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Greek Airports: Efficiency Measurement and Analysis of Determinants

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Ελληνικά Αεροδρόμια: Μέτρηση της Αποδοτικότητας και Ανάλυση των Προσδιοριστικών Παραγόντων

Θεόδωρος Τσέκερης

Περίληψη

Τα αεροδρόμια αποτελούν συγκοινωνιακές υποδομές με ιδιαίτερη σημασία για την περιφερειακή ανάπτυξη και εδαφική συνοχή της Ελλάδας. Η εργασία αυτή παρουσιάζει την μέτρηση της τεχνικής αποδοτικότητας των Ελληνικών αεροδρομίων με χρήση της μη-παραμετρικής μεθόδου της Περιβάλλουσας Ανάλυσης Δεδομένων (Data Envelope Analysis ή DEA), με σκοπό τη συγκριτική αξιολόγησή τους (benchmarking). Τα δεδομένα των εκροών αφορούν στον αριθμό των επιβατών και το βάρος (κιλά) των εμπορευμάτων που μεταφέρονται αεροπορικώς, και τον αριθμό των πτήσεων από και προς τα Ελληνικά αεροδρόμια. Τα δεδομένα των εισροών αφορούν κυρίως σε φυσικά μεγέθη των αεροδρομίων, όπως στο εμβαδόν των αεροδιαδρόμων, το εμβαδόν των χώρων στάθμευσης των αεροσκαφών, το εμβαδόν των τερματικών αεροσταθμών, καθώς και τις συνολικές ώρες λειτουργίας κάθε αεροδρομίου. Η διαστρωματική ανάλυση των παραπάνω δεδομένων με τη μέθοδο DEA αναφέρεται στο έτος 2007.

Το παρόν μικροοικονομικό πλαίσιο ανάλυσης προσδιορίζει περιφερειακά αεροδρόμια με σχετικά χαμηλή αποδοτικότητα, σε σχέση με λίγα αεροδρόμια με τη σχετικά μέγιστη αποδοτικότητα (benchmarks). Η σημαντική έλλειψη αποδοτικότητας στα περισσότερα περιφερειακά αεροδρόμια της χώρας μπορεί να αποδοθεί κυρίως στην σχετικά χαμηλή ικανότητα διαχείρισης των πόρων τους, έτσι ώστε να αυξήσουν το παραγόμενο μεταφορικό έργο. Ωστόσο, τα περισσότερα αεροδρόμια χαρακτηρίζονται από σχετικά υψηλή αποδοτικότητα κλίμακας και εμφανίζουν αύξουσες αποδόσεις κλίμακας.

Τα αποτελέσματα αυτά παρέχουν κίνητρα επενδύσεων για την αναβάθμιση ή/και επέκταση των αεροδρομίων, καθώς και διαχείρισή τους με βάση επιχειρηματικά κριτήρια ώστε να περιοριστεί η ανεπαρκής χρήση των πόρων τους. Η αύξηση του παραγόμενου

έργου τους και η εκμετάλλευση των οικονομιών κλίμακας μπορεί να επιτευχθεί και με την ανάπτυξη νέων χωρικών οργανωτικών δομών, με βάση τη λειτουργία κομβικών περιφερειακών αεροδρομίων (regional hubs), στην περιοχή του Αιγαίου και, πιθανώς, σε άλλες περιφέρειες. Επιπλέον, η ενίσχυση του ανταγωνισμού μπορεί να προσελκύσει περισσότερους αεροπορικούς φορείς χαμηλού κόστους, με απευθείας πτήσεις μεταξύ των περιφερειακών αεροδρομίων και αεροδρομίων του εξωτερικού.

Η χρήση μη-παραμετρικών στατιστικών ελέγχων δείχνει ότι, σε αντίθεση με την θερινή περίοδο λειτουργίας (από τέλη Μαρτίου μέχρι τέλη Οκτωβρίου), η χειμερινή περίοδος λειτουργίας οδηγεί σε σημαντικές απώλειες της αποδοτικότητας των αεροδρομίων. Αυτή η επίδραση της εποχικότητας αφορά ιδιαίτερα στα περιφερειακά αεροδρόμια με έντονη τουριστική κίνηση. Το γεγονός αυτό καθιστά αναγκαία τη λήψη μέτρων για την αντιμετώπιση της ελλιπούς χρήσης των πόρων στα συγκεκριμένα αεροδρόμια κατά τη χειμερινή περίοδο. Τέτοια μέτρα δύνανται να περιλαμβάνουν, π.χ., τον ευέλικτο σχεδιασμό του εσωτερικού χώρου των εγκαταστάσεων των αεροσταθμών, ώστε να προσαρμόζονται περισσότερο στις χρονικά μεταβαλλόμενες ανάγκες των αεροπορικών εταιριών, καθώς και πολιτικές εναλλακτικού τουρισμού για την επέκταση της ζήτησης την χειμερινή περίοδο.

Οι εκτιμήσεις του προτύπου παλινδρόμησης με αποκοπή τιμών (truncated regression) και χρήση τεχνικής bootstrap δείχνουν τη θετική και στατιστικά σημαντική επίδραση της νησιωτικής τοποθεσίας, των απευθείας αεροπορικών συνδέσεων με αεροδρόμια του εξωτερικού και του μεγέθους της ζήτησης στην αποδοτικότητα των Ελληνικών αεροδρομίων. Τα αποτελέσματα υπογραμμίζουν τις ιδιαιτερότητες των αεροδρομίων της χώρας, οι οποίες ενδείκνυνται να λαμβάνονται υπόψη στη διαμόρφωση πολιτικών που επικεντρώνουν στην αναβάθμιση των λειτουργιών τους.

Λέξεις-κλειδιά: Αερομεταφορές, Αεροδρόμια, Ανάλυση Αποδοτικότητας, Συγκριτική Αξιολόγηση, Περιβάλλουσα Ανάλυση Δεδομένων, Εποχιακή Ζήτηση, Ελληνικά Νησιά, Μέθοδοι Παλινδρόμησης με Τεχνικές Bootstrap.

Abstract

This paper presents a performance evaluation of the Greek airports, based on the application of the Data Envelope Analysis (DEA) method for benchmarking their technical efficiency, and the use of non-parametric test and bootstrapped truncated regression for analysis of its determinants. The non-parametric test indicates the critical impact of the seasonality of demand on the performance of Greek airports. The use of bootstrapped regression technique show the statistically significant effect of location, size and operating characteristics on their technical efficiency, signifying the peculiarities of the Greek airport system.

Keywords: Airport efficiency, Benchmarking, Data Envelope Analysis, Greek islands, seasonal demand, bootstrapped regression models.

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1. Introduction

The significant geographical peculiarities of Greece, including mountainous terrain and scattered island complexes, have rendered airplane as an indispensable mode of communication. This fact reflects the significantly high number of airports (39 as of 2007) in relation to the population of the country. The present paper provides an original empirical study of benchmarking and efficiency measurement of the Greek airports, based on the Data Envelope Analysis (DEA) approach. The DEA approach has been widely implemented for the efficiency analysis of many airports in Europe (e.g., Pels et al. (2003), Barros and Dieke (2007), Tapiador et al. (2008)) and elsewhere (e.g., Lin and Hong (2006), Barros (2008), Chi-Lok and Zhang (2009)).

The impact on the DEA efficiency scores of the considerable seasonal variations of demand in most peripheral airports is particularly examined. Moreover, the nature and size of the various determinants of airport efficiency are analyzed by use of a bootstrapped regression technique. The aim of the above tasks is to identify factors that may limit future growth, and "best practices" and measures for improving the competitiveness and efficiency of the country's airport system.

2. Description of the Study Data

The analysis of efficiency of the Greek airports is based here on the use of cross-sectional data for the year 2007. According to the availability of data and their suitability in other DEA-based airport performance evaluation studies in the relevant literature (e.g., see Graham, 2005), the present dataset includes three outputs concerning air traffic, i.e., number of passengers, amount of cargo and number of flights, and four inputs concerning airport infrastructure and operating characteristics, i.e. the airport runway, terminal and airplane parking areas, and total operating hours.

In order to account for the effects of seasonal demand variations, the data on passengers, cargos, flights and operating hours are also separated into two periods, which correspond to the summer (between end of March and end of October) and winter (the rest of the year) operating periods of the Greek peripheral airports, respectively, as designated by the Civil Aviation Authority (CAA) of the Greek Ministry of Transport.

Tables 1 and 2 show the values of outputs and inputs, respectively, which are used in the current DEA model for the total annual, winter and summer operating periods. The data are from the CAA, while information about airport infrastructure has also been obtained from www.airliners.gr. The fact that the standard deviation of each output variable is higher than the corresponding mean (see Table 1) shows the relative heterogeneity of the traffic characteristics of Greek airports. It is indicatively noted that in 2007 only four major airports (those of Athens, Thessaloniki, Heraklion and Rhodes) concentrated about the 72% of the total passenger traffic and the 94% of the total amount of cargo.

Table 1. Outputs (passengers, cargos and flights) in the DEA model for the annual, winter and summer operating periods.

Airport	Passengers			Cargos (kg)			Flights		
	Total	Winter	Summer	Total	Winter	Summer	Total	Winter	Summer
Aghialos	19366	1798	17568	182	0	182	206	26	180
Aktio	338197	5191	333006	1456	35	1421	3260	354	2906
Alexandroupoli	306208	113954	192254	734672	333999	400673	3512	1442	2070
Araxos	136987	232	136755	0	0	0	1344	10	1334
Astypalaia	18610	6903	11707	3013	1161	1852	976	434	542
Athens	16632798	5230591	11402207	121782114	49524121	72257993	193123	68376	124747
Chania	1896890	186443	1710447	2094817	798998	1295819	15430	2774	12656
Chios	258717	82460	176257	787328	332517	454811	5265	1912	3353
Corfu	2038256	108721	1929535	948295	284134	664161	15638	1602	14036
Heraklion	5482881	444515	5038366	3170305	1267699	1902606	46012	6744	39268
Ikaria	26373	7212	19161	43299	18976	24323	626	166	460
Ioannina	140874	54625	86249	11236	3549	7687	2308	936	1372
Kalamata	114917	1911	113006	245	0	245	980	72	908
Kalymnos	19934	6352	13582	0	0	0	722	250	472
Karpathos	192573	21780	170793	127645	56743	70902	3588	874	2714
Kasos	14118	4195	9923	21443	6284	15159	1596	508	1088
Kastelorizo	9564	1626	7938	25264	7114	18150	494	150	344
Kastoria	4827	1692	3135	523	29	494	208	94	114
Kavala	378368	64109	314259	453884	164613	289271	4196	1038	3158
Kefalonia	382592	12458	370134	34693	6132	28561	4108	584	3524
Kos	1676968	83424	1593544	1134105	339956	794149	14524	2058	12466
Kozani	4139	1244	2895	0	0	0	198	76	122
Kythira	31566	6226	25340	119101	41897	77204	674	192	482
Leros	29956	8520	21436	74242	36989	37253	1256	418	838
Limnos	145586	39625	105961	449409	167444	281965	3572	1272	2300
Milos	33624	11324	22300	47685	39455	8230	1320	506	814
Mykonos	446516	22868	423648	142092	4492	137600	6874	578	6296
Mytilini	574514	139558	434956	1194014	485039	708975	8874	2914	5960
Naxos	28959	7801	21158	2298	1529	769	882	260	622
Paros	37093	8157	28936	44	0	44	1664	422	1242
Rhodes	3669992	272790	3397202	3170951	1096551	2074400	32776	5466	27310
Samos	501401	66622	434779	675983	263533	412450	7480	2010	5470
Santorini	769974	63252	706722	251605	47430	204175	8966	996	7970
Sitia	35979	10994	24985	3399	811	2588	1806	666	1140
Skiathos	278769	1927	276842	0	0	0	2526	88	2438
Skyros	13182	1380	11802	0	0	0	588	164	424
Syros	7915	2883	5032	0	0	0	332	128	204
Thessaloniki	4395201	1279834	3115367	10615077	4298058	6317019	50244	16558	33686
Zakynthos	1002888	7442	995446	0	0	0	7046	364	6682
Mean	1079417	215196	864221	3797959	1528956	2269003	11672	3166	8505
Strd. Deviation	2845883	851853	2047626	19474182	7920955	11553409	31973	11091	21130

Table 2. Inputs (operating hours and runway, terminal and airplane parking areas) in the DEA model for the annual, winter and summer operating periods.

Airport	Operating hours			Runway	Terminal area	Parking area
	Total	Winter	Summer	(sq.m.)	(sq.m.)	(sq.m.)
Aghialos	1683.50	708.57	974.93	124155	400	59450
Aktio	2470.57	620.00	1850.57	129195	6775	34075
Alexandroupoli	3015.71	1350.71	1665.00	116190	2600	24624
Araxos	1901.11	608.93	1292.18	134550	2000	34000
Astypalaia	1564.29	664.29	900.00	29670	614	4750
Athens	8760.00	3720.00	5040.00	351000	238000	900000
Chania	8760.00	3720.00	5040.00	150750	13500	74400
Chios	3353.21	1162.50	2190.71	45000	400	8000
Corfu	8760.00	3720.00	5040.00	106875	26662	70450
Heraklion	8760.00	3720.00	5040.00	122130	43300	140000
Ikaria	1616.43	686.43	930.00	41400	1200	8000
Ioannina	2330.54	935.54	1395.00	108000	2150	19700
Kalamata	1785.89	664.29	1121.61	119745	2520	22100
Kalymnos	1422.14	642.14	780.00	90800	2000	16500
Karpathos	3460.71	763.93	2696.79	63000	800	20000
Kasos	2140.71	730.71	1410.00	27250	100	1500
Kastelorizo	1564.29	664.29	900.00	19975	300	2500
Kastoria	1486.07	631.07	855.00	121410	1150	8400
Kavala	3203.29	1294.50	1908.79	135000	6800	100000
Kefalonia	2776.07	608.93	2167.14	109350	6200	25200
Kos	8760.00	3720.00	5040.00	108000	5900	78640
Kozani	1575.36	675.36	900.00	54900	300	5400
Kythira	1636.07	631.07	1005.00	44400	1720	12800
Leros	1733.93	608.93	1125.00	30450	655	6000
Limnos	3383.46	1296.75	2086.71	135000	5600	66584
Milos	1231.96	549.46	682.50	20000	1400	7800
Mykonos	3753.11	683.11	3070.00	57000	8510	28500
Mytilini	5792.21	1751.96	4040.25	108630	2500	21600
Naxos	2158.57	786.07	1372.50	27000	420	4000
Paros	1455.89	592.32	863.57	17750	265	4300
Rhodes	8760.00	3720.00	5040.00	148770	49150	110600
Samos	4618.96	1705.00	2913.96	91350	8850	53600
Santorini	5259.54	813.75	4445.79	63750	3700	36800
Sitia	2137.86	675.36	1462.50	93510	1000	24000
Skiathos	2257.29	631.00	1626.29	50520	6400	7800
Skyros	1564.29	664.29	900.00	90000	750	15000
Syros	1473.43	620.00	853.43	32400	1200	10000
Thessaloniki	8760.00	3720.00	5040.00	266600	37850	215000
Zakynthos	3479.00	597.86	2881.14	67020	26500	58500

Table 3. Determinants of the technical efficiency of Greek airports.

Airport	Island	Category 1	Category 2	Category 3	Category 4	Mixed use (civil & military)	WLU	Access (km from the nearest city)
Aghialos				*		*	19367.82	30.0
Aktio			*			*	338211.56	2.0
Alexandroupoli		*					313554.72	6.5
Araxos			*			*	136987.00	45.0
Astypalaia	*				*		18640.13	8.0
Athens		*					17850619.14	33.0
Chania	*	*				*	1917838.17	14.0
Chios	*			*			266590.28	4.0
Corfu	*	*					2047738.95	1.5
Heraklion	*	*				*	5514584.05	5.0
Ikaria	*				*		26805.99	12.0
Ioannina			*				140986.36	5.0
Kalamata		*				*	114919.45	9.0
Kalymnos	*				*		19934.00	7.0
Karpathos	*			*		*	193849.45	18.0
Kasos	*				*		14332.43	1.0
Kastelorizo	*				*		9816.64	4.0
Kastoria			*				4832.23	12.0
Kavala		*				*	382906.84	29.0
Kefalonia	*	*					382938.93	9.0
Kos	*	*					1688309.05	27.0
Kozani					*		4139.00	5.0
Kythira	*				*		32757.01	8.0
Leros	*				*		30698.42	8.0
Limnos	*	*				*	150080.09	22.0
Milos	*			*			34100.85	6.0
Mykonos	*		*				447936.92	4.0
Mytilini	*	*					586454.14	8.0
Naxos	*			*			28981.98	3.0
Paros	*			*			37093.44	9.0
Rhodes	*	*					3701701.51	16.0
Samos	*	*					508160.83	17.0
Santorini	*		*			*	772490.05	7.0
Sitia	*		*				36012.99	1.0
Skiathos	*		*				278769.00	4.0
Skyros	*				*	*	13182.00	11.0
Syros	*				*		7915.00	3.0
Thessaloniki		*				*	4501351.77	16.0
Zakynthos	*	*					1002888.00	6.0

Notes: Category 1: International airports servicing both domestic and international scheduled and non-scheduled flights.
Category 2: Domestic airports which serve domestic flights and constitute legislated points of inbound and outbound traffic to/from the country through non-scheduled flights.
Category 3: Domestic airports which serve domestic flights and constitute occasional points of inbound and outbound traffic to/from the country through non-scheduled flights, based upon arrangement with operators/carriers.
Category 4: Purely domestic airports servicing only domestic flights.

Table 3 illustrates the variables used here as determinants of airport efficiency, involving location, size and operating characteristics. In terms of the location, the presence of the majority (28) of airports in *islands* signifies their crucial role in territorial cohesion and their economic and social development, particularly through servicing the domestic and international tourist movements during the summer period. Another location variable is *access*, which refers to the road network distance between an airport and its nearest city. In terms of the managerial and operating status, the Greek airports are centrally managed through the CAA and are state-owned, except of the international airport of Athens, which is operated as a private-sector company and constitutes the major hub of the domestic air transport network.

They are distinguished into four categories: *Category 1* includes the 15 international airports which serve both the domestic and international scheduled and non-scheduled flights; *Category 2* includes 8 domestic airports which serve domestic flights and they constitute legislated points of inbound and outbound traffic to/from the country through non-scheduled flights; *Category 3* includes 6 domestic airports which serve domestic flights and they constitute occasional points of inbound and outbound traffic to/from the country through non-scheduled flights, based upon arrangement with operators/carriers; *Category 4* includes 10 purely domestic airports servicing only domestic flights. In addition, the Greek airports can be distinguished into those of *single* (only civil) *use* and *mixed* (civil and military) *use*. The latter category encompasses 12 airports (half of them in islands), indicating their significant role in the national defence and security in the region. The size of airports is expressed in terms of the *workload unit* (WLU) which aggregates passengers and cargos as follows: 1 WLU equals 1 passenger or 100 kg of cargo. This measure captures the aggregate effect of demand on airport efficiency.

3. Methodological Issues

3.1. Estimation of efficiency scores

The DEA approach employs a series of linear programming problems with multiple inputs and outputs for evaluating the relative efficiency of a set of decision-making units (airports) against a production frontier. It circumvents problems related to the functional form and distributional assumptions, which are commonly met in parametric (stochastic frontier analysis) methods. Based on Farrell (1957), the DEA model may assume a constant returns-to-scale (CRS) relationship between inputs and outputs (Charnes et al., 1978), or, alternatively, a variable returns-to-scale (VRS) relationship, by adding a convexity constraint to the problem of maximizing the ratio of weighted outputs to weighted inputs (Banker et al., 1984).

The model can be either input-oriented, when trying to determine the minimum inputs for producing a given level of output, or output-oriented, when concentrating on the maximization of outputs with given levels of (exogenous) inputs (Coelli, 1996). The output-oriented model is adopted here, provided that each airport aims at servicing as many passengers, cargos and flights as possible, given a certain level of budget-constrained resources, typically originating from European funds for peripheral airports and the Public Investment Program of the Greek government.

The model assuming CRS measures the overall technical efficiency, encompassing the pure technical and scale efficiencies, whereas the one assuming VRS measures the pure technical efficiency only. The ratio of the overall technical efficiency score to pure technical efficiency score yields the measure of scale efficiency. Regarding that the overall technical efficiency is due to managerial skills and scale effects, the efficiency scores obtained from the model with VRS reflects the managerial skills of airport operators. It is noted that the current dataset meets the DEA conventions that the minimum number of decision-making units (airports) must be larger than three times the number of inputs plus outputs, i.e., $[3 \times (6+3)] < 39$, and that the minimum number of units must be equal to or larger than the product of the number of inputs and outputs, i.e., $[6 \times 3] < 39$.

3.2. Regression techniques for analysis of determinants of efficiency

Following the implementation of the DEA for estimating the efficiency score, y_i, of each airport $i = 1, \ldots, N$ (first-stage), the effect of the k-th determinant (observation-specific variable) of efficiency, denoted as x_{ki}, for that airport, with $k = 1, \ldots, K$, can be assessed (second-stage), through adopting the following regression specification:

$$y_i = \sum_{k=1}^{K} \beta_k \, x_{ki} + \varepsilon_i, \quad i = 1, \ldots, N \tag{1}$$

where β_k is the coefficient of k-th determinant of efficiency, and ε_i is a continuous, independent and identically distributed, random variable (for brevity purposes, the constant term is here omitted). As the efficiency scores, y_i, have an upper bound of one, there may be a truncated bias in using ordinary least-squares (OLS) regression for solving equation (1). Although tobit analysis has been the most popular approach to address this problem, Simar and Wilson (2007) demonstrated the potential bias and inconsistency in parameter estimates. This is because the efficiency scores are point estimates without a probability distribution around them, as required by the tobit or any other parametric regression technique, and, as relative indexes, are correlated with the explanatory variables used in the second-stage.

Hence, they proposed the use of truncated regression with bootstrapping techniques to construct bootstrap confidence intervals and obtain unbiased and consistent parameter estimates. Barros (2008) showed for the performance evaluation of Argentinean airports that the truncated regression with a bootstrap model fitted the data well with statistically significant parameter estimates, compared to the tobit model estimates. A bootstrapped maximum likelihood approach is adopted to estimate the latter model, wherein the bias-corrected distance function estimator yields consistent and efficient results, as shown in (Simar and Wilson, 2007).

4. Results of the DEA efficiency scores

4.1. Efficiency scores for the total annual period

Table 4 shows the DEA efficiency scores of the Greek airports for the total annual period of the study. The last column indicates whether an airport has variable returns-to-scale (VRS), which may be decreasing (DRS) or increasing (IRS) ones, implying that its dimension does make a difference on efficiency, or constant returns-to-scale (CRS), implying that inputs and outputs may be linearly scaled without changing efficiency.

Table 4. Results of the DEA efficiency scores for the total annual period.

Airport	CRS technical efficiency	VRS technical efficiency	Scale efficiency	Position on frontier
Aghialos	0.113	0.236	0.479	IRS
Aktio	0.359	0.408	0.881	IRS
Alexandroupoli	0.603	0.699	0.863	IRS
Araxos	0.332	0.492	0.675	IRS
Astypalaia	0.357	0.506	0.706	IRS
Athens	1	1	1	CRS
Chania	0.853	0.900	0.948	DRS
Chios	1	1	1	CRS
Corfu	0.739	0.743	0.995	IRS
Heraklion	1	1	1	CRS
Ikaria	0.183	0.233	0.785	IRS
Ioannina	0.418	0.459	0.912	IRS
Kalamata	0.241	0.378	0.638	IRS
Kalymnos	0.178	0.274	0.652	IRS
Karpathos	0.620	0.621	0.998	DRS
Kasos	1	1	1	CRS
Kastelorizo	0.269	1	0.269	IRS
Kastoria	0.064	0.087	0.729	IRS
Kavala	0.389	0.418	0.931	IRS
Kefalonia	0.455	0.483	0.942	IRS
Kos	1	1	1	CRS
Kozani	0.077	0.103	0.741	IRS
Kythira	0.165	0.209	0.791	IRS
Leros	0.403	0.510	0.790	IRS
Limnos	0.341	0.351	0.974	IRS
Milos	0.438	1	0.438	IRS
Mykonos	0.614	0.626	0.981	IRS
Mytilini	0.855	1	0.855	DRS
Naxos	0.317	0.373	0.851	IRS
Paros	0.771	1	0.771	IRS
Rhodes	0.880	0.905	0.972	DRS
Samos	0.491	0.492	0.998	DRS
Santorini	0.946	0.957	0.989	DRS
Sitia	0.441	0.501	0.879	IRS
Skiathos	0.923	1	0.923	IRS
Skyros	0.195	0.254	0.768	IRS
Syros	0.100	0.141	0.710	IRS
Thessaloniki	1	1	1	CRS
Zakynthos	0.452	0.550	0.822	IRS
Mean	0.528	0.613	0.837	
Median	0.441	0.510	0.879	
Strd. Deviation	0.316	0.315	0.174	

There are important differences in efficiency found among airports (see also the measure of standard deviation), which can be attributed to both variations in pure technical and scale efficiency. The average level of the overall technical efficiency of Greek airports is somewhat higher than the half (53%) of optimum efficiency. This outcome suggests the need for designing and implementing suitable policies aimed at making better use of currently wasted resources.

Only 6 airports are found to operate on the efficient frontier, having both CRS and VRS efficiency scores equal to unity, namely, their outputs cannot be further produced without increasing the inputs. These airports, including Athens, Thessaloniki, Heraklion, Kos (Category 1), Chios (Category 3) and Kasos (Category 4), can be regarded as having adequate scale dimension. Nonetheless, most airports have relatively high scale efficiency, with 24 of them operating above the 80% of the optimum value. This outcome stresses that scale constitutes a dominant source of efficiency of Greek airports. In addition, there are five airports, all situated at Aegean islands (Kastelorizo, Milos, Mytilini, Paros and Skiathos), which display pure technical efficiency at the optimum level, but their scale is not found to be efficient (<1). In such cases, the airports may face problems raising revenues and should concentrate on taking full advantage of their scarce resources.

Moreover, most airports (33 out of 39) have VRS, and 27 of them have IRS, implying that an increase in an input unit is expected to yield a larger than proportionate increase in their outputs. Hence, these 27 airports are likely to experience economies of scale when their output increases in the long run. In particular, they can exploit economies of size and enhance the scale of air traffic operations, e.g., through developing hub strategies which can increase outputs, yielding lower average costs and thus higher profits.

On the other hand, there are only 6 airports with DRS, which are situated at Aegean islands (Karpathos, Mytilini, Rhodes, Samos and Santorini) and Crete (Chania). The long-run average costs of these airports rise as their output increases. Therefore, the corresponding airport authorities may consider decreasing the scale of air traffic operations to reduce average costs, e.g., through implementing slot management or pricing strategies.

As has been mentioned in previous studies in the relevant literature (see Section 1), the outcome of the benchmarking process may be influenced by such key factors as airport size, since large airports are likely to experience economies of scale, and the nature of traffic, e.g., share of international passengers, which involve higher costs and increased revenues than domestic passengers. Large airports with these characteristics can affect the results of DEA, which may be sensitive to extreme values and outliers (see Wilson, 1995). For this reason, the impact of the international Athens airport, which accounts for 39.5% of passenger traffic, 82.2% of the total amount of cargo and 42.4% of the total number of flights, on the resulting frontier is examined here by re-implementing the DEA without this observation (see Table 5).

Table 5. Results of the DEA efficiency scores for the total annual period, excluding the Athens airport.

Airport	CRS technical efficiency	VRS technical efficiency	Scale efficiency	Position on frontier
Aghialos	0.113	0.236	0.479	IRS
Aktio	0.337	0.379	0.889	IRS
Alexandroupoli	0.630	0.688	0.916	IRS
Araxos	0.315	0.392	0.805	IRS
Astypalaia	0.357	0.506	0.706	IRS
Chania	0.702	0.773	0.908	DRS
Chios	1.000	1.000	1.000	CRS
Corfu	0.595	0.637	0.933	DRS
Heraklion	1.000	1.000	1.000	CRS
Ikaria	0.183	0.236	0.773	IRS
Ioannina	0.418	0.459	0.912	IRS
Kalamata	0.222	0.289	0.769	IRS
Kalymnos	0.178	0.301	0.592	IRS
Karpathos	0.619	0.621	0.996	DRS
Kasos	1.000	1.000	1.000	CRS
Kastelorizo	0.269	1.000	0.269	IRS
Kastoria	0.064	0.093	0.682	IRS
Kavala	0.381	0.397	0.961	IRS
Kefalonia	0.455	0.483	0.942	IRS
Kos	1.000	1.000	1.000	CRS
Kozani	0.077	0.103	0.741	IRS
Kythira	0.165	0.342	0.483	IRS
Leros	0.403	0.509	0.790	IRS
Limnos	0.341	0.351	0.974	IRS
Milos	0.438	1.000	0.438	IRS
Mykonos	0.614	0.626	0.981	IRS
Mytilini	0.833	1.000	0.833	DRS
Naxos	0.317	0.372	0.854	IRS
Paros	0.771	1.000	0.771	IRS
Rhodes	0.861	0.887	0.971	DRS
Samos	0.491	0.492	0.998	DRS
Santorini	0.914	0.957	0.955	DRS
Sitia	0.441	0.501	0.879	IRS
Skiathos	0.760	0.839	0.906	IRS
Skyros	0.195	0.254	0.768	IRS
Syros	0.100	0.151	0.662	IRS
Thessaloniki	1.000	1.000	1.000	CRS
Zakynthos	0.382	0.475	0.804	IRS
Mean	0.498	0.588	0.825	
Median	0.428	0.504	0.884	
Strd. Deviation	0.299	0.304	0.181	

The returns-to-scale are found to be the same among the two sets of results (with and without including the Athens airport) for all airports, except of Corfu (which appears DRS in the latter case). The Wilcoxon signed rank test is employed to identify any significant difference in the efficiency scores of the two sets. This is a non-parametric test which circumvents any assumption about the distribution of differences between paired scores and considers information about both the sign and magnitude of the differences. The results strongly reject the statistical significance of score differences between the two sets, in terms of the CRS, VRS and scale efficiency scores[1]. Thus, the distinct size and traffic characteristics of the Athens airport cannot be considered as statistically significantly influencing the distribution of efficiency scores of the other Greek airports.

4.2. Seasonal analysis of the efficiency scores

Tables 6 and 7 present the resulting efficiency scores obtained from the separate DEA conducted for the winter (low-demand) and summer (high-demand) operating periods, respectively. In the winter period, there are only 4 airports (Athens, Thessaloniki, Chios and Kasos) which keep operating on the efficient frontier, having both CRS and VRS efficiency scores equal to unity (see Table 6). It is noted that the CRS efficiency scores of Heraklion and Kos airports, which are equal to unity over the total annual period, drop to 53% and 36%, respectively, during the winter period. Moreover, there are only 15 airports operating above the 80% of the optimum scale efficiency, while 8 airports operate with DRS, compared to 6 airports over the total period.

[1] The *z*-values for the differences in the CRS, VRS and scale efficiency scores are equal to 0.029, 0.326 and 0.232, with significance levels at 97,7%, 74,4% and 81,7%, respectively.

Table 6. Results of the DEA efficiency scores for the winter period.

Airport	CRS technical efficiency	VRS technical efficiency	Scale efficiency	Position on frontier
Aghialos	0.033	0.070	0.473	IRS
Aktio	0.125	0.176	0.712	IRS
Alexandroupoli	0.735	0.746	0.985	DRS
Araxos	0.007	0.011	0.590	IRS
Astypalaia	0.393	0.713	0.551	IRS
Athens	1	1	1	CRS
Chania	0.356	0.414	0.859	DRS
Chios	1	1	1	CRS
Corfu	0.228	0.245	0.928	DRS
Heraklion	0.529	0.574	0.922	DRS
Ikaria	0.122	0.193	0.632	IRS
Ioannina	0.466	0.574	0.813	IRS
Kalamata	0.041	0.061	0.672	IRS
Kalymnos	0.160	0.253	0.631	IRS
Karpathos	0.620	0.878	0.706	IRS
Kasos	1	1	1	CRS
Kastelorizo	0.233	1	0.233	IRS
Kastoria	0.073	0.126	0.576	IRS
Kavala	0.263	0.273	0.963	IRS
Kefalonia	0.234	0.328	0.712	IRS
Kos	0.360	0.493	0.730	DRS
Kozani	0.067	0.118	0.569	IRS
Kythira	0.131	0.216	0.606	IRS
Leros	0.373	0.743	0.502	IRS
Limnos	0.353	0.362	0.976	IRS
Milos	0.452	1	0.452	IRS
Mykonos	0.205	0.254	0.806	IRS
Mytilini	0.852	1	0.852	DRS
Naxos	0.262	0.349	0.750	IRS
Paros	0.542	1	0.542	IRS
Rhodes	0.467	0.572	0.817	DRS
Samos	0.391	0.392	0.997	DRS
Santorini	0.430	0.561	0.766	IRS
Sitia	0.501	0.813	0.616	IRS
Skiathos	0.069	0.118	0.580	IRS
Skyros	0.132	0.225	0.587	IRS
Syros	0.098	0.176	0.560	IRS
Thessaloniki	1	1	1	CRS
Zakynthos	0.075	0.236	0.318	IRS
Mean	0.369	0.494	0.718	
Median	0.353	0.392	0.712	
Strd. Dev	0.294	0.338	0.201	

Table 7. Results of the DEA efficiency scores for the summer period.

Airport	CRS technical efficiency	VRS technical efficiency	Scale efficiency	Position on frontier
Aghialos	0.134	0.261	0.513	IRS
Aktio	0.371	0.382	0.972	IRS
Alexandroupoli	0.515	0.589	0.874	IRS
Araxos	0.376	0.462	0.815	IRS
Astypalaia	0.316	0.390	0.810	IRS
Athens	1	1	1	CRS
Chania	0.868	0.895	0.970	DRS
Chios	1	1	1	CRS
Corfu	0.761	0.762	0.999	IRS
Heraklion	1	1	1	CRS
Ikaria	0.206	0.235	0.878	IRS
Ioannina	0.365	0.391	0.934	IRS
Kalamata	0.250	0.375	0.665	IRS
Kalymnos	0.174	0.301	0.578	IRS
Karpathos	0.614	0.676	0.908	DRS
Kasos	1	1	1	CRS
Kastelorizo	0.300	1	0.300	IRS
Kastoria	0.054	0.072	0.751	IRS
Kavala	0.400	0.416	0.963	IRS
Kefalonia	0.460	0.464	0.991	IRS
Kos	1	1	1	CRS
Kozani	0.081	0.092	0.881	IRS
Kythira	0.183	0.209	0.878	IRS
Leros	0.405	0.440	0.920	IRS
Limnos	0.318	0.329	0.964	IRS
Milos	0.401	1	0.401	IRS
Mykonos	0.705	0.705	1	CRS
Mytilini	0.808	1	0.808	DRS
Naxos	0.348	0.380	0.917	IRS
Paros	0.876	1	0.876	IRS
Rhodes	0.914	0.914	0.999	DRS
Samos	0.500	0.506	0.988	IRS
Santorini	1	1	1	CRS
Sitia	0.388	0.409	0.949	IRS
Skiathos	1	1	1	CRS
Skyros	0.219	0.261	0.838	IRS
Syros	0.094	0.128	0.734	IRS
Thessaloniki	1	1	1	CRS
Zakynthos	0.473	0.479	0.988	IRS
Mean	0.535	0.603	0.873	
Median	0.405	0.479	0.934	
Strd. Deviation	0.322	0.324	0.172	

There is a total of 16 airports whose both pure technical and scale efficiency are reduced during the winter period, while 2 airports (Kastelorizo and Paros) experience scale efficiency losses, but their pure technical efficiency remains at the optimum level. There are 6 airports (Astypalaia, Ioannina, Karpathos, Kastoria, Sitia and Syros) whose overall technical and scale efficiency decrease, compared to the total period, but their pure technical efficiency increases during the winter period. Besides, there are 3 airports (Kozani, Kythira and Leros) wherein only the scale efficiency drops, but their pure technical efficiency increases during the winter period. Last, there are 3 airports (Kalamata, Kalymnos and Samos) whose only the pure technical efficiency decreases, but their scale efficiency increases during the winter period.

On the contrary, in the summer period, there are 8 airports (Athens, Thessaloniki, Heraklion, Kos, Chios, Kasos, Santorini and Skiathos) which operate on the efficient frontier (see Table 7). There are 32 airports operating above the 80% of the optimum scale efficiency, and only 4 airports (Karpathos, Mytilini, Rhodes and Chania) with DRS. There are only 2 airports (Alexandroupoli and Limnos) whose both pure technical and scale efficiency decrease, compared to the total period, while 2 airports (Milos and Mytilini) experience scale efficiency loss, but their pure technical efficiency remains at the optimum level. Therefore, most airports whose pure technical and/or scale efficiency are not found to be improved in the summer period are mainly situated at less tourist destinations, like in North Aegean (Limnos, Mytilini and Samos), low-demand island destinations in South Aegean (Astypalaia, Kalymnos, Karpathos, Kythira, Leros and Sitia), and peripheral mainland regions (Alexandroupoli, Ioannina, Kastoria, Kozani and Kalamata) of the country.

Table 8 shows the results, in terms of the *z*-values and significance levels, of the Wilcoxon signed rank test of the seasonal differences of efficiency scores. The comparison between the total and winter periods indicate that all types of efficiency are statistically significantly degraded (as reflects the positive sign) during the winter period. The opposite holds for the summer period (as reflects the negative sign), where the overall technical and scale efficiency are improved, compared to the total period.

Table 8. Wilcoxon signed rank test of the seasonal differences of the airport efficiency scores.

Compared periods	CRS technical efficiency	VRS technical efficiency	Scale efficiency
Total *vs.* winter	3.864***	2.356**	4.567***
Total *vs.* summer	-1.594	1.156	-3.616***
Winter *vs.* summer	-3.408***	-2.174**	-4.360***

Note: (*) statistical significance at 10%, (**) statistical significance at 5%, (***) statistical significance at 1%.

Specifically, the statistically significant negative value of the difference of scale efficiency demonstrates that the scale economies of Greek airports are principally dependent on their operations during the summer period. The positive (but, statistically non-significant) value of the VRS efficiency score difference between the total and summer periods depicts the lack of managerial skills to accommodate the increased levels of tourist flows in the latter period. Finally, the comparison between the winter and summer periods verify that all types of efficiency are statistically significantly improved (as reflects the negative sign) during the latter period.

5. Analysis of determinants of efficiency

The current analysis uses the CRS efficiency scores, as they identify the overall inefficiency of airports. Table 9 demonstrates the results of the determinants of airport efficiency, based on the bootstrapped truncated regression model. The results of the tobit regression with bootstrap are also presented for comparison purposes. The two models yield coefficients of the same sign, except for the mixed-use dummy variable. Nevertheless, the truncated regression model is found to perform better, on the basis of the lower variance and statistical significance (at the conventional levels of confidence) of five parameter estimates, compared to the tobit model wherein only two parameter estimates are found to be statistically significant.

Table 9. Results of the determinants of airport efficiency

Determinant	Tobit regression	Truncated regression
Constant	0.108	-0.090
Island	0.231**	0.286**
Category 1	0.192	0.319**
Category 2	0.270**	0.423***
Category 3	0.277	0.312**
Mixed use	-0.003	0.040
WLU (millions)	0.186	0.183*
Access	-0.003	-0.003
Variance	0.222***	0.169***

Note: (*) statistical significance at 10%, (**) statistical significance at 5%, (***) statistical significance at 1%.
A number of 1000 bootstrap replications has been produced to obtain standard errors and confidence intervals.

More specifically, the findings of the truncated regression model indicate the positive and statistically significant impact on airport efficiency of (a) island location, which largely relates to the increased output of airports situated at tourist destinations, (b) Categories 1, 2 and 3 allowing (permanent or temporary) international flight connections, compared to Category 4 corresponding only to domestic flight connections, and (c) size of operations, in terms of the WLU, which can be attributed to the economies of scale (see Graham, 2005). The positive sign of the coefficient related to the mixed (civil and military) operations denotes the beneficial (although statistically non-significant) impact of the additional capacity met in those airports on their overall technical efficiency. The negative sign of the coefficient related to the ground (road) access shows the adverse (but statistically non-significant) effect of the distance from the nearest city on airport efficiency.

6. Conclusions

Airport operations constitute an important element of the regional development and territorial cohesion in Greece. The present analysis signified sources of inefficiency of the Greek airport system and can help the identification of appropriate strategies to improve its performance. The fact that most airports experience increasing returns-to-scale promotes the incentives for their upgrading or expansion through employing new funding schemes, which involve the participation of the private sector. Also, it may encourage the development of new organizational structures for coordinated peripheral airports, e.g., through establishing regional-oriented hubs in the Aegean region, to exploit economies of size and enhance the scale of operations. In this direction, the strengthening of the air transport liberalization process can lead international low-cost carriers to expand or establish new direct flight connections with island airports.

In contrast with the summer period, the air traffic operations in the winter period were found to contribute to statistically significant losses in efficiency. The significant impact of seasonality on efficiency, particularly in those airports with increased tourist movements, indicates the need for adopting suitable measures to address the underutilization of their facilities during the winter period. Such measures can refer to the flexible design of the overall configuration and interior arrangements of terminals, e.g., by building and tearing down walls, or expanding them up or out, to make airport facilities more responsive to the changing needs of low-cost carriers (see De Neufville, 2008; Psaraki-Kalouptsidi, 2010). Finally, the promotion of strategies for alternative tourism can help to temporally spread the air travel demand into the winter period.

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