1.061 | 1.003 | 1.109 (8) |
| A05 | 1.000 | 1.060 | 1.000 | 1.000 | 1.060 (14) | A24 | 1.184 | 0.982 | 1.234 | 0.960 | 1.163 (3) |
| A06 | 0.862 | 0.998 | 0.880 | 0.980 | 0.860 (36) | A25 | 1.071 | 0.921 | 1.014 | 1.057 | 0.987 (26) |
| A07 | 0.972 | 0.975 | 0.950 | 1.023 | 0.948 (30) | A26 | 1.029 | 1.026 | 1.086 | 0.948 | 1.056 (15) |
| A08 | 0.947 | 1.022 | 0.941 | 1.007 | 0.968 (29) | A27 | 0.568 | 1.031 | 0.566 | 1.004 | 0.586 (38) |
| A09 | 1.042 | 1.056 | 1.037 | 1.006 | 1.101 (9) | A28 | 1.036 | 1.018 | 1.043 | 0.994 | 1.055 (16) |

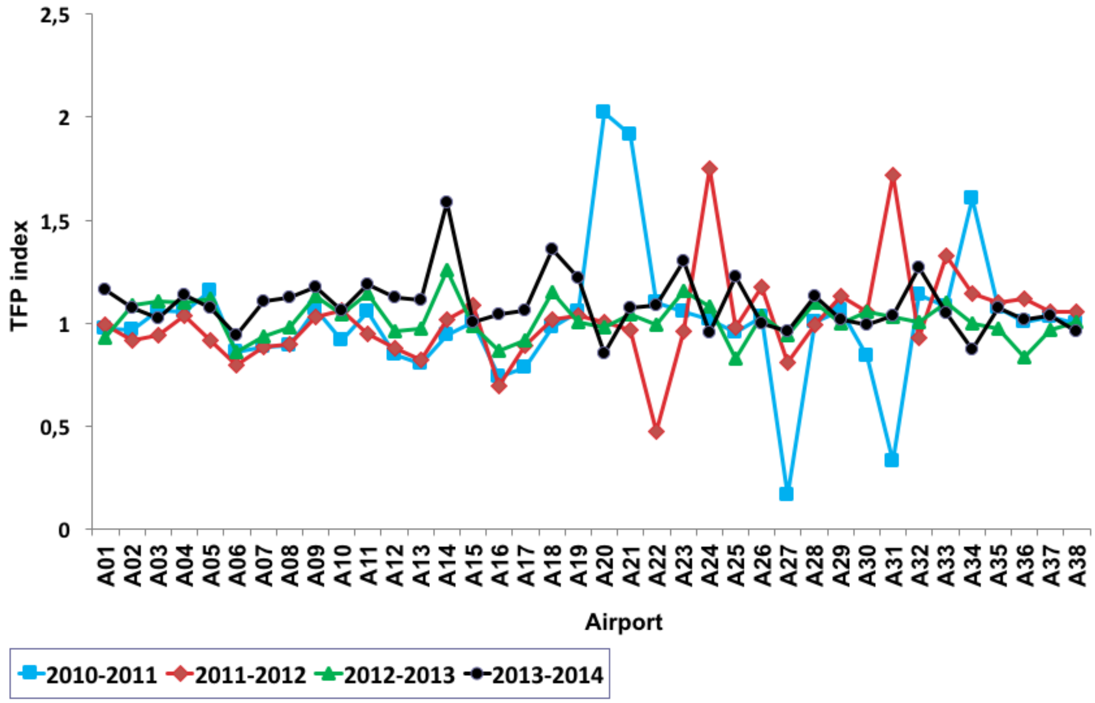
| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A10 | 0.996 | 1.023 | 1.002 | 0.994 | 1.018 (22) | A29 | 1.000 | 1.051 | 1.000 | 1.000 | 1.051 (18) |
| A11 | 1.031 | 1.048 | 1.031 | 1.000 | 1.081 (10) | A30 | 0.985 | 0.996 | 0.989 | 0.996 | 0.981 (28) |
| A12 | 0.944 | 1.004 | 0.955 | 0.989 | 0.947 (31) | A31 | 0.825 | 1.067 | 0.822 | 1.003 | 0.880 (34) |
| A13 | 0.882 | 1.040 | 0.885 | 0.998 | 0.918 (32) | A32 | 1.087 | 0.990 | 1.128 | 0.964 | 1.077 (12) |
| A14 | 1.211 | 0.971 | 1.167 | 1.037 | 1.175 (2) | A33 | 1.136 | 0.997 | 1.110 | 1.023 | 1.132 (5) |
| A15 | 1.029 | 0.992 | 1.036 | 0.993 | 1.020 (21) | A34 | 1.194 | 0.940 | 1.222 | 0.977 | 1.123 (6) |
| A16 | 0.842 | 0.980 | 0.861 | 0.978 | 0.825 (37) | A35 | 1.106 | 0.952 | 1.000 | 1.106 | 1.053 (17) |
| A17 | 1.000 | 0.910 | 1.000 | 1.000 | 0.910 (33) | A36 | 1.000 | 0.987 | 1.000 | 1.000 | 0.987 (27) |
| A18 | 1.146 | 0.974 | 1.130 | 1.014 | 1.117 (7) | A37 | 1.022 | 0.999 | 1.045 | 0.978 | 1.021 (20) |
| A19 | 1.045 | 1.029 | 1.042 | 1.003 | 1.075 (13) | A38 | 0.964 | 1.042 | 1.030 | 0.936 | 1.004 (25) |

When analyzing the sources of the changes in the TFP index, it is clear that more than half of the airports (55.3%) have a positive technological change, none have zero change and the remaining airports (44.7%) have negative change. It should be noted that, with a few exceptions, the technological change has a very low variability. This implies that airports had small differences in technological level throughout the examined period. On the other hand, half of the airports had an increase in efficiency, which reaches up to 27.2% (annually), 13.2% had no change and the remaining (36.8%) had a decrease in efficiency, which goes down to -43.2%. Moreover, the breaking down of the technical efficiency into pure technical efficiency and scale efficiency shows mixed results: Some airports obtained simultaneous gains in both components and other obtained gains in one, but losses in the other. The results on Table 3 show that the variability of efficiency change, compared to the technological change, is slightly larger. As mentioned previously, the average efficiency level increased only very slightly (0.4% growth per year) over the study period. From the perspective of individual performance (Table 4), the largest efficiency change indices are found in three airports: A21, A14 and A34 experienced an increase in cumulated efficiency of more than 100% (annually more than 19%). When examining the components of this productivity change, it becomes evident that for those three airports the increase in productivity growth rates is due to the improvement in the efficiency change (27.2%, 21.1% and 19.4% annual average efficiency change, respectively) and a decrease of 5.7%, 2.9% and 6% for A21, A14 and A34, due to technological regress.

Further, the decomposition of efficiency change components for these three airports indicates the pure efficiency change (31.7% for A21, 16.7% for A14 and for 22.2% for A34) and scale efficiency change (-3.4% for A21, 3.7% for A14 and -2.3% for A34). It should be noted that, although A21 had the largest increase in efficiency between 2010 -2014, it is still at the bottom of the scale at the end of the period. The efficiency rates of four airports A22, A16, A31, A27 cumulatively dropped by more than 50% between 2010 and 2014. Of these airports, the efficiency of A27 in 2014 was found to be as low as a tenth of efficiency in 2010. In other words the productivity level of A27 experienced the largest decline. Its productivity in 2014 was 11.8% what it was in 2010, a decline of 41.4% per year on average. The detailed decomposition of TFP as shown in Table 4 indicates that the negative trend in the efficiency change component is the major cause for lower TFP index in the airport (-43.2% annual average efficiency change) as the technology had a corresponding improvement of 3.1%. Infrastructure changes in those four airports seem responsible for efficiency change results during this period. Considerable terminal enlargement at Karpathos (A22), Nea Aghialos (A27) and Araxos (A31) airports and huge apron development works at Ioannina (A16) caused efficiency decrease as observed in the analysis.

The results also indicate that 71% of the airports were efficient as regards management; out of those almost 52.6% improved managerial efficiency in the use of resources.

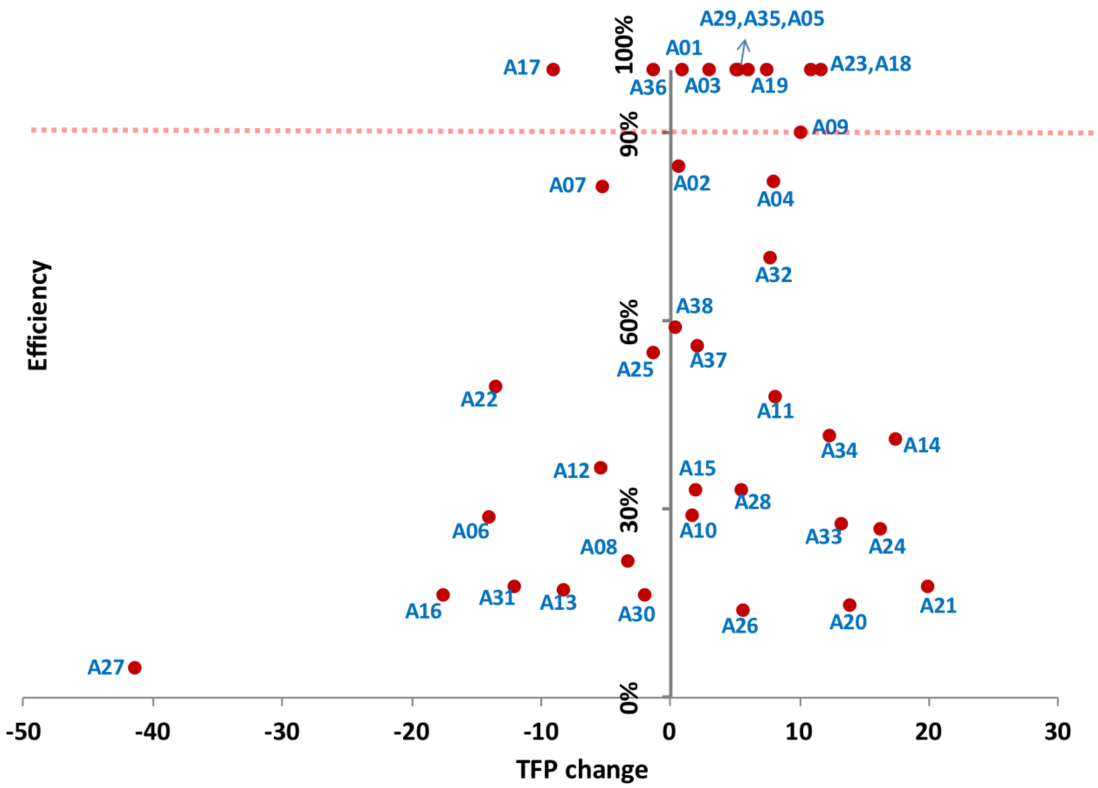
In order to study the productivity change of consecutive years and obtain individual information for each airport, we present on Figure 2 the total productivity growth of each year during the period 2010-2014. For example, Figure 2 shows that only A06 and A27 airports registered negative TFP growth over the entire study period and this is mainly explained by the efficiency change component. In contrast, four airports A04, A09, A19 and A33 registered positive TFP growth over the entire study period and this is explained by the two components, except A33 which is explained mainly by the efficiency change component. A20 registered the maximum positive TFP growth (102%) between 2010-2011, while the same airport shows a negligible TFP growth in 2011-2012 (0.4%), a negative TFP growth in 2012-213 (-2.3%) and the highest negative TFP growth (-15%) in 2013-2014. The latter is particularly important, as figure 2 shows, that in 2013-2014, out of 38 airports 30 exhibit positive TFP growth, ranging from 0.6% (A15) to 59% (A14). The productivity growth in the above airports is achieved either through the introduction of best operating and management practices or adoption of new technology.




Note: Airports' names corresponding to numbers above are shown in Appendix.

**Fig.2.** Annual TFP Index 2010-2014.

Further analysis on individual airport profile is shown on Figure 3, where we present the classification of Greek airports on the basis of their relative efficiency (VRS) in the year 2014 (score in Figure 1) and the results of the TFP change in the period 2010–2014 (Table 4). In figure 3 we choose a threshold of about 90% for good efficiency and consider that below this value airports have scope to improve efficiency.




Note: Airports' names corresponding to numbers above are shown in Appendix.

**Fig. 3.** VRS Efficiency 2014 & TFP Change (2014-2010) average.

A. High efficiency and positive productivity growth: Airports in this group located in the upper right quadrant show a constantly high efficiency and productivity growth during the period 2010-2014. For airport benchmarking those airports are a reference point. Airports in this group should try to maintain their position by implementing targeted business strategies. Those airports are: Thessaloniki. Heraklio, Kos, Mykonos, Skiathos, Santorini, Paros, Kastelorizo

B. High efficiency and negative production growth. Airports in the upper left quadrant show a good efficiency level during the period examined here, however their productivity declines. It seems that they manage their resources efficiently, but they do not show notable progress. Airports in this group should try to achieve a rapid growth in the future, perhaps through positive technological change, if they want to keep their good position. This group includes: Chios and Kasos.

C. Low efficiency and negative productivity growth. Airports in this lower left quadrant show low to medium efficiency in managing their resources and at the same time their productivity declines during the period 2010-2014. Further analysis is necessary in order to identify areas causing those results and action needed to improve efficiency. The conclusion is that there is scope for improvement. This group includes: Mytilini, Milos, Karpathos, Samos, Alexandroupoli, Limnos, Araxos, Ioannina, Kavala, Syros, Nea Aghialos

D. Low efficiency and positive productivity growth. Airports in the lower right quadrant show medium to low efficiency levels, but a positive productivity growth during this period. It is very possible that if those airports continue on their productivity improvement trend, they will soon be relocated in the upper right quadrant of airports with high efficiency and positive productivity growth. It is highlighted here that 17 out of 38 airports fall in this group. This group includes: Chania,Rodos,Kerkyra,Naxos,Sitia,Leros,Zakynthos,Kalamata,Ikaria,Astypalaia,Aktio,Kefallinia,Kithira,Kalymnos,Kastoria,Skyros,Kozani.

## 5. Concluding remarks

The aim of this study is to evaluate the operating efficiency and productivity changes of the Greek airports, during the first five years of the severe economic crisis in Greece. Data analysis showed that during the study period 2010-2014, tourist arrivals in Greece followed an upward trend. During this period Greek airports have strongly supported tourism, making a vital contribution to the Greek economy in the first years of the economic crisis.

We applied DEA analysis using panel data for the period 2010-2014 for the 38 Greek airports, which are owned, controlled and managed centrally by the HCAA. It has become evident that overall Greek airports have considerable scope for improvement, as the average efficiency ratio is stable close to 54% in the study period, peaking at 55.6% in 2014. Only seven out of the thirty-eight airports included in the study exhibit the highest level of efficiency and maintain this throughout the whole period (2010-2014). Those are: Thessaloniki, Heraklio, Kos, Chios, Paros, Kastelorizo and Kasos.

Year to year efficiency analysis showed no regular trend or variation in the efficiency of the Greek airports during the examined period. Even though there are some differences between the efficiency ratios, the results show that airports are characterized either by a low or a high ratio of efficiency. The analysis showed that noteworthy changes were mainly triggered by exogenous factors such as significant increase in traffic or in infrastructure. However, in cases of very low efficiency not even substantial traffic increase was enough to considerably improve it.

The analysis was further extended using the Malmquist TFP analysis in order to determine whether the total productivity of individual airports is improving or deteriorating over the study period.

The empirical results indicate that the average airport productivity increased by 3.6% over the examined period. At the end of 2014, 25 airports out of 38 (65.8%) had, on average, a higher productivity level than in 2010 ranging between 0.4% and 20%. Overall, the breakdown of total productivity changes of Greek airports into the change in efficiency gain (EC) and technical progress (TC) showed mixed results. The positive change in TFP, in 7 airports (out of 25) suggest that there is an improvement in technology, in 10 in technical efficiency and in the remaining 8 airports that change is due both to technical efficiency and technology.

We extended our study by classifying Greek airports on the basis of their relative efficiency (VRS) in the year 2014 and the results of the TFP change in the period 2010–2014. The first group of airports characterized by high efficiency and positive productivity growth included eight airports, out of which five will be privatized. The second group included airports with high efficiency and negative production growth. Two airports are included here, none of which will be privatized. Third group includes 11 airports with low efficiency and negative productivity growth and indications are that there is scope for improvement. Three of those will be privatized. Finally, the last group includes 17 airports showing low to medium efficiency in managing their resources and at the same time their productivity increases during the period 2010-2014. If those airports continue to improve their productivity, soon they will be in the first group of high efficiency and positive productivity growth. Six out of those will be privatized. From the “efficiency productivity matrix” it becomes evident which airports can still increase their total productivity through efficiency improvements. Through our analysis, we were able to discriminate among airports that are excellent in both performance dimensions and therefore, they could be proposed as benchmark airports.

In conclusion, the analysis shows that there is great challenge ahead for both categories of Greek airports: those under the ownership and management of the HCAA and, according to present situation, will remain under the HCAA, and those that will be privatized, once in the procedures are completed in autumn 2016. As shown by our analysis, there seems to be potential for improvement both in technical and technological efficiency. Policy implications lead to investors certainly using all information to employ international best practices for their new acquisitions. However, at the same time, our research analysis provides HCAA policy makers with findings to use in order to improve performance of the various airports remaining under their management, but most important, to set a development strategy for each one of those airports. Route development (Halpern, N. and Graham, A., 2015), improved connectivity (Fragoudaki and Giokas, 2016) and strategic marketing should be applied in order to develop the performance of each airport.

As highlighted in the analysis, there is scope for improvement. For example, some airports suffered regression in total productivity and some airports registered regress in terms of technical efficiency change, which is the result of different factors such as managerial policies, scale, etc. Consequently, these airports should upgrade the operational procedures to improve the efficiency of their operations and to catch up with the best practice airports.

This research differs from the recent one on the performance of Greek airports (Fragoudaki and Giokas, 2016) in the following: The previous research and analysis of Greek airports performance evaluated the performance of the Greek airports and also identified factors contributing to performance differences (Section 2, above). The analysis was based on one year (2011). In the present research, we advance the analysis to the evaluation of the operational efficiency of the airports subject to changes in external factors, using panel data for the first five years of the severe economic crisis in Greece. In addition, we analyze the productivity changes of each airport during the study period. This dual analysis highlights the resilience and potential of each airport. In view or the forthcoming privatization of the 14 out of 38 airports, the results of our research emphasize the necessity and provides the grounds for the development of a commercial strategy for each individual airport. Moreover our research can be used as a reference, once the mixed ownership and management system is in place.

Finally, limitations of financial and qualitative data have prohibited further analysis at present. However, in order to advance knowledge in the operations at Greek airports, within the competitive global environment, it is suggested and also considered necessary, to address contemporary issues, such as environmental aspects and quality of services.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## APPENDIX

| MODEL NUMBER | AIRPORT CITY NAME | IATA CODE | MODEL NUMBER | AIRPORT CITY NAME | IATA CODE |
|---|---|---|---|---|---|
| A1 | Thessaloniki | SKG | A21 | Kastoria | KSO |
| A2 | Rodos | RHO | A22 | Karpathos | AOK |
| A3 | Heraklio | HER | A23 | Santorini | JTR |
| A4 | Kerkyra | CFU | A24 | Kithira | KIT |
| A5 | Kos | KAW | A25 | Milos | MLO |
| A6 | Alexandroupoli | AXD | A26 | Skyros | SKU |
| A7 | Mytilini | MJT | A27 | Nea Aghialos | VOL |
| A8 | Limnos | KALM | A28 | Aktio | PVK |
| A9 | Chania | CHQ | A29 | Paros | PAS |
| A10 | Kefallinia | EFL | A30 | Syros | JSY |
| A11 | Zakynthos | ZTH | A31 | Araxos | GPA |
| A12 | Samos | KASM | A32 | Naxos | JNX |
| A13 | Kavala | KVA | A33 | Kalymnos | JKL |
| A14 | Kalamata | KLX | A34 | Ikaria | JIK |
| A15 | Astypalaia | JTY | A35 | Kastelorizo | KZS |
| A16 | Ioannina | IOA | A36 | Kasos | KSJ |
| A17 | Chios | JKH | A37 | Leros | LRS |
| A18 | Mykonos | JMK | A38 | Sitia | KASD |
| A19 | Skiathos | JSI | | | |
| A20 | Kozani | KZI | | | |

Note: Airport city names shown above are according to HCAA, therefore they differ from known names found in general tourism use (i.e. Rodos/Rhodes, Kerkyra/Corfu).

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