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An application of DEA to measure the efficiency of Spanish airports prior to privatization

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Abstract

Most airports compare their efficiency according to the results of some partial productivity ratios. However, this approach does not provide a good understanding of their overall performance. In this paper, we apply data envelopment analysis to analyze the technical efficiency and performance of each individual Spanish airport. Results are used to extract some policy considerations before the process of privatization of the Spanish airport system.

Keywords: DEA; Airport; Performance; Privatization; Productivity

1. Introduction

During the last years, we have observed a conceptual change in the provision of transport infrastructure. Liberalization measures have been common in this sector, accompanied by a process of partial or total privatization of services and infrastructures. In the air sector, airports, air traffic control facilities, and government airlines are increasingly given a more commercial orientation, and in many cases they have been partially or fully privatized.

The reform started in the late 1970 s when the United States deregulated its domestic airline market. This change had a positive impact on the sector: productive and allocative efficiency were improved, load factors raised and traffic grew substantially more than it would have done in the absence of deregulation (see, e.g., Caves et al., 1987; Morrison and Winston, 1995; Baltagi et al., 1995).

The process initiated in the United States had some demonstration effect for the rest of the world. In Europe, a gradual approach was politically more acceptable to Member States than the United States "big bang" type of deregulation. Some political concern and national pride appeared in the arena, regarding if "European open skies" was a legitimate goal to attain. For details of the various "Packages" of reforms, see Button et al. (1998), Vincent and Stasinopoulos (1990) and Stasinopoulos (1992, 1993).

Deregulation of air markets, combined with some other factors, has contributed to the steady growth of demand in aviation markets. Additionally, the existence of a more competitive environment has also changed the industry and airlines need to be more efficient in order to survive in the market. As a result of this traffic growth, international air transport requires a modern infrastructure with enough capacity to accommodate future demand. This includes airports, navigation and air traffic control systems, and adequate institutions to regulate these facilities.

In some airports and during some periods of time, due to the banking pattern of arrivals and departures, the available infrastructure is reaching its technical capacity. To analyze if the origin of the problem lies or not in a poor management is an important question for the industry. It is necessary to evaluate if a fixed physical capacity, is able to provide services to more air traffic movements and passengers. In other words, the existence of some X-inefficiencies, associated with public ownership or price policies, needs to be reconsidered.

In this article, we analyze the technical efficiency of the Spanish airports applying data envelopment analysis (DEA). This methodology has been used extensively in many industries where multiple outputs and inputs need

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to be studied. Results of the analysis are useful to establish some policy considerations and to analyze some possible implications which can be predicted from a future privatization of the Spanish airport system.

2. Provision and performance of airport infrastructure

Some economists and policy makers have argued that airports are public goods, and contribute to the economic development of regions. There have also existed some concerns about the existence of natural monopoly in the provision of certain activities within the airport infrastructure. This was the main reason why commercial airports had to be regulated in order to obtain a maximum social benefit for the community.

Until late 1980 s, public ownership of airports was a worldwide model that was generally accepted. Since then, strong movements have been made in many countries in order to privatize or deregulate their airports. Although the form of public ownership can be heterogeneous and privatization vary across countries (see Ashford and Wright, 1992), it is generally regarded that privatization plus regulation may imitate closely the market conditions through an adequate system of incentives.

Privatization appears as a consequence of the creation of new opportunities to deal with issues of airport efficiency and profitability. In some countries where the aviation industry is not well developed, privatization is closely related with the financial requirements of the public sector. However, in other countries, gains in efficiency are usually the main reason why some mature airports start the privatization process.

Airport privatization presents a serious number of concerns. The existence of monopoly in the provision of some activities may originate a loss of service, high fares, poor level of maintenance and under-investments in the facilities. Besides the existence of these problems, some authors have claimed that efficiency gains are dubious. Haririan and Vasigh (1994) found, in a survey of 79 airports, that the majority of airport managers do not think privatization will lead to lower operating costs and greater efficiency, but some practical experiences have shown the opposite. Pino (1995) expressed that some important financial issues have to be revised in the existing models of privatization in order to guarantee an adequate level of maintenance and investment.

In addition to the problems indicated above, the relationship between airports and airlines must also be further studied. In the United States, incumbent airlines have imposed some capacity restrictions, blocking some airport expansions that would provide more slots to new entrants. Evans and Kessides (1993) indicated that the bulk of any deviation from competitiveness in the airline industry is better explained by the existence of dominant airlines in the airport, and expressed that the market advantages of the airlines are usually the result of the control of scarce airport facilities. This finding is consistent with the observed trend about control of airports by the most important groups of incumbent airlines. However, it is difficult to determine how these local monopoly rents are shared between airport operators and airlines. In this line of investigation, Pels et al. (1997) studied the effect of the policies of airport operators on the airlines profitability and network choice. They found that price competition between airports has little effect on the demand serviced by each airport.

The interest in monitoring and comparing the airport performance is increasing in importance after privatization. It is highly important to identify the best performers in the airport industry and to determine the main variables that could help to improve the efficiency, which are under control of airport managers. In an era where airports are subject to more competitive pressures, it is crucial to know what their relative performance is.

Performance studies can be highly informative in answering the following questions: Are private airports more efficient than their public counterparts? Is contracting out a good plan to improve performance? Are multi-airport systems more efficient than individual airports? This type of studies can be very helpful in policy decisions to choose the best framework to organize the airport system.

There are also other economic agents that are going to benefit from this kind of studies. Investors are a special group interested in identifying new business opportunities. Airlines have a special interest in knowing if an airport can reduce its costs without compromising quality, as a way to be competitive. Economic regulators of privatized airports have also good reasons to monitor airport performance, especially when a price-cap regulation has to be negotiated.

Doganis (1992) expressed that airports are heterogeneous in relation to the services provided. For this reason, comparisons between different airports are not common. Doganis and Graham (1987) found that most airports only use partial financial indicators to present their own results. The logic of indicator methodology is related with the degree in which an activity satisfies an objective.

The limitations of partial indicators in capturing the multi-dimensional characteristics of airports performance have been recognized in previous studies. These partial performance ratios that compare one or more basic variables have evident shortcomings. They can only be used to obtain a first glance, and robust consequences based on this comparability cannot be usually extracted. For example, some financial measures can be misleading indicators, as a consequence of the relative market power that might exist. Monopolistic airports might be able to make substantial profits even if they were inefficient.

Doganis et al. (1995) compared the relative performance of some European airports with the average performance of 25 airports in the sample, using different partial ratios: unit costs, productivity and revenue ratios. Hooper and Hensher (1997) summarized the most common partial ratios used in previous studies dealing with the evaluation of the airport performance.

Partial indicators have provided some insights to airport managers, but these managers usually face the problem of interpreting a relatively big set of indicators. In addition, some regulation agencies claim to rank the regulated airports in a sequential order according to their performance. For these reasons, it is necessary to obtain a comprehensive performance measure that summarizes the multifaceted activities carried out in the airport.

According to Hensher and Waters (1993), the main methods to generate comprehensive performance measures are the following:

- Non-parametric index number.
- Parametric model estimation (econometric approach).
- Non-parametric DEA (DEA mathematical programming).

All approaches obtain a single dimensionless overall index of efficiency. These indices may be applied to an individual airport, ranking only its own relative performance over time or relative to a group of airports, evaluating their relative performance during one or several periods of time. Lovell (1993) argued that the last two approaches differ in many ways, but the essential differences are found in the nature of the analytical approach. The econometric approach is stochastic and parametric and DEA uses linear programming techniques.

In this work, we have chosen DEA because it provides an extremely useful framework in this context. Some advantages that this methodology presents in comparison with others are that it does not impose a parametric structure on the data, it provides a good approach to measure total factor productivity and its information requirements are less restrictive.

3. The Spanish airport system

The administration of airports in Spain is under control of the publicly owned company Aeropuertos Españoles y Navegación Aérea (AENA). It manages a network of 42 airports with more than 116 million of passengers in 1998 and five air traffic control centers with more than 1.8 million air traffic movements and three flight information regions. In 1998, 9181 employees worked in the corporation and its revenues were around 1120 million of euros.

AENA has a statutory regime that permits it to function as a private company in relation to contractual arrangements and labor agreements. In the last years, it has shifted towards a more commercial orientation and some partnerships with the private sector have been established. In this line, the construction of the new terminal of Palma de Mallorca and the new cargo terminal in the airport of Barcelona can be cited as examples of new management instruments used inside the new philosophy of the corporation.

AENA is not subsidized by the State. The absence of subsidies has promoted the development of commercial activities carried out within airport facilities. Financial sustainability of airport business has reinforced the search of new sources of revenues or cost reductions. Commercial revenues are increasingly being important sources of income generation for the Spanish airports.

Besides the enormous efforts to be more competitive, AENAs role needs to be revised. Costas-Centivany (1999) suggested that a reform of Spanish legislation on air transportation is required urgently and is even more necessary with the new demands that a liberalized market have created. In particular, the author expressed as a key reform the elimination of some administrative and managerial ambiguities in AENAs role.

Although some benefits have been obtained in the European air industry by the processes of liberalization, the lack of adequate capacity of airports and air traffic control systems is the principal constraint to obtain the optimal gains from deregulation. Knowing if these constraints could be alleviated by the privatization of airports is the next challenge for European authorities. European airline companies and governments officials do not know how to resolve the problems of air traffic control. Governments suggest that the demand must be adjusted to the existing facilities, knowing that in some cases these facilities are clearly insufficient to attend a market growing at an annual rate of 6%. However, airlines ask for more political courage to resolve a situation close to be chaotic.

The situation about air traffic control in Europe is getting worse. Last year was the worst in the history in relation to delays. Delays superior to 15 min affected to around 30% of flights and air traffic control was the most important cause of these delays.[1] This situation is far away to be resolved. Although companies consider that delays are one of the principal problems for the future, because they cause a big cost to consumers and to the image of airlines, lack of commitment of European governments is the general rule.

[1] Karl–Heinz Neumeister, General Secretary of EAA, manifested that this situation is understandable if we analyze the air traffic control in Europe. There exist 31 different national systems, with more than 49 centers with different program languages and operating systems. And for uttermost circumstances, there still exist many legal restrictions favoring military operations with a system of priorities totally outdated.

4. A DEA model

Charnes et al. (1978), in their seminal paper, described the DEA methodology as a "mathematical programming model applied to observed data that provides a new way of obtaining empirical estimates of extremal relationships such as the production functions and/or efficiency production possibility surfaces that are the cornerstones of modern economics". Since then, numerous applications employing the DEA methodology have been presented and involve a wide area of contexts: education, health care, banking, armed forces, sports, transportation, agriculture, retail stores and electricity suppliers. Originally, designed to evaluate data management units (DMUs), which use multiple inputs to produce multiple outputs, without a clear identification of the relation between them, DEA has progressed throughout a variety of formulations and uses to other kind of industries.[2] Seiford (1994) cited more than 400 articles in a comprehensive bibliography and stated that DEA methodology is an important analytical tool whose acceptance is no longer in doubt.

We do not intend to cover the basic aspects of DEA models. A good introduction to DEA notation, formulation and geometric interpretation can be consulted in Charnes et al. (1994), Ali and Seiford (1993) and Coelli et al. (1998). As discussed therein, a model can be described by the envelopment surface, orientation of the model, invariance of units, and efficiency measurement. There are three basic DEA models: variable returns to scale (VRS), constant returns to scale (CRS) and additive model. These can be used to seek which ones of the n DMUs determine the frontier of the envelopment surface. Units that do not lie on the frontier are inefficient and the measurement of the grade of inefficiency is determined by the selection of the model.

The choice of a DEA model depends on some assumptions regarding the data set to be employed and in some prior results about the industry to be studied. The data set has to describe the activities of the units in the best possible way. It is especially important to have some idea about the hypothetical returns to scale that exist in the industry. This knowledge is going to determine the envelopment surface–constant return to scale CRS or variable return to scale VRS[3] of the model.

Once that the selection of envelopment surface has been made, an orientation of the model to determine the measurement of the efficiency is needed. There are three basic orientations: input, output and output/input. An input orientation focuses on proportional decrease of the input vector, the output orientation adjusts the proportional increase of the output vector and the output/input orientation does not discriminate the importance of possible increase of output or decrease of input. The units involved in the study determine the selection of the orientation, and it is very important to have in mind what the real possibilities of managers are. In the "structure-conduct-results" tradition the investigator must try to establish what the conduct of agents and the structure of the market are in order to determine a possible orientation for the model.

In DEA analysis, it is generally assumed that there are n production units to be evaluated, using amounts of m different inputs to produce quantities of s different outputs. Specifically, the oth production unit consumes x_{io} units of input i ($i = 1$ to m) and produces y_{ro} units of output r ($r = 1$ to s). The oth production unit can now be described more compactly with the vector (X_o, Y_o), which denote, respectively, the vectors of input and output values for DMU_o.

Next, we consider the dominance comparisons for this production unit using the data set as a reference. DEA considers the dominance of the linear combinations of the n production units, i.e. $(\sum_k \lambda_k X_k, \sum_k \lambda_k Y_k)$, with the scalar restricted to be non-negative.[4] The production unit o is dominated, in terms of inputs, if at least one linear combination of production units shows that some input can be decreased without worsening off the rest of inputs and outputs. The production unit o is dominated in terms of outputs if at least one linear combination of production units shows that some output can be increased without worsening off the rest of inputs and outputs.[5]

Thus, the method serves to partition a set of production units into two subsets: the efficient production units and the inefficient ones. The method also serves to calculate the level of inefficiency of a given inefficient production unit.

Airport managers can affect the efficiency of the airport using their inputs (runways, terminal buildings, employees, etc.) in different manners. In this paper, an output orientation is going to be employed. We think that once an airport has invested in the building of new runways or new terminals, it is difficult for managers to

[2] DEA can be applied to scenarios where the data cannot be strictly interpreted as inputs or outputs or there is no direct functional relationship between the variables. In such situations, a general guideline to the classification of the variables is that variables for which lower levels are better are considered inputs, while outputs are those variables for which higher amounts are desirable.

[3] CCR and BCC acronyms are sometimes used in reference to CRS and VRS models. The acronyms come from the initial of the authors of the papers that employed these two different envelopment surfaces (Charnes et al., 1978; Banker et al., 1984).

[4] The different assumptions about the scalar produce distinct envelopment surfaces: VRS, CRS or extensions of these basic models.

[5] This discussion is very close to the definition of Pareto–Koopmans efficiency. The unit o is considered fully efficient if and only if the performance of other DMUs does not provide evidence that some of the inputs or outputs of the unit o could have been improved without worsening off some of its other inputs or outputs. This definition of relative performance has its origin in Farrell (1957).

disinvest to save costs, therefore invalidating the input orientation. In this sense, it is more credible to use airport facilities as intensively as possible, since factors of production are fixed or semi-fixed.

Formally, the DEA output efficiency for the unit o is calculated through the following linear programming problem:

$$\max_{\phi,\lambda,s^+,s^-} \quad z_0 = \phi + \varepsilon \cdot \mathbf{1}s^+ + \varepsilon \cdot \mathbf{1}s^-,$$

$$\text{s.t.} \quad Y\lambda - s^+ = \phi Y_o,$$

$$X\lambda + s^- = X_o,$$

$$\mathbf{1}\lambda = 1,$$

$$\lambda, s^+, s^- \geqslant 0,$$

where, X and Y are the input and output matrixes, respectively, X_o and Y_o are the input and output vectors of the unit o, respectively, ϕ and λ are parameters calculated in the model, and represent the maximum proportional output that can be attained and the linear convex combination that dominates the oth unit, respectively, ε and s^+, s^- are the Archimedian constant and the slack variables, respectively.

The model compares the production unit o with all the convex linear combinations of production units. Due to the existence of different scale airports in Spain, a VRS approach is used. Nonetheless, the CRS model and scale efficiencies are also calculated.

The linear programming problem is solved for every airport in the sample in order to obtain its relative performance. The efficiency measure obtained is considered the technical efficiency and is calculated as the inverse of the maximum proportional output that can be obtained for the indicated inputs.

4.1. The data

We used data of the Spanish airports for 1997 to evaluate airports efficiency using the DEA model defined above. All information has been obtained from the annual reports of AENA. We measured output with three variables: air traffic movements, number of passengers and number of tons of cargo transported in each airport. Input variables were introduced as expenditures and were classified according to: labor, capital and materials.[6] Capital costs include amortization of fixed assets.

Included variables have a clear interpretation. There are no problems regarding data comparability, since AENA is the only source of information. This is particularly relevant in reference to the cost of capital. Differences in accounting practices across countries usually difficult the comparison of airports at an international level.

Table 1 shows four different results for the airports included in the sample. The first column expresses the CRS technical efficiency measure, the second and third column are the VRS technical efficiency and the scale efficiency, respectively. The fourth column displays if the DMU is operating in an area of increasing or decreasing returns to scale.[7]

An examination of Table 1 reveals that there are only 11 of 37 airports operating in the frontier: Badajoz, Barcelona, Lanzarote, Madrid, Melilla, Mallorca, Tenerife Norte, Tenerife Sur, Valladolid, Vitoria y Zaragoza. The number of times that these airports act as "peers" of inefficient airports is an important issue to be considered when we try to obtain the information about best practices in the sector. This concept is related with the establishment of standards of performance for an industry. We will refer later to this aspect in order to analyze how an airport can determine some targets.

There are only eight airports that form the frontier if we consider CRS envelopment surface. The CRS approach is calculated dropping the restriction of convex linear combinations. Nine airports operate in the area of decreasing returns to scale: Alicante, Almeria, Ibiza, Gran Canaria, Menorca, Malaga, Tenerife Sur, Santiago and Valencia. These airports can be characterized by giving service to cities of medium size or touristic destinations. Meanwhile, 20 airports are operating in the area of increasing returns of scale. For this group of airports it would be necessary to accomplish a demand analysis in order to study the real possibilities of increasing the demand with adequate changes in prices or with a reconfiguration of the equilibrium in the network. The last decision would imply the closure of some airports, diverting its traffic to some other close airport in the region.

Two airports present some important differences that deserve a separate comment: Cordoba and Salamanca. These airports have the extremes of scale inefficiencies and the characteristics of both cities make difficult to conceive some possible expansion in the use of their facilities. It would be necessary to evaluate the characteristics of the traffic of these airports and if it is

[6] The authors are conscious that some other measures of input, such as, number of runways, number of gates, terminal area and number of employees would have made the experiment more realistic but lack of available data preclude us from using these of variables. Gillen and Lall (1997) applied DEA to the airport sector using real input variables and they measured the efficiency of two different productive processes: terminal services and movements. Envelopment surfaces were estimated according to variable returns to scale and constant returns to scale, respectively.

[7] We note here that the efficiency measures have been expressed as $1/\phi$, where ϕ is the parameter calculated in the formulation of DEA-LP program. The scale efficiency is the quotient obtained by the division of the technical efficiency with constant returns to scale and variable returns to scale. If this scale efficiency is near one, it expresses that the airport is near to the optimal scale of operations. The area of operation has been obtained by running a DEA problem with non-increasing returns to scale.

Table 1
Efficiency measures of Spanish airports during 1997

Airport	CRS eff	VRS eff	Scale eff	Area
Alicante	0.615	0.710	0.867	drs
Almeria	0.340	0.342	0.994	drs
Asturias	0.446	0.455	0.981	irs
Badajoz	0.236	1.000	0.236	irs
Barcelona	1.000	1.000	1.000	—
Bilbao	0.726	0.742	0.979	irs
Cordoba	0.072	1.000	0.072	irs
Coruña	0.418	0.432	0.969	irs
Fuerteventura	0.760	0.789	0.964	irs
Girona	0.259	0.275	0.941	irs
Granada	0.303	0.314	0.967	irs
Hierro	0.338	0.405	0.835	irs
Ibiza	0.720	0.747	0.964	drs
Jerez	0.381	0.391	0.975	irs
Lanzarote	1.000	1.000	1.000	—
La Palma	0.519	0.527	0.985	irs
Gran Canaria	0.729	0.838	0.870	drs
Madrid	1.000	1.000	1.000	—
Menorca	0.655	0.669	0.979	drs
Malaga	0.600	0.722	0.830	drs
Melilla	1.000	1.000	1.000	—
Mallorca	1.000	1.000	1.000	—
Pamplona	0.787	0.825	0.954	irs
Reus	0.433	0.529	0.819	irs
Salamanca	0.173	1.000	0.173	irs
San Javier	0.380	0.406	0.936	irs
San Sebastian	0.421	0.456	0.923	irs
Tenerife norte	1.000	1.000	1.000	—
Tenerife sur	0.818	1.000	0.818	drs
Santander	0.475	0.490	0.970	irs
Santiago	0.522	0.556	0.938	drs
Sevilla	0.319	0.320	0.997	irs
Valencia	0.637	0.645	0.989	drs
Valladolid	0.883	1.000	0.883	irs
Vigo	0.513	0.535	0.959	irs
Vitoria	1.000	1.000	1.000	—
Zaragoza	1.000	1.000	1.000	—

possible to divert it to close airports, such as Valladolid and Malaga, respectively.

The CRS and VRS average efficiencies obtained by Spanish airports are 0.60 and 0.70, respectively. It would be desirable that these efficiency results will be used to allocate funds in favor of more efficient airports. In addition, the performance of airports plays an important role in the process of privatization. The value of airports or the x-factor in price cap regulation is directly influenced by the results of the analysis.

Other important implication is that the position of the regions is not homogenous. Canarias, Madrid, Cataluña, Euskadi, Melilla, Baleares and Aragon are in better position to operate their airports.[8] At this point, we have compared the possible gains in efficiency that can be obtained inside the system of airports of Spain.

In Table 2, we present a summary of the additional output as well as the possible reduction of input that can be attained by each Spanish airport. Results are obtained by projecting the vector (X_o, Y_o) into the vector $(\hat{X}_o, \hat{Y}_o)$. This projected point is obtained by the proportional increment of output $1/\phi$ and by the vector of slack variables (s^+, s^-) determined in the solution of the DEA model with variable returns to scale. The projected points, by construction, lie in the frontier and are usually referred as the targets of each individual airport. In the table, absolute values are used for the difference $(X_o, Y_o) - (\hat{X}_o, \hat{Y}_o)$, understanding that the managers have the following objectives: to service more passengers, cargo and movements of aircraft using less resources.

The first column in Table 2 shows the number of additional passengers that can be transported. Sevilla is the Spanish airport that presents the maximum figure with almost 4 million of additional passengers. The second column shows the number of additional tons of cargo that can be transported in each individual airport. In this case, Malaga and Sevilla present its maximum with a total around 15,000 tons. The third column shows the number of additional air traffic movements that can be serviced. Sevilla is again the airport that can accommodate the maximum additional movements in its runways with a figure around 40,000 movements in the year. The results obtained by the airport of Sevilla are clearly influenced by the construction of the high-speed train between the cities of Sevilla and Madrid.[9] In the fourth column, we can observe that Malaga, Santiago and Girona show slacks in the labor costs over 100 million of ptas, respectively. Although AENA enjoys a regulated status that allows it to function as a private company in relation to labor contractual agreements, more flexible labor practices need to be introduced in order to alleviate this allocative inefficiency. Two airports: Sevilla and Girona can be highlighted in reference to the fifth column with total excess of capital capacity of 207 and 309 million of ptas, respectively. These figures reflect an overinvestment in the capacity of these two airports. The problem with this kind of inefficiency is that it cannot be corrected in the short run and once the airports have been expanded it is difficult to change their size. In the sixth column, the slacks in material costs are shown.

[8] Canarias, Baleares, Cataluña and Euskadi have formed a group of regions that reclaim the management of the airports of their respective territory before the possible process of privatization (Europa Press, February 28, 2000).

[9] This example shows a potential source of problems inherent to the process of privatization of the Spanish airports. Policy makers must be aware that the implementation of high-speed train networks change the modal equilibrium and as a consequence they may modify the value and the performance of the airports. This issue is specially true if the use of the airport is sub-optimal as a consequence of the loss of some scale economies. This kind of changes can vary highly the demand function of airport services (e.g., Anchorage International and Dayton International, Gillen and Lall, 1997).

Table 2
Additional output and input slacks of Spanish airports

Airport	Additional output			Input slacks		
	Passeng 000s	Cargo tonnes	ATMs	Labor 000s pta	Capital 000s pta	Material 000s pta
Alicante	1801	2787	15,212	84,319	0	0
Almeria	1397	3187	15,124	54,294	20,793	0
Asturias	1222	2587	9765	26,501	0	65,125
Badajoz	0	0	0	0	0	0
Barcelona	0	0	0	0	0	0
Bilbao	1149	6372	9974	0	0	0
Cordoba	0	0	0	0	0	0
Coruña	900	1606	7602	7820	0	26,798
Fuerteventura	654	9426	6855	0	0	0
Girona	1335	3141	14,267	108,067	309,733	0
Granada	1319	3009	12,741	0	16,129	0
Hierro	146	303	3472	0	15,704	0
Ibiza	1200	8520	12,315	50,925	55,197	0
Jerez	1077	1854	9383	16,689	0	136,183
Lanzarote	0	0	0	0	0	0
La Palma	1377	2087	9512	0	0	0
Gran Canaria	1532	7379	15,240	88,458	0	0
Madrid	0	0	0	0	0	0
Menorca	1879	3644	12,805	22,893	31,682	0
Malaga	2763	15,547	25,033	146,774	0	0
Melilla	0	0	0	0	0	0
Mallorca	0	0	0	0	0	0
Pamplona	651	1199	1793	23,772	0	6331
Reus	462	1692	5099	20,043	0	23,455
Salamanca	0	0	0	0	0	0
San Javier	447	669	4089	55,016	0	1208
San Sebastian	206	413	4431	0	22,185	0
Tenerife norte	0	0	0	0	0	0
Tenerife sur	0	0	0	0	0	0
Santander	212	1282	4940	34,275	84,894	0
Santiago	1742	4738	14,439	117,674	80,524	0
Sevilla	3928	14,522	42,807	0	207,306	0
Valencia	2892	5491	18,643	81,793	0	0
Valladolid	0	0	0	0	0	0
Vigo	484	1631	6848	0	45,583	0
Vitoria	0	0	0	0	0	0
Zaragoza	0	0	0	0	0	0

The extreme case of Jerez airport with more than 136 million of ptas is highlighted.

There are only three airports: Bilbao, Fuerteventura and La Palma, that are considered inefficient but cannot reduce any input. In this case, their managers must concentrate their efforts in increasing their traffic. However, this issue is conditioned by the demand characteristics of the airport and other network effects. These variables can be out of the direct control of managers. The rest of the inefficient airports might also reduce some of the inputs, having in mind some considerations that have been previously mentioned.

In Table 3, we present a summary of the number of times that each airport in the frontier is a "peer" or a target for the rest of the airports. We highlight the fact that Lanzarote airport appears 23 times as a target for the rest of the airports and it is a good example to examine for the majority of the airports that do not lie in the frontier. This exercise can be considered a first step to benchmark the airports. The information about the set of "successful airports" can enhance the performance of each airport. For example, the airport of Las Palmas de Gran Canaria has the following set of peers: Barcelona (0.157), Madrid (0.097), Lanzarote (0.202), Mallorca (0.009), and Tenerife Sur (0.537). The value inside the parenthesis represents the weight of each airport in the convex linear combination and is determined by the value of λ in the DEA model. So, the managers of this airport could improve the performance, learning from the experiences observed in the three most important airports of Spain, and focusing in the characteristics of Lanzarote and Tenerife Sur.

It is difficult to anticipate with our analysis if peer airports are going to present gains in efficiency if they are

Table 3
Summary of the number of times an efficient airport is a peer

Airport	Times
Lanzarote	23
Valladolid	10
Badajoz	9
Barcelona	8
Melilla	8
Madrid	5
Mallorca	4
Tenerife sur	3
Tenerife norte	2
Vitoria	2
Zaragoza	1

finally privatized, but some previous experiences, such as BAA, have shown that gains resulting from private ownership might exist. The rest of airports have some gains to achieve, independently if they are or not privatized.

5. Conclusions

New airport management strategies have appeared in the provision or airport services as a consequence of the new era of liberalization in air transport inside the European Union. The spur of competition among airlines has challenged the European governments to produce more adjustments in airport infrastructures to accommodate the future growth of air transport. To assess whether private ownership is the solution of capacity constraints is the challenge that European governments have ahead. In this context, we have selected a DEA model with output-orientation to evaluate the performance of Spanish airports before a privatization process is initiated.

Results of our analysis show that there are some airports whose performance is clearly poor. Other airports present some problems if we focus our attention on the scale inefficiencies, and it is difficult to conceive how these airports are going to reach the targets. This fact must be taken into account if the privatization of the airports is going to be carried out. The true value of the airport must be corrected having in mind that some inefficiencies (probably due to the public ownership) are present in the system.

Other remarkable aspect is that 20 airports operate in the area of increasing returns to scale and 9 in the area of decreasing returns to scale. This fact may suggest that there exist room for a policy of reallocation of traffic from DRS airports to IRS, when the airports involved in the reallocation are close.

The results also show that some regions of Spain, such as, Madrid, Baleares, Cataluña, Canarias and Euskadi, have some airports performing in the frontier. For this reason, these regions could have incentives to reclaim the ownership of these airports. This issue is going to originate a bargaining process between the national and regional governments. Regional concerns about the privatization of airports are completely legitimated due to the important role that airports play in the regional context with respect to productivity and economic growth. To find a balanced compromise, that satisfies all the agents involved in the process, is not going to be an easy task.

Whether airports are privatized or not, the role of government needs to be revised. In the first case, a regulatory agency has to correct the possible abuse of monopoly power. Corporatization and privatization are thought to improve the performance of the airports, but these measures need to be accomplished with adequate process of economic regulation in order to be effective. In the second case, an efficient provider of infrastructure under a tight performance scrutiny and with adequate instruments needs to be envisaged. Independently, of the ownership of the assets, monitoring continuously the performance of the different activities provided by the airport authorities is really necessary, and is going to be demanded by different economic agents.

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References

Ali, A., Seiford, L.M., 1993. The mathematical programming approach to efficiency analysis. In: Fried, H.O., Lovell, C.A.K, Schmidt, S.S. (Eds.), The Measurement of Productive Efficiency: Techniques and Applications. Oxford University Press, New York.

Ashford, N., Wright, P.H., 1992. Airport Engineering. Wiley, New York.

Baltagi, B.H., Griffin, J.M., Rich, D.P., 1995. Airline deregulation: The cost pieces of the puzzle. International Economic Review 36 (1), 245–258.

Banker, R.D., Charnes, A., Cooper, W.W., 1984. Some models for estimating technical and scale inefficiencies in data envelopment analysis. Management Science 30 (9), 1078–1092.

Button, K.J., Haynes, K., Stough, R., 1998. Flying into the Future: Air Transport Policy in the European Union. Edward Elgar. Cheltenham.

Caves, D.W., Christensen, L.R., Tretheway, M.W., Windle, R.J., 1987.An assessment of the efficiency effects of US Airline deregulation via an international comparison. In: Bailey E. E. (Ed.), Public

Regulation: New Perspectives on Institutions and Policies. MIT Press, Cambridge MA.

Charnes, A., Cooper, W., Lewin, A.Y., Seiford, L.M., 1994. Data Envelopment Analysis. Theory, Methodology and Applications. Kluwer Academic, Boston.

Charnes, A., Cooper, W.W., Rhodes, E., 1978. Measuring the efficiency of decision making units. European Journal of Operational Research 2 (6), 429–444.

Coelli, T., Rao, D.S.P., Battese, G.E., 1998. An Introduction to Efficiency and Productivity Analysis. Kluwer Academic, Boston.

Costas-Centivany, C.M., 1999. Spain's airport infrastructure: adaptations to liberalization and privatization. Journal of Transport Geography 7, 215–223.

Doganis, R.S., 1992. The Airport Business. Routledge, London.

Doganis, R.S., Graham, A., 1987. Airport Management: The Role of Performance Indicators. Transport Studies Group, Polytechnic of Central London, London.

Doganis, R.S., Lobbenberg, A., Graham, A., 1995. The Economic Performance of European Airports. RR3, Department of Air Transport, College of Aeronautics, Cranfield University, Cranfield.

Evans, W.N., Kessides, I.N., 1993. Localized market power in the US airline industry. The Review of Economics and Statistics 75 (1), 66–75.

Farrel, M.J., 1957. The measurement of productive efficiency. Journal of the Royal Statistical Society A 120, 253–290.

Gillen, D., Lall, A., 1997. Developing measures of airport productivity and performance: An application of data envelopment analysis. Transportation Research E 33 (4), 261–273.

Haririan, M., Vasigh, B., 1994. Airport privatization: procedures and methods. Transportation Quarterly 48 (4), 393–402.

Hensher, D.A., Waters II, W.G., 1993. Using Total Factor Productivity and Data Envelopment Analysis for Performance Comparisons Among Government Enterprises: Concepts and Issues. Institute of Transportation Studies, The University of Sydney, Sydney.

Hooper, P.G., Hensher, D.A., 1997. Measuring total factor productivity of airports. An index number approach. Transportation Research E 33 (4), 249–259.

Lovell, C.A.K., 1993. Production frontiers and productive efficiency. In: Fried, H.O., Lovell, C.A.K., Schmidt, S.S. (Eds.), The Measurement of Productive Efficiency. Techniques and Applications. Oxford University Press, Oxford.

Morrison, S., Winston, C., 1995. The Evolution of the Airline Industry. Brookings Institution, Washington.

Pels, E., Nijkamp, P., Rietveld, P., 1997. Substitution and complementarity in aviation: airports vs airlines. Transportation Research E 33 (4), 275–286.

Pino, M., 1995. Airport funding. In: Jenkins, D., Ray C.P. (Eds.), Handbook of Airline Economics. Aviation Week Group, New York.

Seiford, L.M., 1994. A DEA bibliography (1978–1992). In: Charnes, A., Cooper, W., Lewin, A.Y., Seiford, L.M. (Eds.), Data Envelopment Analysis. Theory, Methodology and Applications. Kluwer Academic, Boston.

Stasinopoulos, D., 1992. The second aviation package of the european community. Journal of Transport Economics and Policy 26, 83–87.

Stasinopoulos, D., 1993. The third phase of liberalization in community aviation and the need for supplementary measures. Journal of Transport Economics and Policy 27, 323–328.

Vincent, D., Stasinopoulos, D., 1990. The aviation policy of the european community. Journal of Transport Economics and Policy 24, 95–100.