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The Efficiency of European Airports: Do the Importance in the EU Network and the Intensity of Competition Matter?

by

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Abstract

In this paper we study the efficiency of European airports by applying a DEA model to 57 airports. The sample covers 95% of all the airports with a traffic of at least 5 millions passengers (yearly). We find that largest airports (with more than 10 millions passengers) are more efficient, while airports classified by the European Commission as national have spare capacity and should improve their performances. Largest airports have decreasing returns to scale, while national ones will get a reduction in their average costs if they increase their size of operation. Moreover we investigated the determinants of the estimated efficiency scores. The Tobit regression shows that efficiency is positively related with airport's connectivity index in the European network (i.e. airports with better connections at the network are more efficient) and with the intensity of competition between airports (i.e. airports with nearby competitors on several destinations tend to be more efficient). These results imply that policy makers (in regulating airports' fares and subsidizing development plans) and managers (in evaluating their assets utilization) should take into account that a well connected destinations map and the presence of indirect competition coming from other airports can improve the performances in the management of European airports.

JEL classification: [L930, L590, L110]

Keywords: air trasportation, efficiency, connectivy, airports' competition.

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1. Introduction

The European air transportation sector has shown a robust growth during the last years. In the period 2000 – 2005 passengers increased at an annual rate of 3.5%.[1] This is the effect of liberalization: the EU started in 1993 the open skies regime, allowing every European carrier to operate flights from every airport located in country members. New carriers entered the market – especially the low cost airlines – increasing the supply and reducing the price. Recently the EU and the US have signed an Open Skies agreement, that should provide a further improvement to the sector. As stated by Gillen D. – Lall A. (1997), the carriers' increased competition has provided a strong stimulus to improve airport performances, since airlines cannot easily pass increases in airport charges to consumers. In this light, it is important to know whether European airports are able to operate efficiently using the current capacity so that, as argued by Sarkis J. – Talluri S. (2000), airlines can select the more efficient airports and both the European Community and the single governments can optimally allocate resources to airport improvement programs, rather than being subject to lobbies and political pressures. This is the goal of this paper. More in details, our aim is twofold: First we want to estimate the efficiency of each airport included in the sample. Second, we want to investigate the relationships between the obtained efficiency scores and some crucial competitive variables: the airport's relative importance within the European air transportation network and the competitive pressure exerted on each airport by the nearest ones.

We apply to our dataset the air transportation model proposed by Pels *et al*. (2003), which consider each airport as a firm producing two outputs: aircraft movements and passengers. Our main findings are the following ones: First, we find that many airports can improve their efficiency on both types of output, and that, in general, European airports are more efficient in dealing with passengers rather than with aircraft movements: when we consider the latter only 19% of European airports are efficient, while this percentage increases to 33% if we take passengers into account (i.e. only one third of airports are efficient on this output). More in details, by splitting airports, according to the EU classification, into Great European Airports (i.e. those with more than 10 millions passengers per year) and National Airports (i.e. those with less than 10 millions and more than 5 millions passengers per year), we obtain that the larger airports

[1] During the same period the annual growth in France is 1%, in Germany 2.7%, in Great Britain 4.6%, in Spain 5.1%. See ICCSAI (2007) for a comprehensive analysis of the trends in the European countries.

tend to be more efficient than the national ones.[2] However, since an airport close to the physical efficiency frontier (or on the frontier itself) it is heading for saturation in its capacity to offer airport services (Pacheco R.R. – Fernandes E. (2003)), these results imply that large European airports are operating at full capacity while the national airports have spare capacity.

Second, large airports are mainly working under decreasing returns to scale; on the contrary, increasing returns to scale prevail in National European airports. Hence, from a cost perspective, large airports should decrease their scale of operation to enjoy a reduction in average costs. As just mentioned, these airports are close to capacity saturation. Hence in case of an increase of the large European airports' activities (e.g. London Heathrow or Paris Charles de Gaulle), the combination of these two factors (capacity saturation and decreasing returns to scale), on the one hand, will require further investments (to overcome capacity saturation), on the other hand will lead to higher unit costs (due to decreasing returns to scale). National airports instead exhibit increasing returns to scale and so an increase in their scale of operation will produce a reduction in average costs.

Third, by performing an econometric analysis on the estimated efficiency scores on a set of explanatory variables we have identified that airports tend to be more efficient if they play a strategic role in the European network and if they are subject to some competitive pressure (i.e. if there are airports which may act as substitutes from a location point of view). We find instead no evidence that efficiency is greater if you airlines dominates an airports.

We measure airports' performance through the estimation of an efficient frontier, adopting a DEA (Data Envelopment Analysis) model, i.e. a non – parametric method. Several contributions have investigated the productivity measures of airports using the DEA model. Gillen D. – Lall A. (1997) provide the most influential paper, pointing out the advantages of the DEA method when studying the efficiency of airports and setting a model of airport management based on two outputs: terminal services (i.e. passengers) and aircraft movements. They investigate a dataset composed by 21 US airports (out of the 30 top US airports).[3] Other studies on the efficiency of US airports are provided by Sarkis J. – Talluri S. (2004) and by Oum T.H. –

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[2] See EU classification. Airports with less than 5 millions but more than 1 million passengers are classified as ``Great Regional Airports", while those with less than 1 million are classified as ``Small Regional Airports".

[3] They show that, concerning aircraft movements, having hub airlines and expanding the number of gates increase the efficiency; terminal efficiency is instead improved by (again) increasing the number of gates and by managing them in order to ensure their effective utilization.

Yu C. (2004).[4] Pels E. *et* al. (2003) are the closest contribution to our study since they investigate the efficiency of a sample of 33 European airports (between 1995 and 1997). They show that many airports can improve efficiency and that there are no region – specific effects on efficiency. This paper differs for several features: First our dataset is larger (57 European airports) and more balanced (all airports with more than 30 millions passengers are included in the sample, and small airports are excluded, so that DEA estimates are more robust). Second we run a two-stage analysis whether the determinants of the efficiency scores are investigated. To the best of our knowledge this is the first attempt to link airport's efficiency and their relative position within the European network: by using graph theory we can identify each airport strength/weakness within the network, i.e. how it is connected with each other network's node. Third, this is the first attempt to estimate the impact on efficiency of the so – called indirect competition between airport, measured as the number of routes in a given airport which have the same route supplied by another airport located nearby.[5]

Several other papers analyze airports' efficiency on a single countries. Parker D. (1999) investigates the impact of privatization on a sample of 22 British airports, to find that it has no impact on their efficiency. Yoshida Y. (2004) and Yoshida Y. – Fujimoto H. (2004) explore the efficiency of Japanese airports and focus on regional airports, which seem to be less efficient because suffering of political pressure.[6] Australian airports have been investigated by Hooper P.G. – Hensher D.A. (1997) and by Abbott M. – Wu S. (2002), showing again that privatization has no impact on efficiency. Fernandes E. – Pacheco R.R. (2002) and Pacheco R.R. – Fernandes E. (2003) analyze the case of Brazilian airports, focusing on the performances of domestic airports, accomplishing a benchmark analysis. Barros C.P. – Sampaio A. (2004) examine a sample of 10 Portuguese airports, providing benchmarks and determinants of economic efficiency, arguing that Portuguese airports should be privatized. Murillo – Melchor C. (1999) studies the efficiency of 33 Spanish airports, showing that large size airports have decreasing

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[4] Sarkis J. - Talluri S. (2004) perform a benchmarking analysis based on DEA and clustering over a sample of 44 US airports. Oum T.H. - Yu C. (2004) compute factors productivity for airports included in the 2003 ATRS (Air Transport Research Society) Global Airport Benchmarking Report, which covers 37 US airports, 6 North American airports, 26 European airports, and 21 of the Asian countries. They show that both the airport size and capacity constraints (which create costs paid by airlines and passengers) improve airports' productivity.

[5] Differently from Pels *et al*. (2003), we cannot run a parametric analysis (e.g. an estimation of a stochastic frontier) because we have problems with the degree of freedom (i.e. our observations are too few if compared with the number of explanatory variables, given that cross – products have to be taken into account.

[6] Regional Japanese airports exhibit over capacity because local politicians direct more investments in their region, in order to gain consensus.

returns to scale.

We apply a DEA model to a sample of 57 European airports. Outputs and physical inputs (e.g. runways, terminal surface, etc.) for each airport have been collected for 2006. The sample covers 100% of largest European airports (which are 31) and 90% of those classified by the EU Commission as National airports (26 airports out of 29).[7]

The paper proceeds as follows. The methodology adopted to compute each airport connection to the European network, the index of competitive pressure and the main features of the DEA model are presented in Section 2. In Section 3 we describe our data set and show some summary statistics about European airports. Our estimated results about efficiency are reported in Section 4, while the two-stage analysis performed to investigate its determinants is presented in Section 5, while concluding comments are highlighted in Section 6.

2. Metodology: network connectivity, airport's competitive pressure and DEA

The aim of this Section is to provide the methodological tools to compute the index of network connectivity for each airport, the index of competitive pressure and to investigate the production frontier according to a DEA model.

2.1 The index of network connectivity

Much of the work on airport network connectivity is based on graph theory.[8] A network can be described as an array of nodes connected by links. Among the several features of a network, one of the most important is its mobility, i.e. the ease of travelling from one node to another (Milgran (1977)). The latter is measured as the number of steps required to link any pair of nodes. In the context of air transportation the airports are the nodes and point-to-point flights are the connections. The minimum number of flights connecting each pair of airports is known as the "shortest path length".[9] To compute it we have first to estimate the minimum number of steps required to connect each pair of airports. For example, if there is a direct link between airport A

[7] The sample does not include the airports of Belfast, Bristol and Nice.

[8] This has been used to model a wide array of networks: social, communications, neural, transportations.

[9] In general three main network types are defined (Stoneham (1977), Albert – Barabasi (2002), Watts – Strogatz (1998)): scale-free networks (characterized by a power law decay), broad-scale networks (where the power law regime is followed by a sharp cut-off) and single-scale networks (with a rapidly decaying tail). Several contributions (Guimerà *et al*. (2005), Li – Cai (2004), Bagler (2004) and Guida – Funaro (2007) have shown that the complex air travel systems can be classified as scale-free small world networks.

and airport B, the Shortest Path Length (SPL) between A and B is 1. On the other hand, if A and B are both connected to a third airport C but not directly linked, their SPL is 2. To describe a network of N airports, a N×N adjacency matrix A is introduced. An element a_{ij} is 1 if and only if there is a direct connection between the two airports; otherwise it is set to 0. A standard algorithm is deployed to calculate the minimum number of steps between each pair of airports (Bagler, 2004). Let SPL_{ij} be the shortest path length between airports *i* and *j*. Then SPL, the N×N matrix of shortest path lengths, is known as the connectivity matrix. For each airport a connectivity index CI_i is defined as

$$CIi = \sum_{j=1, i \neq j}^{N} \frac{SPL_{ij}}{N-1} \qquad (1)$$

The index is the average of the minimum path lengths between airport *i* and all other airports in the network. Estimation makes use of the Innovata database.[10] The analysis of shortest path lengths is carried out at the European level for all 478 airports with at least one scheduled passenger flight during the year 2006. Since the aim is to evaluate the potential for individual airports to enable connections between European destinations, some measures of centrality are needed. Following Freeman (1977), we define the "betweenness" of airport *k* as the number of minimal paths within the whole network that pass through node *k*. The higher the betweenness, the more central an airport is to the network and the more important its role as a connection node.

Calculation of shortest path lengths at the European level shows that many optimal connections have more than one solution. This may be because of the high level of integration associated with the most important European airports that collectively provide several alternative routes between minor destinations with SPL ≥ 2.[11] To distinguish those cases where one has no alternative but to pass through airport *k*, we introduce a new measure of centrality named "essential betweenness". This is defined as the number of unavoidable minimal paths passing through an airport, i.e., the number of minimal paths that are unique solutions for their nodes. Figure 1 shows the difference between these two measures of network centrality. In this example, airport E can only be reached by passing through airport D. Airports B, C, and D each have some

[10] Innovata is a provider of Scheduled Reference Services in partnership with IATA. The SRS airline schedules database contains data from over 892 airlines worldwide. It that contains published information on scheduled flights and includes the departure airport, departure time, arrival airport, arrival time, frequency, and operating airline.
[11] For example, a passenger with one layover may have the choice of changing at Paris, Madrid, or London.

degree of betweenness. However, only airport D has a measure of essential betweenness.

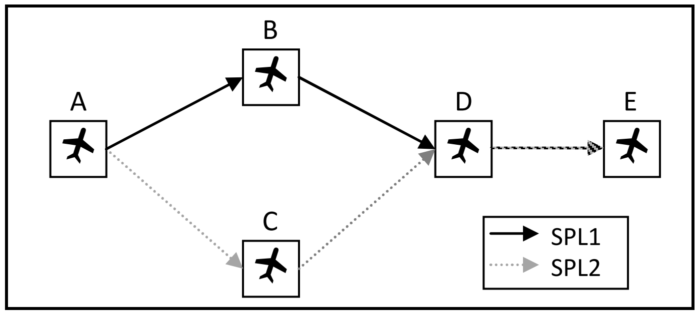

Figure 1: An example of the betweenness and essential betweenness connectivity indexes

Figure 2 shows instead the connectivity indexes for the European airports that will be used as explanatory variable to estimate the determinants of the airports' efficiency. The airports located at North – East have a good connectivity index with the network but they are also an essential node to reach a certain European region, e.g. the Scandinavian countries. Largest airports, e.g. Amsterdam, have a good connectivity index but they are not essential nodes to achieve a given region, because other airports may act as nodes to achieve the same destinations.

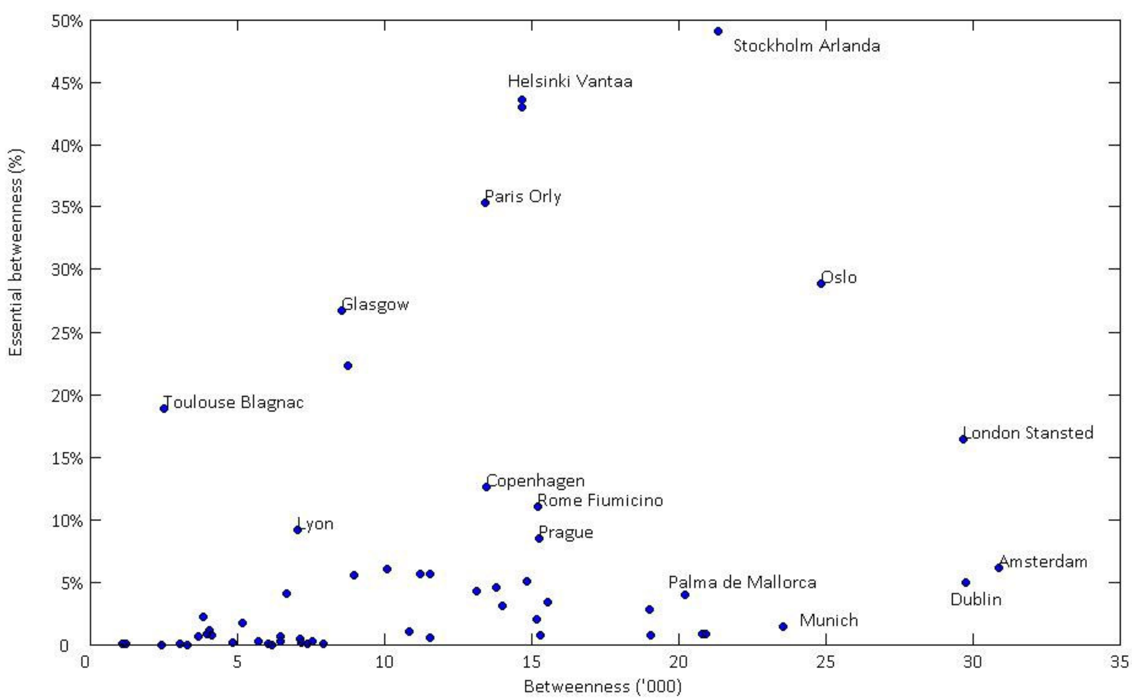

Figure 2: The relative importance of the largest European airports in the European network

2.2 The index of competitive pressure

We want to compute, on a single point-to-point connections, the alternative routes.[12] The possibility of using, for the same connection, an alternative airport depends on several factors, among which the distance between the airports. In our analysis we set some general limits to identify an alternative airport. The origin-distribution surveys carried out by airports and national authorities (CAA for example) point out that, in general, the higher number of passengers comes from areas which are within 1-1.5 hour[13] distance of the airport.[14] Since we do not have time information, we use a distance limit between the airports equal to 100 kilometres. Under this specification there are 371 European airports (75% of the total) with at least one potential competitor (see Table 1). Available data refer to European airports, therefore we only considered those routes which take off and land in European airports.

We considered links between original route airports and all their alternative airports in order to identify those routes potentially in competition (Figure 3).

Potential competitor number within a 100 km range	Number of airports	% on the total
0	*121*	*24.6%*
1	*110*	*22.4%*
2	*103*	*20.9%*
3	*83*	*16.9%*
4	*75*	*15.2%*

Source: Aviasolution's cartographies processing.

[12] If we consider the demand of a single airport, we can assume that the passenger's choice depends on time and costs to reach the airport, flight frequency and fare level. Some authors (e.g. Fewings, 1999) provide evidence that in France, UK and Germany (respectively) there are 32, 34 and 28 airports within less than an hour distance.
[13] See in the prospectus, for example, the analysis of SAVE listing.
[14] Fuellhart (2003) shows the presence of competition among airports within 60-90 miles top distance.

Table 1: Number of airports with potential competitiors

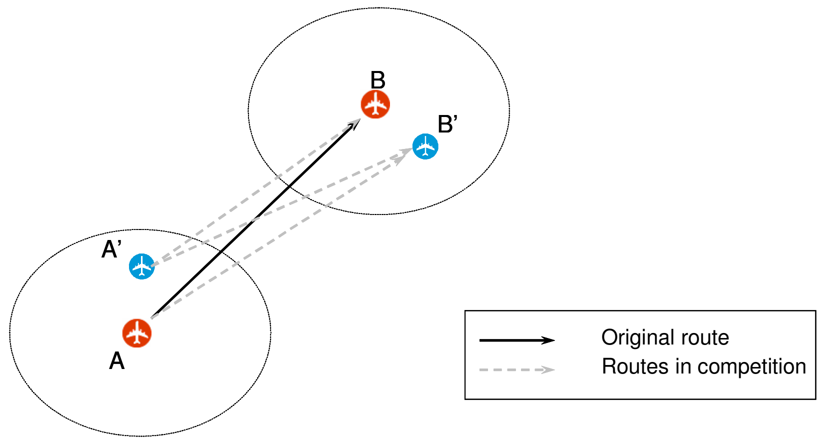

Figure 3: An example of indirect competition among routes

The cost of a longer journey to reach the alternative airport is proportional to the route length; therefore we decided not to consider those links which were 10% longer than the original route. Looking at the example in Figure 3, assuming that the distance between the original airports A-B is 1,000 kilometres and that the distances between airports A and A' and B and B' are less 100 kilometres, then we can say that A'-B and A-B' are alternative routes, while the route A'-B' could be a possible alternative route only if A-A'+B-B' is less than 100 kilometres in length.

Using such limits, there are 1,061 routes which have an alternative: they represent the 33.1% of the whole intra-European routes. Furthermore, the routes with an alternative represent about 50% of the Available Seat Kilometers (ASK) supplied on intra-European routes. Considering all the alternative routes as a single market, the market share of the dominant airline noticeably decreases in comparison with the outcomes of direct competition. Figure 4 shows how each European airport is exposed to competition: the largest airports (e.g. London Heathrow and Paris Charles de Gaulle) are exposed to a mild competitive pressure, since about 10% of their connections are supplied also by nearby airports.

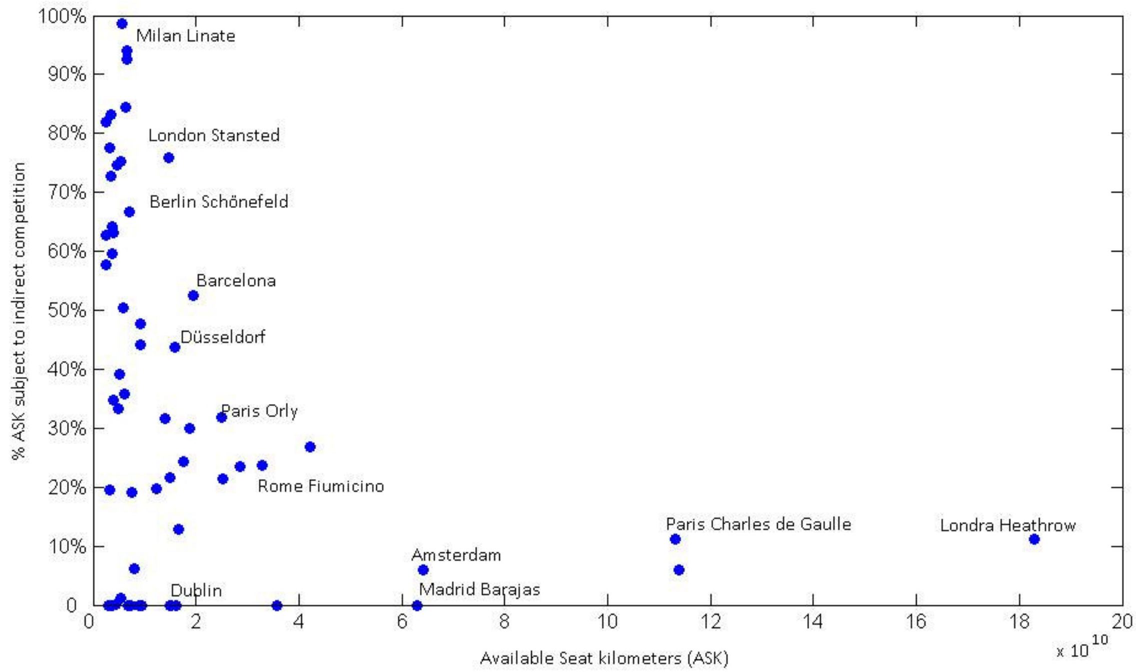

Figure 4:

2.3 Estimating a production frontier using a DEA model

The determination of the efficiency in the management of an airport involves the estimation of a production frontier, so that inefficiency is measured as the distance of an airport from that frontier. We adopt a DEA model where a sequence of linear programming problems creates a piecewise linear frontier, implicitly assuming that outputs can be fully explained from the inputs.[15] We focus on a input oriented DEA model, since we assume that the decisions concerning the output levels are out of control of the airports' management (Gillen - Lall (1997) and Pels *et* al. (2003)).

The DEA approach has two models: a Constant Return to Scale (CRS) model and a Variable Return to Scale (VRS) model, which allow to distinguish between Technical Efficiency (TE) and Scale Efficiency (SE).[16] The choice between CRS and VRS usually depends on the context and purpose of the analysis (e.g. managerial benchmarking (VRS) or long – run welfare

[15] Under this approach, the efficiency of an airport is estimated relative to the performance of other airports.
[16] See Charnes *et* al. (1978), Coelli (1996) and Färe *et* al. (1994) for a discussion on DEA model.

analysis (CRS)), on the length of the time interval covered by the available data (VRS is more appropriate for a short – run interval), and on the relevance of factors (e.g. regulation, time limits to the hours of operation, weather conditions) limiting the possibility of operating under the optimal scale of production.[17] Moreover, the size of available sample may be relevant in the choice between CRS and VRS: for instance, in small samples there are few large units and so, under the VRS model, they tend to be efficient for the simple reason that there are few units to compare. Our sample is rather homogenous (only the larger European airports are considered) and related to short-run, so that the adoption of a VRS model seems appropriate.

The VRS model implies solving the following constrained minimization problem for each airport included in the sample:

$$
\begin{aligned}
&\underset{h,\lambda}{Min} && h_0 \\
&s.t. && \sum_{l=1}^{L} \lambda_l y_{i,l} \geq y_{i,0}; i = 1,\ldots,m \\
& && h_0 x_{j,0} - \sum_{l=1}^{L} \lambda_l x_{j,l} \geq 0; j = 1,\ldots,n \qquad (1) \\
& && \sum_{l=1}^{L} \lambda_l = 1 \\
& && h_0, \lambda_l \geq 0
\end{aligned}
$$

where L is the total number of airports, m is the number of outputs considered and n is the number of inputs. The variables h and λ represents the weights to be determined by solving the programming model. The constraint $\sum_{l=1}^{L} \lambda_l = 1$ is included to distinguish between TE and SE. An intuition of this result is displayed in Figure 5. TE is given by the horizontal segment between the location of the generic airport A and the closest segment on the VRS frontier. The latter coincides with h_0 in problem (1). SE is instead equal to the horizontal segment between the linear combination on the VRS frontier corresponding to airport A, and the same linear combination on the CRS frontier. This combination is obtained as the solution of a problem similar to (1), and identifies only one efficient airport. The idea is that under the CRS model each unit varies all the inputs, while some of them are constrained under the VRS model. If SE = 1 the unit is efficient, since it is on the CRS frontier. If instead SE < 1 then we know that VRS are prevailing, but not

[17] See Pels *et* al. (2003) and Barros - Sampaio (2004) on the latter point.

the direction of these returns. The latter are identified by running another program with the following constraint: $\sum_{l=1}^{L} \lambda_l \leq 1$ (instead than $\sum_{l=1}^{L} \lambda_l = 1$). Then if this new estimate of SE is lower than 1 and h_0 from this new program is equal to (lower than) h_0 under program (1), we have decreasing (increasing) returns to scale.

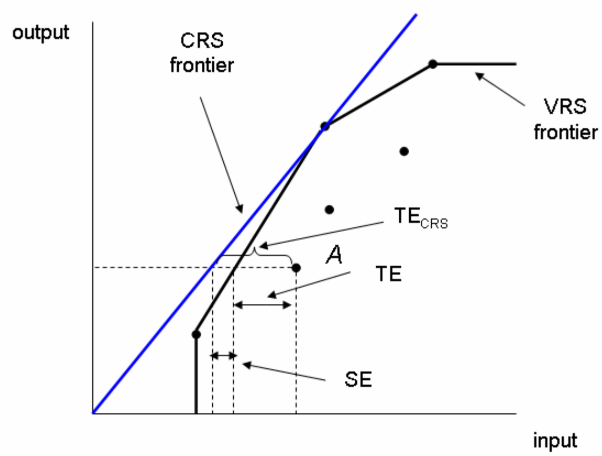

Figure 5: DEA input oriented, TE *vs* SE

We adopt the Gillen - Lall (1997) and the Pels *et* al. (2003) model of airport activities, such that an airport can be regarded as an interface between airlines and the passengers. Hence we need to consider both Air Transport Movements (ATM) and Air Passenger Movements (APM) and to treat ATM both as an output (for aircrafts movements) and as an input (for passenger movements).[18] This means that we can estimate both an efficiency in ATM (without considering APM) and also an efficiency in APM (where ATM is treated as an input).

[18] ATM can be considered as an intermediate good that is produced by the airport and consumed in the production of APM.

3. The data

The data set used in this contribution is composed of information from collected statistics regarding a sample of 57 European airports for the year 2006. The sample covers 100% of the largest European airports (those classifies in category A) and 90% of the so-called large national airports (classified in category B). Since we need data on inputs, such as the number of parking positions or the lines of baggage claims, we had to contact directly each airport's management and to build a new data set. We run a direct investigation covering 60 airports, but 3 of them (5%) did not provide the necessary information. For each airport we have information on the two output variables: the yearly number of aircraft movements (ATM) and the yearly number of passenger movements (APM). When dealing with the ATM frontier we consider the following inputs: the entire area of the airport (AREA), the total length of the runways (RUNWAYS), the total number of the aircraft parking positions (PARKING). The analysis of the APM frontier involves instead the following inputs: the yearly number of aircraft movements (ATM), the terminal surface (TERMINAL), the number of check--in desks (CHECK), the number of the aircraft parking positions (PARKING) and the number of lines for baggage claim (CLAIM). Table 2 presents descriptive statistics for each output and input variable in the sample data.

	Mean	**St. – Dev.**	**Min**	**Max**
APM (num)	16.685.197	13.953.384	5.000.000	67.686.450
ATM (num)	188.231	118.933	48.000	532.900
AREA (hectares)	906	757	140	3.300
TERMINAL (sqm)	136.635	161.233	11.100	928.000
PARKING (num)	81	56	21	270
CHECK (num)	130	113	29	539
CLAIM (num)	11	7	3	34
RUNWAYS (meters)	6.471	3.598	2.160	19.464

Table 2: Descriptive statistics for categories A and B Europen airports

The average number of passengers is about 17 millions while the average of aircraft movements is 188.000. The typical European airport has a terminal surface of 136.635 Sqm, about 81 aircraft parking positions, 130 check – in desks, 11 lines of baggage claims and it covers an area of 906 hectares. The average runway length is 6.471 meters.

4. Results

Table 3 shows the DEA efficiency scores regarding the European airports relating the ATM model, reporting both the CRS and VRS frontiers. There are 11 airports on the VRS frontier, i.e. with *TE* = 1: 5 (16%) of the largest ones (category A), i.e. London Heathrow, Paris Charles De Gaulle, Frankfurt, Dublin and Manchester, and 6 (23%) of category B (Larnaca, Milan Linate, Faro, Liverpool, London Luton, Newcastle). The category distance from the frontier, measured as the average distance from the VRS frontier of those airports with *TE* < 1, is as follows: 0,27 for category A, 0,30 for category B. The average inefficiency is greater in the National airports. Since we know that being close to the physical frontier is a signal of capacity saturation, this result implies that large European airports are working either at full capacity or close to it, while there is spare capacity in National airports.[19]

Country	Airport	CRS	VRS	Returns to Scale
Austria	Wien	0,69	0,69	IRS
Belgium	Brussels	0,52	0,52	IRS
Cyprus	Larnaca	0,54	1,00	IRS
Czech Republic	Praha	0,65	0,70	IRS
Denmark	Copenhagen	0,57	0,57	IRS
Finland	Helsinki Vantaa	0,62	0,66	IRS
France	Lyon Saint Exupéry	0,47	0,53	IRS
	Marseille Provence	0,48	0,55	IRS
	Nice Côte d'Azur	0,73	0,74	IRS
	Paris Charles de Gaulle	0,59	1,00	DRS
	Paris Orly	0,60	0,62	IRS
	Toulouse Blagnac	0,30	0,39	IRS
Germany	Hamburg	0,60	0,62	IRS
	Berlin Schönefeld	0,45	0,63	IRS
	Berlin Tegel	0,70	0,76	IRS
	Cologne Bonn	0,37	0,38	IRS
	Düsseldorf	0,78	0,79	IRS
	Frankfurt	0,66	1,00	DRS
	Hannover	0,45	0,58	IRS
	Munich	0,74	0,94	DRS
	Stuggart	0,82	0,84	IRS
Greece	Athens	0,51	0,54	IRS
Holland	Amsterdam	0,56	0,85	DRS

[19] As mentioned before when dealing with the choice between CRS and VRS, some caution is necessary in judging the efficiency scores reported for the largest airports (i.e. London Heathrow and Paris Charles De Gaulle) under the VRS model. Indeed if we observe their scores under the CRS model, where they are compared with all airports and not only between them, their efficiency is lower, especially for Paris Charles De Gaulle.

Country	Airport	CRS	VRS	Returns to Scale
Hungary	Budapest	0,56	0,64	IRS
Ireland	Dublin	1,00	1,00	CRS
Italy	Bergamo Orio al Serio	0,45	0,77	IRS
	Catania	0,52	0,91	IRS
	Milan Linate	0,98	1,00	IRS
	Milan Malpensa	0,57	0,57	IRS
	Naples	0,57	0,88	IRS
	Rome Fiumicino	0,79	0,82	DRS
	Venice	0,53	0,67	IRS
Norway	Oslo	0,82	0,86	IRS
Poland	Warsaw	0,52	0,58	IRS
Portugal	Faro	0,70	1,00	IRS
	Lisboa	0,72	0,77	IRS
Spain	Alicante	0,68	0,90	IRS
	Barcelona	0,62	0,97	DRS
	Gran Canaria	0,70	0,72	IRS
	Lanzarote	0,48	0,96	IRS
	Madrid Barajas	0,50	0,89	DRS
	Málaga	0,76	0,79	IRS
	Palma de Mallorca	0,56	0,57	IRS
	Tenerife South	0,35	0,71	IRS
Sweden	Stockholm Arlanda	0,51	0,52	IRS
Switzerland	Genere	0,94	0,95	IRS
	Zurich	0,73	0,76	DRS
UK	Birmingham	0,51	0,58	IRS
	Edimburgh	0,68	0,74	IRS
	Glasgow	0,61	0,72	IRS
	Liverpool	0,96	1,00	IRS
	London Gatwick	0,82	0,82	IRS
	London Heathrow	0,84	1,00	DRS
	London Luton	1,00	1,00	CRS
	London Stansted	0,68	0,72	IRS
	Manchester	1,00	1,00	CRS
	Newcastle	0,75	1,00	IRS

Table 3: DEA scores for aircraft movements (ATM)

If we consider the existence of a country effect, we notice that, only taking into account the largest countries, in France there is only 1 efficient airport (out of 6), and that the average distance from the frontier is 0,43. The same number of efficient airports is reported for Germany (1 out of 9) and Italy (1 out of 7), while in Spain there is no efficient airports. The average distance from the frontier is, respectively, 0,31, 0,23, 0,19. The UK has the greater number of efficient airports: 5 out of 10, with an average distance from the efficient frontier equal to 0,27. Hence we can say that the country which was the first in Europe to implement both liberalization and an incentive regulation (based on price cap) has now the benefit of an higher efficiency level in managing its airports.

Concerning the returns to scale, the very large airports (i.e. Heathrow, Paris, Frankfurt, Amsterdam, etc.) exhibit decreasing returns to scale, signaling that, from a cost perspective, they will get lower average costs by decreasing their scale of operation. In general the category A airports show a high percentage of airports with increasing returns to scale (20), while 9 of them have decreasing returns to scale. Only 2 are operating at the optimal scale. The category B airports operate at increasing returns to scale (25 out of 26). Hence there is evidence that the category B airports may benefit of a reduction in average costs if they can increase their scale of operation, i.e. the volume of aircraft movements.

The results concerning the efficiency scores obtained with the DEA model when the output passengers are considered (APM) are shown in Table 4. There are 19 airports on the frontier, of which 13 (43%) belonging to category A and only 6 (22%) to category B. In general European airports are more efficient in dealing with passengers than with aircraft movements. The category A average distance from the efficient frontier (computed for those airports not on the frontier) is equal to 0,23, while the same variable for the category B airport is equal to 0,26. Again larger airports are more efficient than the national ones, but in the main time they are close to saturation, even more than when we consider the aircraft movements.

Country	Airport	CRS	VRS	Returns to scale
Austria	Wien	0,73	0,76	IRS
Belgium	Brussels	0,62	0,65	IRS
Cyprus	Larnaca	0,86	1,00	IRS
Czech Republic	Praha	0,79	0,88	IRS
Denmark	Copenhagen	1,00	1,00	CRS
Finland	Helsinki Vantaa	0,60	0,63	IRS
France	Lyon Saint Exupéry	0,51	0,62	IRS
	Marseille Provence	0,39	0,47	IRS
	Nice Côte d'Azur	0,55	0,71	IRS
	Paris Charles de Gaulle	0,78	0,86	DRS
	Paris Orly	1,00	1,00	CRS
	Toulouse Blagnac	0,52	0,66	IRS
Germany	Hamburg	0,67	0,67	IRS
	Berlin Tegel	1,00	1,00	CRS
	Berlin Schönefeld	0,60	0,80	IRS
	Cologne Bonn	0,56	0,62	IRS
	Düsseldorf	0,65	0,66	DRS
	Frankfurt	0,84	0,95	DRS
	Hannover	0,45	0,57	IRS
	Munich	0,60	0,60	CRS

Country	Airport	CRS	VRS	Returns to scale
	Stuggart	0,64	0,69	IRS
Greece	Athens	0,62	0,65	IRS
Holland	Amsterdam	0,87	0,98	DRS
Hungary	Budapest	0,55	0,63	IRS
Ireland	Dublin	1,00	1,00	CRS
Italy	Bergamo Orio al Serio	0,88	1,00	IRS
	Catania	0,70	0,90	IRS
	Milan Linate	0,80	0,86	IRS
	Milan Malpensa	0,65	0,67	IRS
	Naples	0,80	1,00	IRS
	Rome Fiumicino	0,94	1,00	DRS
	Venice	0,65	0,75	IRS
Norway	Oslo	1,00	1,00	CRS
Poland	Warsaw	0,43	0,50	IRS
Portugal	Faro	0,63	0,96	IRS
	Lisboa	0,76	0,78	IRS
Spain	Alicante	1,00	1,00	CRS
	Barcelona	0,92	1,00	DRS
	Gran Canaria	1,00	1,00	CRS
	Lanzarote	0,86	1,00	IRS
	Madrid Barajas	0,82	0,91	DRS
	Málaga	1,00	1,00	CRS
	Palma de Mallorca	1,00	1,00	CRS
	Tenerife South	1,00	1,00	CRS
Sweden	Stockholm Arlanda	0,78	0,79	DRS
Switzerland	Genere	0,56	0,60	IRS
	Zurich	0,71	0,73	DRS
UK	Birmingham	0,64	0,66	IRS
	Edimburgh	0,82	0,91	IRS
	Glasgow	0,75	0,81	IRS
	Liverpool	0,56	0,85	IRS
	London Gatwick	0,95	0,97	IRS
	London Heathrow	1,00	1,00	CRS
	London Luton	0,72	0,79	IRS
	London Stansted	1,00	1,00	CRS
	Manchester	1,00	1,00	CRS
	Newcastle	0,68	0,94	IRS

Table 4: DEA scores for passengers movements (APM)

If we look at the different countries performances, we observe that, differently from when we take aircraft movements into account (where it is in the worse position), Spain shows the highest relative efficiency: 7 airports out of 8 are on the efficient frontier. Italy and the UK have both 3 airports on the frontier (respectively out of 7 and of 10), while both France and Germany have only one efficient airport. The average distances from the frontier are the following ones: 0,34 for France, 0,30 for Germany, 0,20 for Italy and 0,15 for UK. Hence we ca say that Spain is the most efficient countries concerning passengers, while France is the less efficient one.

If we look at the returns to scale, again most of the largest European airports exhibit decreasing returns to scale, but the important exceptions of London Heathrow and Munich (they have constant returns to scale) and of London Gatwick (increasing returns to scale). There are 9 category A airports (out of 31) with decreasing returns to scale, 12 with constant returns to scale and 12 with increasing returns to scale. Hence, only considering passengers, we have the interesting result that more than one third of largest European airports are enjoying the benefits of operating at the lower bound of the average costs curve, while more than one third can obtain a reduction in their average costs in dealing with passengers by increasing their scale. If we look at the European category B airports, almost all of them (24 out of 26) have increasing returns to scale, with the only exceptions of two Spanish airports exhibiting constant returns to scale: Alicante and Tenerife. Hence the so called National European airports can reduce their average costs by increasing the number of passengers. Again we observe that larger airports are close to saturation while National ones have spare capacity. Moreover, further investments are required in many large airports, while a consistent number of large airports and almost all the National ones, being not too close to the physical frontier, should first improve their capacity utilization by increasing the number of passengers and then they may increase their scale of operation in order to take the advantage of lower average costs. In general we observe that it is easier to reach both the efficiency and the optimal size in managing passengers rather than aircraft movements.

Figure 6 shows the efficiency scores on both aircraft movements and passengers by each airport. Only 4 airports are on the frontier both for ATM and APM: Larnaca, Dublin, London Heathrow and Manchester. The majority (35) of the remaining 53 airports are more efficient in dealing with passengers than with aircraft movements. Overall, the less efficient European airports at the moment are those located in the middle of the picture, i.e. Marseille, Warsaw and Hannover. The correlation between the efficiency scores obtained in the two outputs is positive but rather low (0,53) showing that at the moment is rather difficult to be efficient on both outputs.

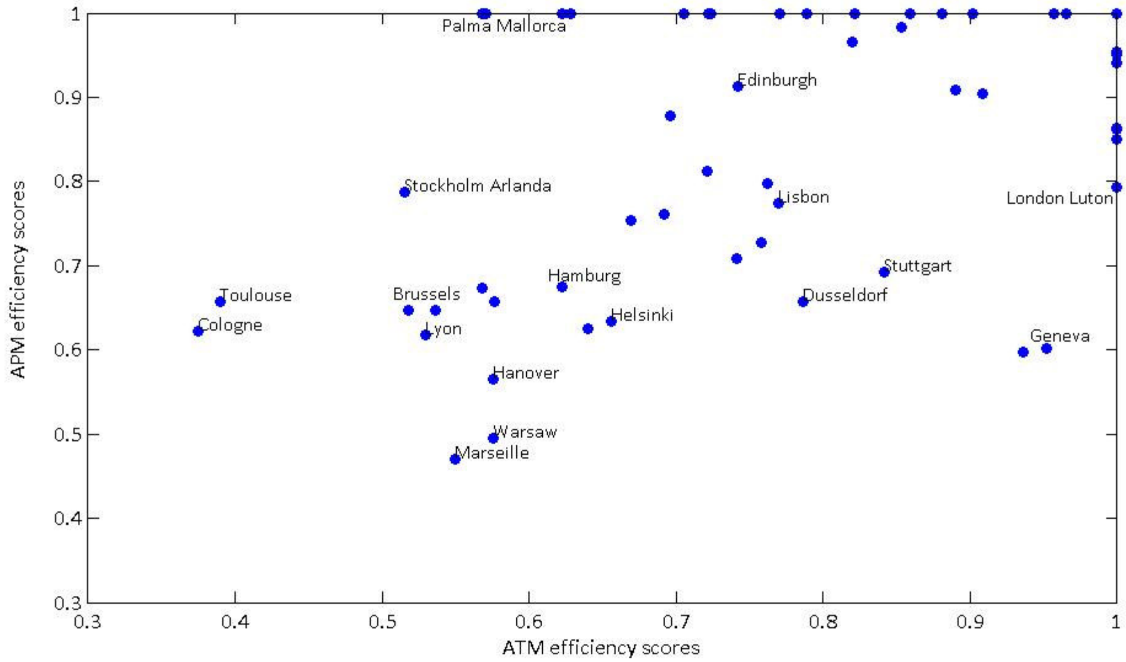

Figure 6: The efficiency scores of the European airports

To sum up, the analysis of the efficiency cores points out that, for both the outputs considered in this contribution (i.e. aircraft movements and passengers), the inefficiency is higher the smaller is the airport. This implies that large airports are close to saturation, since they are operating close to the physical frontier. On the contrary there is spare capacity in European airports with less than 10 million passengers. In general the efficiency is higher for passengers, i.e. airports exhibit an higher ability to manage passengers rather than aircraft movements: this may be due to an exogenous shock (the robust increase in the demand for passenger air transportation due to the development of low costs carries), to regulatory constraints (e.g. time limits in aircraft movements) and to lack of competition between airports in attracting carries.

5. The determinants of efficiency

The last part of our empirical analysis regards the sources of efficiency differentials among airports, to assess the impact of the relative importance of each airport in the European network and of the competitive pressure exerted by other airports. The research hypotheses are: First, the more an airport is connected to the European network the higher is its efficiency, since this factor allows a more intense exploitation of the physical inputs available at the airport. By being well connected to the network or by being a key node to reach a given territory the airport can capture an important factor of air transportation demand, which has the benefit of increasing its capacity utilization. However, if an airport operates as an essential facility to reach a given region within Europe, it may also be the case that it supplies some flights under a certain degree of universal service obligation (i.e. the airport has some connections which are operated with low load factors or with a rather low frequency during the day/week). Hence this second effect may reduce the efficiency if the airport operates as a key node in the European network. Second, the more intense it is the competitive pressure on an airport, since it can be substituted by near airports in many point-to-point connections within the European network the higher is its efficiency, since higher competition leads the management of an airport to adopt more efficient business conducts (among which lower fares) which have the effect of attracting more airlines. Hence an higher competitive pressure increases the airport's capacity utilization.

By assuming cross – sectional heteroskedasticity (see Abbott - Wu (2002)), DEA efficiency scores are regressed on a number of exogenous variables, covering specific characteristics of airports. Two dependent variables are taken into account: TE_{ATM} and TE_{APM} , i.e. the airport's distance from the VRS frontier in 2006. These scores are regressed on four explanatory variables: BETWEEN (the betweenness connectivity index showing how the airport is well connected with all the other European airports), ESSEN_BETWEEN (the variable which computes the importance of an airport to reach a given territory within Europe, i.e. how much the airport is a key node to reach certain towns and regions), COMPETITION (the index showing how many flights departing from the airport can be substituted by other flights departing from near airports and achieving the same destination) and DOMINANCE (a variable that takes into account the effect on the airport efficiency of the presence of a dominant carrier, computed as the share of ASK supplied by the first carrier in a given airport of the total of the airport's ASK). Table 5 shows the descriptive statistics of the explanatory variables.

	Mean	**St. – Dev.**	**Min**	**Max**	**Median**
BETWEEN	11.506	7.478	1.100	30.909	10.112
ESSEN_BETWEEN	7,2%	11,9%	0,0%	49,1%	2,0%
COMPETITION	35,3%	30,7%	0,0%	98,6%	29,9%
DOMINANCE	37%	15,6%	12,8%	77,6%	32,7%

Table 5: Descriptive statistics of explanatory variables for Tobit analysis

To avoid biased estimates due to high correlation between the variables used in the first stage – where the DEA efficiency scores are computed – and the environmental variables introduced in the second stage to explain the efficiency scores, we computed the correlation matrix (shown in Table 6) among the six input variables (i.e. CLAIM, CHECK, TERMINAL, PARKING, RUNWAYS and AREA) and the four explanatory variables just mentioned. For almost all variables the computed correlation is significantly low.

	AREA	*TERMINAL*	*PARKING*	*CHECK*	*CLAIM*	*RUNWAY*
AREA	1,000					
TERMINAL	0,452	1,000				
PARKING	0,733	0,687	1,000			
CHECK	0,631	0,710	0,834	1,000		
CLAIM	0,592	0,732	0,838	0,856	1,000	
RUNWAYS	0,768	0,505	0,744	0,610	0,583	1,000
BETWEEN	0,332	-0,090	-0,037	-0,111	-0,005	0,060
ESSEN_BETWEEN	0,055	0,060	0,191	0,063	0,071	0,220
COMPETITION	-0,107	-0,263	-0,211	-0,186	-0,184	-0216
DOMINANCE	0,313	0,275	0,324	0,280	0,333	0,300

Table 6: Inputs and explanatory variables correlation matrix

We adopt a Tobit regression as Abbott - Wu (2002) to allow for the truncated distribution of the efficiency scores, that lie between zero and one. The results are reported in Table 7.

	ATM				APM			
Variable	Coeff.	St. error	t – stat.	p - value	Coeff.	St. error	t – stat.	p - value
BETWEEN	$1,1(10)^{-5}$	$3,9(10)^{-6}$	$2,78^{**}$	0,005	$1,1(10)^{-5}$	$5,5(10)^{-6}$	$2,05^{**}$	0,041
ESSEN_BETWEEN	-0,43	0,19	$-2,30^{**}$	0,021	-0,20	0,21	-0,98	0,329
COMPETITION	0,08	0,09	1,02	0,306	0,213	0,12	$1,85^{*}$	0,064
DOMINANCE	-0,16	0,15	-1,06	0,290	0,015	0,18	0,08	0,933
CONSTANT	0,658	0,08	$8,17^{***}$	0,000	0,586	0,10	$5,90^{***}$	0,000
* = 10%	** = 5%	*** = 1%	(sig.	level)				

Table 7: Determinants of efficiency

The first four columns of Table 7 are the estimated coefficients, standard errors, t – statistics and the corresponding p – values for the regression of DEA Technical Efficiency (TE) scores on the explanatory variables for efficiency in managing aircraft movements. Significance levels at 1%, 5% and 10% are reported for each explanatory variable. The outcomes are that efficiency is higher for airports with higher interconnections within the European network (BETWEEN), while efficiency is lower the more an airport is essential to reach a given territory within Europe (ESSEN_BETWEEN). The latter result shows that when an airport acts as an essential facility to reach a given region within Europe it is more difficult to reach an efficient use of the airport's capacity. This confirms that probably the universal obligation issues that arises if the airport is a key node to reach certain European regions may prevail over the possibility to capture a demand with no substitution, and so the overall efficiency is reduced. The efficiency in managing aircraft movements is not significantly influenced by the presence of some competitive pressure from other airports and of a single carrier dominance of the airport.

The following four columns in Table 7 report the estimated coefficients, standard errors, t – statistics and p – values for efficiency in managing passengers. In this case the efficiency is again higher for airports well connected (BETWEEN), and for those where there is a competitive pressure (COMPETITION). When passengers are considered, ESSEN_BETWEEN has no significant effect on efficiency.[20] Hence competition shows positive effect on airports' efficiency when they deal with passengers, since the presence of a substitute airport for the same connection probably induces the management of the airport to reduce fares and so airlines can charge lower prices and attract more customers.

To sum up, the analysis shows that efficiency is higher, for both the outputs considered in this study, if an airport is well connected at the European network, i.e. the role of the airport within the network has a strong impact on efficient. This new result should be taken into account by governments and the European Commission when they deal with development programs of the airports, and by managers, that should focus on improving the connectivity of the airport to the network. Moreover, it is interesting that the efficiency in dealing with passengers is higher if the airport is exposed to some degree of competitive pressure by other airports which are considered as substitutes by travellers. Again it is important that policy makers should take into account this insight, since to develop the airports' competitive is a good path to achieve efficiency in their operations. An efficient utilization of inputs dedicated to aircraft movements (e.g. runways, aircrafts' parking positions, etc.) is less likely if the airport acts as an essential

[20] It is important to remember that the environment where we applied the DEA model has to be homogeneous. In Europe regulation is not uniform across the different airports, and the cost of several inputs (e.g. labor, electricity, fuel, etc.) as well. However these differences are not so big to forbid the application of the DEA approach to the airport sector, as shown by many contributions (e.g. Pels *et* al. (2003)).

facility to reach a particular region within Europe, probably due to the presence of connection provide under universal service obligation, i.e. with low load factor and a limited frequency over the available working time.

6. Conclusions

This paper has investigated the efficiency of European airports, by applying a DEA model to a sample of 57 Italian airports, covering about 95% of the total number of airports with more than 5 millions passengers per year. We find that many airports can improve their efficiency on both types of output considered, i.e. aircraft movements and passengers. We show that efficiency is related to airports' size, i.e. airports with more than 10 millions passengers are more efficient than the national ones (with only more than 5 millions). Moreover, further developments in the activities of large airports may lead to an increase in their average costs, since they are mainly operating under decreasing returns to scale. On the contrary, we find that there is spare capacity in National airports and that they are operating under increasing returns to scale.

The econometric analysis on the estimated efficiency scores shows that airports are closer to an optimal inputs' utilization if one airport has good connections with the European network and if it is exposed to a competitive pressure coming from nearby competitors. We do not find evidence that the efficiency is higher the greater is the market share of the dominant carrier in a given airport.

Hence this paper suggests that policy makers (in regulating airports' fares and subsidizing development plans) and managers (in evaluating their assets utilization) should take into account that a well connected destinations map and the presence of indirect competition coming from other airports can improve the performances in the management of European airports.

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